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Research Article

Operating Room Scheduling by Using Hybrid Genetic Algorithm

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ABSTRACT

Hospitals are among the most important institutions of today. For hospitals, efficient use of operating rooms is of great importance. Efficient use of operating rooms is a problem that needs to be solved. The operating room scheduling problem is a very complex problem with large number of constraints. This type of problem called as NP-Hard type problem. NP-Hard type problems do not consist of polynomial values. Therefore, the solution of these problems is very complex and difficult. Solutions consisting of polynomial values can be solved effectively with existing mathematical methods. However, more effective algorithms were needed to solve NP-hard type problems. As a result of the studies, many heuristic, meta-heuristic algorithms such as Genetic Algorithm, Particle Swarm Optimization, Simulated Annealing, Taboo Search Algorithm have been developed to solve the complexity of NP-Hard problems. In this article, the operating room scheduling problem solved with a hybrid genetic algorithm. In this solution, it shows how the algorithm affects the solution area in the changes in the number of surgeons, operating rooms and operating room reservations, which are among the operating room parameters. In the developed software, C# programming language has been preferred in order to provide comfortable use of the end user.

Keywords: *Operating room scheduling, Genetic algorithm, Repair operator, Constrained optimization.*

Hibrit Genetik Algoritma Kullanarak Ameliyat Odası Çizelgeleme

ÖZ

Günümüzün en önemli kurumlarının başında hastaneler gelmektedir. Hastaneler için ise ameliyathanelerin verimli kullanılması büyük önem taşımaktadır. Ameliyathanelerin verimli kullanımı çözülmesi gereken bir problemdir. Ameliyat odası çizelgeleme problemi, kısıt sayısı çok fazla olan, oldukça karmaşık bir problemdir. Bu tip problemler, NP-Hard tipi problem olarak adlandırılmaktadır. NP-Hard tipi problemler polinomik değerlerden oluşmazlar. Bu yüzden, bu problemlerin çözümü de çok karmaşık ve zordur. Polinomik değerlerden oluşan çözümler mevcut matematiksel yöntemlerle etkili bir şekilde çözülebilmektedir. Ancak NP-hard tipi problemlerin çözümü için daha etkili algoritmalara ihtiyaç duyulmuştur. Yapılan çalışmalar sonucunda, Genetik Algoritma (GA), Parçacık Sürüsü Optimizasyonu, Benzetilmiş Tavlama, Tabu Arama Algoritması gibi sezgisel veya meta-sezgisel çok sayıda algoritma, NP-Hard problemlerin karmaşıklığını çözmek için geliştirilmiştir. Bu makalede, hibrit bir genetik algoritma ile ameliyat odası çizelgeleme problemi çözüme ulaştırılmıştır. Bu çözümde, algoritmanın, ameliyathane parametrelerinden olan, cerrah sayısı, ameliyat odası sayısı ve ameliyathane rezervasyon sayısının değişimlerinde, çözüm alanını nasıl etkilediği gösterilmiştir. Geliştirilen yazılımda, son kullanıcının rahat kullanımını sağlamak için, C# programlama dili tercih edilmiştir.

Anahtar Kelimeler: *Ameliyat odası çizelgeleme, Genetik algoritma, Tamir operatörü, Kısıtlı optimizasyon.*

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I. INTRODUCTION

Due to reasons such as today's developing technology, changing economy and a wide range of consumer needs, enterprises have to keep up with these conditions and provide income balance. Enterprises can continue their existence as long as they keep up with developments. The most important step for the continuity of the enterprise is the planning, organization and implementation phase of the income expenditure and savings balance. For this purpose, all enterprises, institutions and organizations from the smallest to the largest give weight to this planning and shift their resources in this direction.

The world population balance is constantly changing and increasing rapidly. This increase brings together the variety of diseases together with the collective life. Hospitals are the most important institutions of this world order. When this situation is combined with the increase in the average age, the number of patients on the waiting list in hospitals increases significantly. The economic aspect of this situation is also important. Hospitals, like all institutions, want to minimize the cost and provide a quality health service as possible. Hospitals allocate one of the largest budgets for operating rooms.

The number of patients waiting for surgery in hospitals is increasing over the years. The calculations also show that observed in Turkey. Calculations from 2002 to 2014 show that the increase in the total annual number of surgeries is more than 8 times [1]. The calculations show that one out of every six people in the world has had a major or minor surgery. Hospitals use many methods to optimize the cost-quality balance. One of the most frequently used methods in recent years has been to benefit from technology and apply to software programs. The main reason for the increasing importance of software programs and other technological tools is to eliminate or minimize the errors of the human factor.

With scheduling, it is possible to ensure that the steps and activities required for all operations such as providing a service and producing a product are placed in the time schedule. Scheduling also determine critical dates such as start, end times, making a sequence of when the transactions will be made and determining which areas will be ready for the new job. There are varieties of optimization problems that can be scheduled. Some of those; Operation Room Scheduling, Workshop Scheduling, Course Scheduling, Nurse Scheduling, Fast Train Scheduling, Vehicle and Driver Scheduling etc. scheduling can be applied for many problems. All these scheduling problems are tried to be solved by using software programs.

While many programs have been done for the operating room scheduling problem and even though it is desired to approach the reality, it is ignored many conditions during the program. The programs made due to these ignored conditions do not correspond to real life and cannot be adapted. In order to find a solution to this problem, many new algorithms and new approaches have been applied and the closest solution is tried to be found.

There are various types of optimization problems in the literature. While some of these problems can be solved by mathematical methods, various algorithms are needed to solve some of them. The more complex and large the problem is, the more difficult it is to solve it with mathematical methods. For this reason, heuristic, meta-heuristic algorithms have been developed to solve problems with a lot of complexity. In general, the concept of meta-heuristic is explained as a heuristic method designed to direct the intuitions specific to each problem to reach quality solutions [2]. It has a meta-heuristic, wide field of study. It ranges from simple search algorithms to the highest level of complexity learning problems. As an example of these algorithms; Genetic Algorithm, Ant Colony Algorithm, Simulated Annealing, Taboo Search, Variable Neighbor Search can be given as examples [3].

II. PROBLEM DEFINITION

In this section, the basics of the Operating Room Scheduling problem discussed in this article are presented. To solve this problem, a program solution module has been realized in hospitals which is one of the most important enterprises of our day, which can help to minimize the waiting time for elective patients by minimizing the total cost.

To solve operating room scheduling problem, it is necessary to understand its specific features and the conditions. In this way, all the facilities required for operating rooms should be understood and appropriate solution methods should be applied. The fact that the decisions to be taken is in compliance with the emergency patient entrances and the restrictions on the available resources will increase the success in making the solution healthier. The priorities mentioned here are; the time of entry and exit of the operating rooms, the capacity status of the beds before and after the operation (It is important for consideration in scheduling), the equipment condition to be used during the operation. In a hospital, the operations can be planned at various time intervals. These schedules can be prepared daily, weekly (Monday to Friday) or in the medium term. Hospitals have to divide the operations into time periods according to their capacity and working status. Otherwise, exceeding the time limits and the emergence of overtime may cause the hospitals to remain in a difficult position.

There are two types of patients; patients arriving by appointment system and coming in emergency. Since patients who require an appointment are specific, it is possible to make a comfortable time planning for such patients. However, it cannot be planned for patients coming to the emergency to be treated according to their condition after the arrival. In this paper, because the emergency patients are not able to plan, the emergency patients are directed to a different hospital or they are directed to another operating room which is kept constantly ready for emergencies and not included in the table in this article.

In this article, the number of patients to be involved in the planning and what surgery will be determined is clear. The duration of each operation may vary and the operation times may vary depending on the extra cases that may occur during the operation. For the implementation of scheduling, the operation hours and the duration of the operating room preparation for the next surgery were fixed by taking into account the mean operative times. Operating rooms may have different characteristics and equipment depending on the operation characteristics. However, in this study, it is accepted that this limitation of the operating rooms may increase the leisure time and may negatively affect the emergency patients which may be included later. So, it is accepted all the operating rooms are equipped with the same equipment that can be used in the same and determined types of operations.

III. OPERATING ROOM SCHEDULING AND OPTIMIZATION

In the first part, it was mentioned that a high amount of budget was allocated for operating rooms, which are the most important parts of hospitals. This section includes the literature response of the operating room scheduling problem and an examination of solutions. While reviewing the literature, the parameters affecting the operating room scheduling problem are also revealed.

There are several review papers addressing the timing of the surgery room [4-6]. In a study conducted in 2013, 3 operating room scheduling problems were examined. In addition, an integrated research framework and planning method are presented for these problems [7]. One of the three strategies can be used in the planning of operating rooms: block scheduling, modified block scheduling and open scheduling [8].

The integer linear programming model proposed by Marques et al. Is aimed to ensure the highest profit rate and minimization of costs for hospitals. For this purpose, they performed weekly and elective operating room scheduling separately [9]. In a similar study, Conforti et al solved the problem of daily and weekly operating room scheduling, provided that restrictions were applied to surgeons who were not working [10]. Marques et al, who previously proposed an integer linear programming model, later proposed a genetic algorithm-based solution approach, but did not give detailed information about the solved examples [11]. Khambhammettu and Persson developed a simulation with the complex integer linear programming method in the surgical room schedules (preoperative, perioperative and postoperative surgery) and analyzed the results with the Friedman test and used the actual data collected from a local hospital to evaluate the proposed model [12]. Molina-Pariente et al, while solving the weekly operating room scheduling problem, compared 17 meta-heuristic algorithms and tried to present the algorithm with the highest efficiency. They aimed to minimize the waiting period of the patients with this method, which uses clinical prioritization method and has been tried once before [13]. Guido and Conforti have proposed a multi-purpose integer linear programming model that aims to plan and manage hospital operating room teams efficiently and develop a hybrid algorithm based on genetic algorithms, aiming at combining the tactical and operational phases during the operation [14].

Xiang et al. Integrate surgical planning issues, their roles, expertise, quality and availability with nurse list restrictions in real life. They applied a mathematical model and an ant colony algorithm to this problem and included the suitability of nurses for this problem [15]. Latorre-Núñez et al. discussed the operation rooms, postoperative anesthesia recovery, the resources required by the surgery, and emergency surgery for the first time in surgery room planning. Bouguerra et al., Who proposed mathematical models, developed an integer linear programming for small sized problems and a genetic algorithm and constructive-heuristic based heuristic algorithm for larger samples [16,17]. Saadouli et al. Treated the resources in two parts (recovery beds and operating rooms) and arranged it in this way. They aimed the solution by using the backpack model for the selection of intra-day operations and the mixed integer programming model for the optimization of the timing of the surgery [18]. Xiang et al. developed the Ant Colony Algorithm to effectively solve such scheduling problems by observing the similarities between the Flexible Work Office Planning Problem and the Operating Room problem [19].

Aringhieri et al. when a surgical section with a fixed number of operating rooms and a variety of features sharing the bed postoperatively was given, they examined the jointly operating room (OR) and advanced scheduling problem. They aimed to plan the operation room and the decision levels at the same time at the weekend. They developed a 0-1 linear programming formulation to prove that the problem was NP-Hard and then developed a 2-level (Tabu and Greedy) meta-heuristic algorithm for solving the problem [20]. Razmi et al. mostly focused on planning unique elements of hospitals (C-Arm Imaging Equipment). In this study, a model for operating room planning is described under a unique equipment constraint. In the first stage, there is a coefficient factor in the use of this unparalleled equipment for programming in the uncertainty of using outstanding equipment in a unique equipment, in the second stage, in emergency surgeries and for surgeons at the third level [21]. In addition to standard scheduling constraints, Wang et al. introduced the idea that many additional restrictions on human and material resources encountered in real life should be taken into account and developed 2 models using mixed integer and constrained programming techniques [22]. Riise et al applied the adaptive structure and improvement algorithm in the problem, which they examined in three groups as daily, weekly and patient admission [23].

Dios et al. presented a Decision Support System for surgical planning currently in use in a few Surgical Units in one of the largest hospitals in Spain, supporting decisions on the appointment of dates and operating theaters to patients in a waiting list [24]. Murray et al. developed a training room simulation for educational purposes [25]. Castro and Marques, who applied standard convex-hull and large-M techniques to integer or complex-integer linear programming, focused on a short-term program on the selection of priority patients from the waiting list [26]. Abedini and colleagues have traditionally proposed a multi-step approach and a rule of priority to establish the starting sequence in the bin-packing model, which is an important method for the operation room block timing [27]. Apart from these studies, there are also studies that address the different aspects of the problem. For example, Beroule et al. have prioritized the sterilization of operating room equipment [28]. However, Alamedaa and Macario highlighted the role of the hospital administrator in their work and expanded the range of work in this field [29]. Veen-Berkx et al. evaluated the policy consequences of emergency surgical intervention capacity in terms of OR use in all elective ORs. The aim is to create a more effective plan with less surgery, and a timeout with a very low time [30]. Riet and Demeulemeester review literature on OR planning, including both elective and non-elective patient categories [31]. Siqueira et al. presented an optimization problem that designed periodic surgery. They presented an optimization method that designed a periodic surgical allocation plan and a recovery bed use plan, with a view to balancing long-term patient inputs and oscillations, as all surgical operations would be performed on time [32]. Roshanaei et al., with the Benders parsing approach, converts the IP (Internet Protocol) model to an integer position and backpack based allocation to the main problem and multiple packaging IP sub-problems [33].

Landaa et al. A hybrid two-phase optimization algorithm that uses the potential of neighborhood search techniques with Monte Carlo simulation has been developed. An integer linear stochastic formulation was given for each sub-problem and aimed to provide an effective algorithmic framework to solve the common progression and assignment scheduling problem, taking into account the uncertainty inherent in surgical times [34]. As a result of the growing demand for health services, China's big city hospitals have faced extremely complicated, delicate and complex operating room planning problems. Xiao et al, tried to obtain a solution by using the Sample Average Approximation approach in order to prevent the cost of cancellations and cancellations due to an explosion of waiting lists. They solved the three-stage patient registry problem using sample mean approach methods and corresponding optimization techniques [35]. Jebali and Diabat, advocated that operating room planning was important in the evaluation of ICU (Intensive Care Unit) beds, including when the patient required an intensive care unit after surgery, and developed a specific Sample Mean Approach algorithm to solve the Model [36].

IV. GENETIC ALGORITHM

Genetic Algorithm is known as an optimization algorithm that works with the principle of parameter coding as well as using random search methods while reaching the solution. The data set given to the algorithm is coded to find the best and healthiest solution.

Genetic Algorithm has been developed and coded by taking into account the reproduction patterns of living beings in nature. The principle is that the strong and the good as in the living things should stand out and survive, and that the weak will disappear over time. A genetic algorithm does not evaluate all the possible solutions that apply to a problem, evaluates only the necessary parts of the problem in order to go to the solution more quickly. For this reason, GA is an appropriate algorithm for small and uncomplicated problems as well as large and complex problems. The genetic algorithm, which was first announced in 1967, realized its real evolution with John H. Holland [37]. Holland strengthened the foundations of the genetic algorithm with the machine he proposed. In addition, he explained the integration of the genetic algorithm into artificial intelligence problems in his book where he describes the adaptation of natural and artificial systems [10]. It is also Holland who considers the Genetic Algorithm as an abstract evolution. Goldberg [38], explained how to apply the genetic algorithm to machine learning and search optimization and announced the algorithm he used for the gas pipeline project as an example at the academic level [11].

Genetic Algorithm is an algorithm that has been studied practically and theoretically in a wide range of fields. The areas where they are actively used are as follows; Scheduling Problems, Game Programming, Finance and Marketing, Optimization Problems, Mathematical Problems, Automatic Programming and Information Systems, Mechanical Learning, Routing Problems, Population Genetics [39].

A. BASIC GENETIC ALGORITHM

In addition to the basic functions that are precisely encoded in each problem, the genetic algorithm can also have genetic operators that require differences for each problem. In order to increase the algorithm quality, all planning should be made beforehand, constraints and operators to be used should be determined. General steps of Genetic Algorithm and some methods and operators that can be developed specific to the problem are shown below.

- All solutions in the search space are coded as arrays.
- Depending on the problem, a random set of solutions is usually created and considered as the initial population.
- Fitness values are calculated for each sequence. These values indicate the quality or health status of each sequence (chromosome).
- Arrays (chromosomes) are randomly selected according to a given probability value and sent to the matching pool.
- The Crossover operator is applied to the matching chromosomes.
- Mutation operator is applied to selected chromosomes.
- A new population is created with these new generation individuals.
- Return to Step 3 with the new population created.
- These processes are considered to be the best individual solution according to the purpose function, whether it has reached the specified generation number or applying another termination criterion.

The Genetic Algorithm basically has 4 operators.

I. Crossover Operator
II. Mutation Operator
III. Reproduction Operator
IV. Parameter coding operator

* The Repair Operator, which should be applied in constrained optimization problems, has been applied in addition to these 4 operators in the operating room scheduling problem, which is a limited optimization problem. In many studies in the literature, the operators of crossover operate, mutation operate and reproduction process in classical GA are described in detail. We did not give a detailed description of these operators in order to decrease the content.

B. REPAIR OPERATOR

In very limited optimization problems such as operating room scheduling, after the Crossover and Mutation operators are applied, the gene information of the offspring in the population pool is lost or in a different position than it should be. This situation leads the algorithm towards deadlock. The solution is to apply the Repair Operator, which has been developed specifically for the problem to individuals in each generation. For this reason, the Repair Operator was used in addition to the existing operators in this study.

Corrupted genes of chromosomes that have lost their normal sequence are corrected by the Repair Operator. This feature is why the Repair Operator is also named by the name Correction Operator. Let's consider a chromosome sequence made up of numbers 0-9. Let's say 2 chromosomes are produced from these numbers. The genes lost after the Crossever Operator was applied are shown in Figure 1.

Following the introduction of the Crossover Operator, genes 5 and 6 appear to have disappeared in the first individuals in the new generation. The Repair Operator should be used to correct the disrupted sequence, replace these lost genes, and create healthy generations. Figure 2 shows the repaired chromosome.

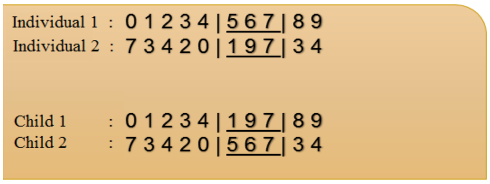


Figure 1. *Without using repair operator*

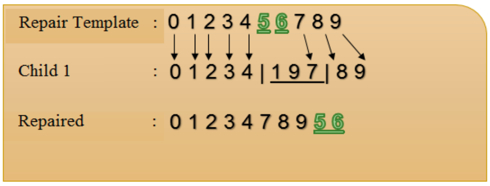


Figure 2. *Using repair operator.*

V. USING GENETIC ALGORITHM IN CONSTRAINED OPTIMIZATION PROBLEMS

Optimization refers to the most efficient use of all resources (money, equipment, raw materials, capacity, labor). In addition, with optimization, targets such as maximizing profit and maximum capacity utilization with the least cost are achieved in the problem to be solved. The biggest challenge in optimization is the excess of problem constraints. This problem has enabled the field of limited optimization problems, which is a new field in the field of optimization, to be added to the literature. New techniques and algorithms have been developed to solve these problems. In the literature, there are many limited optimization problems such as operating room scheduling, nurse work schedule scheduling, and lesson scheduling.

Various methods are used to solve such problems. Reaching a solution through the penalty function is one of these solutions. In this method, chromosomes that do not comply with the restrictions determined before coding are punished. Each specified penalty per constraint is added to the chromosome that does not comply with the constraint (the amount of penalty may vary depending on the importance of the constrained). This method ensures that all chromosomes and genes that do not comply with the hard and soft constraints are punished by the penalty coefficient of each violated constraint (each type of constraint can have a different penalty). These penalties are included in the algorithm as one of the evaluation parameters. The fitness function can be defined as the function that gives a measure of the proximity of an element in the population to the desired result. For example, Let N be an array and get the maximum value of f (x) function as shown in (1) and (2).
In this function, fitness of the i. element;

$$\bar{f} = \sum_{i=1}^{N} f_i \tag{1}$$

$$\frac{f_i}{\bar{\bar{f}}} \tag{2}$$

In constrained optimization problems, penalty points are calculated according to all constraints and then the fitness function is calculated as shown in (3) and (4).

Total Penalty Points (All Constraints),

$$\sum_{k=0}^{t}\sum_{i=0}^{n}\sum_{j=0}^{l} P_k * C_{ij} \tag{3}$$

$$(f) = \frac{1}{1 + \left(\sum_{k=0}^{t}\sum_{i=0}^{n}\sum_{j=0}^{l} P_k \times C_{ij}\right)} \tag{4}$$

*n = number of chromosome l = number of gene, t = number of constraints, Cij= j. gene which has a penalty in i.chromosome, Pk= penalty value belong k.constraint

A. APPLICATION PARAMETER ENCODING

How the values are expressed is very important. Binary coding is incompatible for operating room scheduling. Coding with real numbers will complicate the problem. Therefore, Value Encoding is the most suitable encoding for this kind of problem. Value encoding is divided into sub-branches within itself (Integer encoding, Fraction Coding, etc.) In this article, it was determined that the most appropriate coding method for the operating room scheduling problem is integer coding, which is one of the value coding methods.

In this coding method, chromosomes and genes are expressed with integers. Figure 3 shows the integer encoding used in encoding the algorithm.

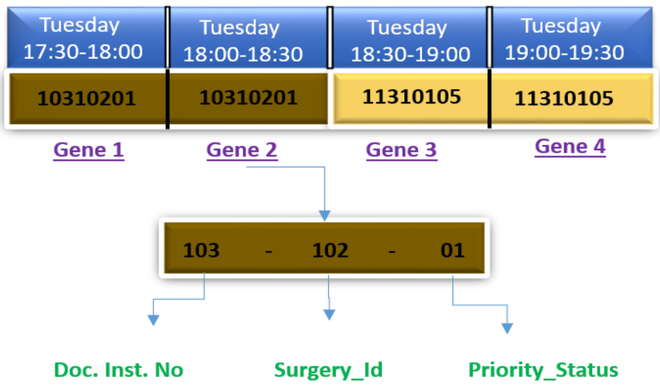


Figure 3. *Chromosome structure [40,41].*

Chromosomes are formed by the combination of genes, and the population is formed by the combination of chromosomes. The 4 genes used in the algorithm are shown in Figure 3. 1 gene consists of the combination of integers combined with 8 different representations. The institution code of the surgeons in the hospital is represented by the first 3 integers. The next 3 integers represent the types of surgery performed by the hospital. In this study, it was assumed that a total of six types of surgeries that are most common in hospitals were performed. These types of surgery are; otolaryngology, orthopedics, radiology and endoscopy, eye diseases, general surgery and pediatrics. There are many reasons that can change the duration of the operation (complications, patient condition, etc.). Therefore, the operations and their duration are predetermined according to the averages and placed in the algorithm. The preparation time of the operating room required for each surgery was calculated and added to the operation time. The total operation and preparation times are added to the algorithm as the total operation time. These values are given in Table 1.

Table 1. *Operating room preparation times and duration of operation.*

Surgery _Name	Surgery _time	Surgery_Preparation _Time
Otolaryngology	2t	t
Orthopedics	4t	2t
Radiology & Endoscopy	t	t
General Surgery	6t	2t
Eye Diseases	2t	t
Pediatrics	t	t

In the study, types of surgery were prioritized. The priorities of six types of surgery are in the last 2 digits of the eight integers in the gene structure. Priority is one of the constraint conditions of the algorithm and penalties are applied to genes that do not fit. According to this ranking, the last 2 integers of the surgery with the highest priority are 06, and the lowest one is 01. Surgery priorities are given below. Pediatrics – (01), Otolaryngology – (02), Eye Diseases – (03), Orthopedics – (04), Endoscopy and Radiology – (05), General Surgery – (06).

B. EXAMINATION OF THE ALGORITHM

For the solution of the operating room scheduling problem, it is solved with Genetic Algorithm, one of the meta-heuristic algorithms. The algorithm is coded in C # programming language.

Parameters determined for the algorithm; Crossover Rate between 50% and 90%, Number of Operating Room between 1 and 3, Number of Chromosome between 2 and 50, Mutation Rate between 0.1% and 1.5%. These ranges were determined according to the studies in the literature and it was aimed to reach the best solution with different combinations. The package program developed includes an easy-to-use reservation section along with the specified parameters.

In the reservation section, the reserved hours predetermined by the surgeons are recorded. The surgeon registers on the system on which day and time he wants to operate, and that hour is fixed on the algorithm. In other words, even as generations progress, the surgery on those reserved days and hours does not change. In addition, one of the restriction parameters of the algorithm is the reservation section.

C. PROGRAM CONSTRAINTS

In constrained optimization problems, the formation of structures that do not comply with the constraint and trying to reduce them is seen as the biggest challenge. Soft and hard constraints were pre-determined and applied for operating room scheduling problems. There are penalty values for each constraint and this penalty is applied to each gene that does not comply with the constraint. The purpose of using the penalty function method is to transfer healthy genes with low penalties to the next generations with the help of genetic algorithm. In this way, the best solution is tried to be reached.

Hard Constraints

I. A surgeon cannot be in more than one operating room at the same time.
II. More than one patient cannot be in the same operating room at the same time.
III. Operations should be in blocks and cannot be interrupted.
IV. Surgery cannot be placed beyond 20:00.
V. At the time of reservation, only the relevant surgeon can undergo surgery.
VI. The number of patients assigned to surgeons is certain, no more can be assigned.

VII. There is priority in operations. The surgery with high priority should be done first (For example, according to the last 2 digits; 06> 05 and 06 should be done before.).

Soft Constraints

VIII. Leisure time during working hours should be reduced as much as possible.

Part of the chromosome is shown as an example in figure 4 while the program is running. On the gene shown; The first 3 integers indicate the surgeon's institution code, the following 3 integers indicate the type of surgery to be performed, and the remaining 2 integers indicate the priority status of each operation. The last 2 digits of the "10410201" surgery, which started on Wednesday at 08.30, is 01, so the priority is the lowest. The last 2 digits of the "10010006" surgery, which started after this surgery is over, is 06, which means it has the highest priority. This is a restriction violation and requires the application of the specified penalty coefficient.

	08:00-08:30	08:30-09:00	09:30-10:00	10:00-10:30	10:30-11:00	11:00-11:30
Monday		10210105	10210105	10210105	10210105	10210105
Tuesday		10110006	10110006	10110006	10110006	10110006
Wednesday	10310201	10410201	10410201	10010006	10010006	10010006

Figure 4. *Examination of the constraint.*

In addition, one of the soft constraints, leisure times are available at 08:00 on Mondays and Tuesdays. These leisure times are also tried to be reduced. It has been assumed that the working hours are 12 hours between 08.00-20.00. One of the severe constraints is that the surgery is not placed beyond the working hours.

VI. EXPERIMENTAL RESULTS

In this section, all parameters affecting the problem solution and the size of their effects are shown with experiments. Factors affecting problem solving and experimental effects are as follows; Number of Surgeons, Number of Operating Rooms, Number of Reservations, Crossover and Mutation rates. The effects of all the factors determined were supported by experiments and shown graphically.

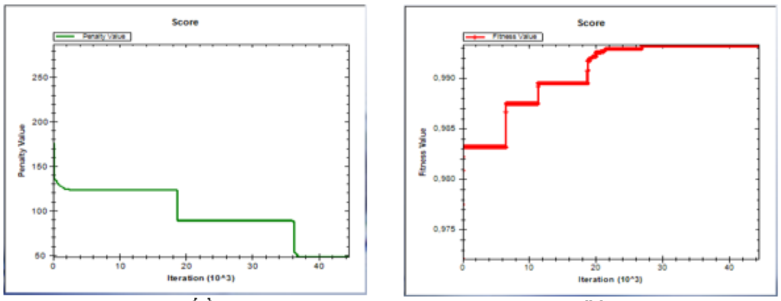
A. THE EFFECT OF NUMBER OF OPERATING ROOMS ON PROBLEM SOLUTION

One of the important issues to be taken into account when performing the Operation Room Scheduling is how many the number of operating rooms is. Operating rooms can be diversified in hospitals. For example, an operating room in the same hospital contains only the materials required for orthopedic surgery, while another operating room contains only the materials required for eye surgery. However, this can prevent the effective use of the operating rooms. When the patient comes to the hospital with many people of orthopedic surgeries, the waiting list increases, while a few people arriving for the eye creates an empty operating time.

Therefore, in this article, it is assumed that every operating room has the same materials and materials required for all types of surgery. In this section, the number of operating room numbers 1 to 3 is given and the experiments are performed under the same conditions. Since one of the constraints of the program is the idle times; gaps are tried to be reduced.

This results in a progression of genes over time to the beginning of the week or to the initial values of the chromosome sequence as iteration progresses. Table 2 and Table 3 show the case where the number of operating rooms is 1 and 2 when other values remain constant.

# Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ratio (1/1000)	Number of Surgeon
1	30	80	5	Constant(8)

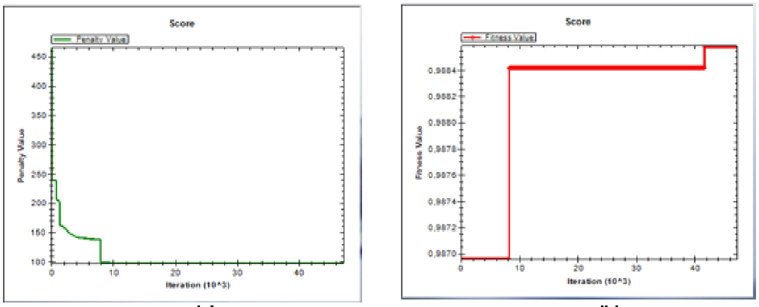


(a) (b)

Figure 5. Number of operating room is 1 (Penalty & Fitness Values).

As the number of operating rooms increases, the process becomes complicated as the chromosome size of each individual will be folded. In this situation, the results show that the process progresses towards the solution as the generation progresses, although the process load increases. Fig. 5 (a), shows that at the end of 45000 iterations, the penalty value of the best chromosome decreased to 48, and Fig. 5 (b), shows that the value of fitness increased to 0.9933.

# Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ratio (1/1000)	Number of Surgeon
2	30	80	5	Constant(8)



(a) (b)

Figure 6. Number of operating room is 2 (Penalty & Fitness Values).

Fig. 6 (a), shows the penalty situation under the same conditions for the operating room. In the experiment with 2 operating room; it shows that the penalty value decreased to 98 and the value of fitness increased to 0.9885. The significant reduction in the penalty point was reflected in the fitness value as shown in Fig. 6 (b) and it was very close to 1.0. In the experiment; the population amount was 30, the crossing rate was 80%, the mutation rate was 0.5% and the number of surgeons was 8 and fixed. Fig. 7 and Fig. 8 show the best solution obtained when the number of operating rooms is 1.

	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
M.day	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006		10110006	10110006	10110006
Tues.	10210105	10210105	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304
Wed.	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10710402	10710402	10710402	10410201
Thurs.	10410201	10410201	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10110006	10110006
Frid.	10810304	10810304	10810304	10810304	10810304	10810304	10610503	10610503	10610503	10710402	10710402	10710402

Figure 7. Solution chromosome operating room 1 (first 6 hours).

	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10110006	10110006	10110006	10110006	10110006	10110006	10210105	10210105	10210105	10210105	10210105	10210105	
Tues.	10510304	10510304	10510304	10710402	10710402	10710402	10310201	10310201				10210105	10210105
Wed.	10410201	10410201	10310201	10310201		10810304	10810304	10810304	10810304	10810304	10810304	10310201	10310201
Thurs.	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10510304	10510304	10510304	10510304	10510304	10510304
Frid.	10710402	10410201	10410201	10310201	10310201								

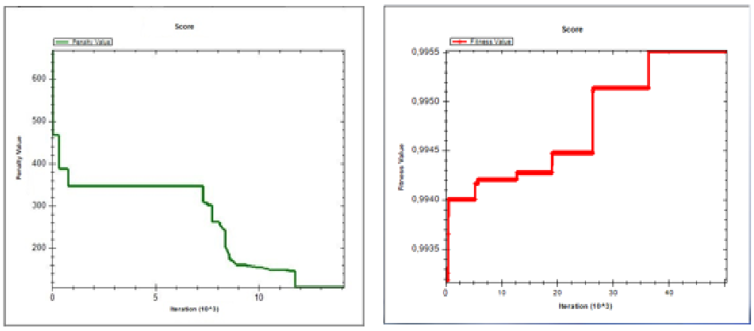
Figure 8. *Solution chromosome operating room 1 (last 6 hours).*

These two experiments show that as the number of operating rooms increases, the size of the chromosome grows and the chromosomes are experiencing extra constraints. This situation increases the complexity of the process, but also increases the number of operating rooms and also provides the opportunity to place the same number of operations on more areas. This situation led to a higher rate of punishment when the number of operating rooms increased, but further reduced the penalty score.

B. THE EFFECT OF NUMBER OF SURGEONS ON PROBLEM SOLUTION

Another input affecting the resolution of this type scheduling problem is the number of surgeons involved in the scheduling. In this section, it is examined how the number of different doctors in the problem affects the solution. Initial inputs; the number of operating room is 2, population size is 30, crossover rate is 80%, mutation rate is 0.5%. And in 2 cases these values were kept constant. In these circumstances, the graph shows how the solution changes when the number of surgeons is 5 and 15. Table 4 and Table 5 show the change of the score when the total number of surgeons is 5 and 15 when other values remain constant.

# Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ration (1/1000)	#Number of Surgeon
2	30	80	5	5



(a) (b)

Figure 9. *Number of surgeons is 5 (Penalty & Fitness Values).*

The high number of surgeons narrows the empty spaces in the chart. It will be difficult to reduce the penalty value as the rate of displacement will decrease due to the reduction of empty spaces due to this narrowing.

In the first experiment, determined the number of surgeon is 5 and run the program. Fig. 9 (a), shows that at the end of 15000 iterations, the penalty value of the best chromosome decreased 630 to 102, and Fig. 9 (b), shows the value of fitness increased to 0.9955. Fig. 10 and Fig. 11 show the best solution obtained when the number of surgeons is 5. Genes are effectively located in the first operating room.

	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
M.day	10210105	10210105		10210105	10210105	10210105	10210105	10710402	10710402	10710402		
Tues.	10410201	10410201	10210105	10610503	10610503	10610503	10410201	10410201	10310201	10310201	10710402	10710402
Wed.	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10610503	10610503	10610503	10410201
Thurs.	10210105	10210105	10610503	10610503	10610503	10310201	10310201	10010006	10010006	10010006	10010006	10010006
Frid.	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10510304	10510304	10510304	10510304

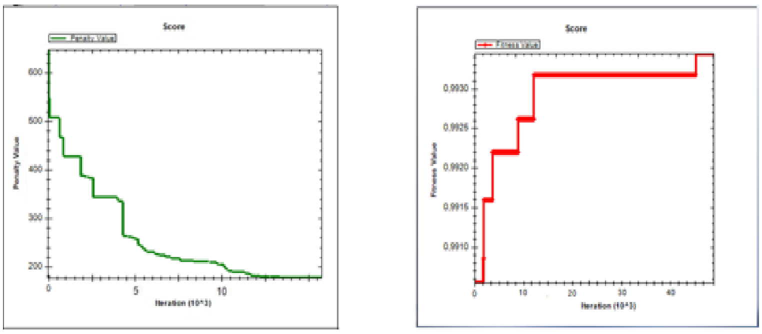
Figure 10. *Solution chromosome operating room 1 (first 6 hours)*

	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10710402	10710402	10710402		10310201	10510304	10510304	10510304	10310201	10510304	10310201	10310201
Tues.	10710402	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006		10210105	10210105
Wed.	10410201	10310201	10310201	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	
Thurs.	10010006	10010006	10010006	10210105	10210105	10610503	10610503	10610503	10310201	10310201		
Frid.	10510304	10510304	10310201	10310201							10410201	10410201

Figure 11. *Solution chromosome operating room 1 (last 6 hours).*

In the second experiment, in same conditions, the number of surgeons is determined as 15. As a result of 15000 iterations, as shown in Fig. 12 (a), the penalty value decreased 612 to 180 value and the value of fitness increased to 0.9935 as shown in Fig. 12 (b).

# Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ratio (1/1000)	#Number of Surgeon
2	30	80	5	15



(a) (b)

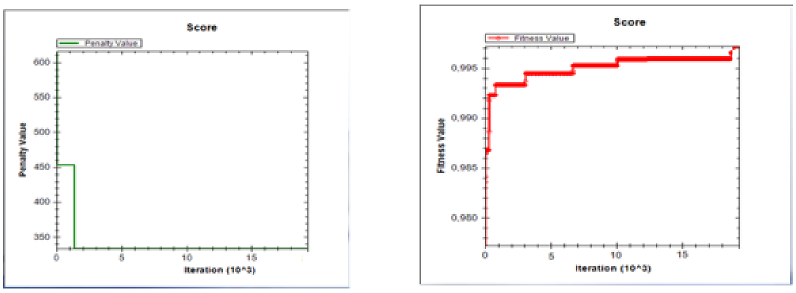
Figure 12. *Number of surgeons is 15 (Penalty & Fitness Values).*

C. THE EFFECT OF NUMBER OF SURGEONS ON PROBLEM SOLUTION

The interface is very useful in the program developed with the C # programming language. Reservation procedures can be used easily by surgeons. In case of reservation, which is one of the hard constraints, no other surgery can be made at the time of the reservation unless it is canceled by the surgeon who made the reservation.

This section shows the effect of reservations made on problem solving. Table 6 and Table 7 show the comparison of the total number of reservations at values 2 and 8 where other values remain constant.

# Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ratio (1/1000)	#Number of Reservation
3	30	80	5	2



(a) (b)

Figure 13. *Number of reservation is 2 (Penalty & Fitness Values).*

In the first experiment, the algorithm parameters; the number of operating rooms was 3, the crossing rate was 80% and the mutation rate was 0.5%. In these conditions, the results of 3 doctors to make a reservation were examined.

After running the program, the program was terminated at the 20000th iteration and the results in figure 13 were obtained. According to these results; The penalty value decreased from 612 to 330 (Figure 13 (a)), while the fitness value increased to 0.997 (Figure 13 (b)).

As the number of hours reservation increases, the non-fixed areas required for the displacement of chromosomes will decrease, so it will be difficult to reduce the penalty value. The number of patients assigned to surgeons is another factor that affects problem resolution. While the number of surgeons was 8, patients between 2 and 8 were assigned to surgeons.

The surgeon who made the reservation and the reservation dates are as follows.

- Tuesday - 12.00 - 105 coded Surgeon (O .R. 1)
- Wednesday - 14.00 - 101 coded Surgeon (O .R. 2)

	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
M.day		10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10510304	10510304	10510304
Tues.	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10510304	10510304	10510304	10510304
Wed.	10410201	10410201	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10810304	10810304
Thurs.	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10510304	10510304	10510304	10510304
Frid.	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10210105	10210105	10310201	10310201

Figure 14. *Solution chromosome operating room 1 (first 6 hours).*

	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10510304	10510304	10510304	10510304	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	
Tues.	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10610503	10610503	10610503	
Wed.	10810304	10810304	10810304	10810304	10810304	10710402	10710402	10710402	10210105	10210105	10310201	10310201	
Thurs.	10510304	10510304	10510304	10610503	10610503	10610503	10410201	10410201				10410201	10410201
Frid.	10310201	10510304	10510304	10510304	10510304	10510304	10510304	10610503	10610503	10610503	10210105	10210105	10210105

Figure 15. *Solution chromosome operating room 1 (last 6 hours).*

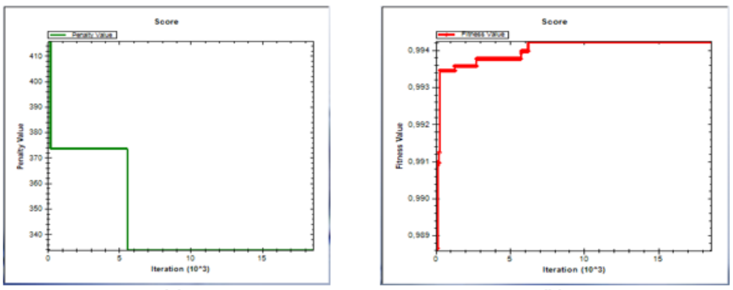
	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
M.day	10210105	10310201	10310201	10810304	10810304	10810304	10810304	10810304	10810304	10610503	10610503	10610503
Tues.	10510304	10510304	10510304	10510304	10510304	10510304	10610503	10610503	10610503		10310201	10310201
Wed.				10510304	10510304	10510304	10510304	10510304	10510304			
Thurs.			10710402	10710402	10710402				10710402	10710402	10710402	10710402
Frid.												

Figure 16. *Solution chromosome operating room 2 (first 6 hours).*

	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10610503		10310201	10310201	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	
Tues.	10310201	10810304	10810304	10810304	10810304	10810304	10810304		10210105	10210105	10710402	10710402	10710402
Wed.		10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006				
Thurs.	10710402	10710402	10710402	10710402	10710402	10710402							
Frid.													

Figure 17. *Solution chromosome operating room 2 (last 6 hours).*

#Number of Operating Rooms	Size of Population	Crossover Ratio (1/100)	Mutation Ratio (1/1000)	#Number of Reservation
3	30	80	5	8



(a) (b)

Figure 18. *Number of reservation is 8 (Penalty & Fitness Values).*

In the second experiment, the algorithm parameters; the number of operating rooms was 3, the crossing rate was 80% and the mutation rate was 0.5%. In these conditions, the results of 8 surgeons to make a reservation were examined. As a result of 20000 iterations, as shown in Fig. 18 (a), the penalty value decreased 430 to 330 and as shown in Fig. 18 (b) the value of fitness increased to 0,995. In this experiment where the other values remained the same, the decrease in the displacement areas of the chromosomes prevented the penalty value from falling sufficiently.

Reservation surgeons and reservation dates are as follows.

- Monday - 09.30 - 102 coded Surgeon (O .R. 1)
- Tuesday – 17.00 - 107 coded Surgeon (O .R. 1)
- Wednesday - 19.00 - 102 coded Surgeon (O .R. 1)
- Thursday - 08.00 - 105 coded Surgeon (O .R. 1)
- Monday - 14.00 - 101 coded Surgeon (O .R. 2)
- Tuesday - 16.30 - 105 coded Surgeon (O .R. 2)
- Wednesday - 15.00 - 106 coded Surgeon (O .R. 2)
- Thursday - 09.00 - 106 coded Surgeon (O .R. 2)
-

The schedule table and reservation hours obtained as a result of the reservations made are shown below.

	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
Monday		10210105	10210105	10210105	10210105	10210105	10210105	10510304	10510304	10510304	10510304	10510304
Tuesday		10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10710402	10710402	10710402
Wednesday	10310201	10410201	10410201	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10110006
Thursday	10510304	10510304	10510304	10510304	10510304	10510304	10210105	10210105	10310201	10310201		
Friday	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006				10010006

Figure 19. *Solution chromosome operating room 1 (first 6 hours).*

	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
Monday	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10210105	10210105			
Tuesday	10410201	10410201	10310201	10310201	10210105	10210105	10710402	10710402	10710402	10410201	10410201	10310201
Wednesday	10110006	10110006	10110006	10110006	10110006	10110006	10110006				10210105	10210105
Thursday	10310201	10310201			10310201	10310201						
Friday	10010006	10010006	10010006	10010006	10010006	10010006	10010006					

Figure 20. *Solution chromosome operating room 1 (last 6 hours).*

	08:00	08:30	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30
Monday	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006				10010006
Tuesday	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006				
Wednesday		10510304	10510304	10510304	10510304	10510304	10510304					10510304
Thursday			10610503	10610503	10610503					10610503	10610503	10610503
Friday												

***Figure 21**. Solution chromosome operating room 2 (first 6 hours).*

	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
Monday	10110006	10110006	10110006	10110006	10110006	10110006	10110006	10110006				
Tuesday	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	10510304	
Wednesday	10610503	10610503	10610503	10610503	10610503	10610503	10610503	10610503	10610503			
Thursday												
Friday												

***Figure 22**. Solution chromosome operating room 2 (last 6 hours).*

D. THE EFFECT OF REPAIR OPERATOR ON GA APPLICATIONS

After the implementation of the Crossover and Mutation operators, some genes which are missing, degenerated or deteriorating occurs in the chromosomes. The repair operator is a genetic operator specially designed and coded to correct these genes and incorporate them into the solution space again.

This section shows how the repair operator is applied and not applied in the genetic algorithm. Fig. 23 was taken from a part of the best chromosome after crossover and mutation operators in the developed package program. Taking into account the duration of the surgery, the "10710402" surgery, which should start at 19.30 on Monday, should be 3 cells. However, in this case, this operation overflows the next day. So this surgery shouldn't be start. In addition, the"10510304"operation, which started at 18.00 pm on Tuesday and had to continue with 6 cells, was interrupted by the "10810304" operation at 19.00. The same situation was evidenced by the interrupting of "10010006" surgery, which had to last 8 cells starting at 15.00 on Wednesday. These are indications of distortions and the solution is moving away. This has revealed the necessity of the repair operator.

	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10110006	10110006	10210105	10210105	10710402	10710402	10710402			10710402
Tues.	10810304	10810304	10810304	10810304	10810304	10810304	10510304	10510304	10810304	
Wed.	10010006	10010006	10010006	10110006	10010006	10110006	10110006	10010006		
Thurs.	10710402	10710402	10710402	10410201	10410201		10410201			10310201
Frid.	10510304	10510304	10510304	10610503	10610503	10610503	10610503			

Figure 23. *Status of the not applied of repair operator.*

Fig. 24 shows that the repair operator has been corrected and applied again to the solution space. The missing surgeries have been repaired.

	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30
M.day	10110006	10110006	10210105	10210105	10710402	10710402	10710402			
Tues.	10810304	10810304	10810304	10810304	10810304	10810304	10510304	10510304	10510304	10510304
Wed.	10010006	10010006	10010006	10010006	10010006	10010006	10010006	10010006		
Thurs.	10710402	10710402	10710402	10410201	10410201					
Frid.	10510304	10510304	10510304	10610503	10610503	10610503				

Figure 24. *Status of the applied of repair operator.*

VII. CONCLUSIONS AND EVALUATIONS

Like other types of problems, the level of complexity should be considered when evaluating the operating room scheduling problem. There are several properties that affect the solution and complexity of the NP-Hard type problem. These features are as follows; Number of Surgeons, Number of Operating Rooms, Crossover Operator and Mutation Operator, Selection Mechanism, Parameter Coding Type, Total Number of Restrictions, Size and Formation of the First Population and Function of the Repair Operator.

In this article, the OR scheduling problem is solved by genetic algorithm. Even if it does not reach a definite solution, the genetic algorithm that provides the closest solution is one of the important optimization algorithms. As a result of the experiments, the most suitable parameter values; It is 40 for the number of populations tested between 2-50, 85% for the Crossover Rate tested between 50% and 90%, and 1.0% for the Mutation Rate between 0.1% and 1.5%.

According to the results of the experiments, although the increase in the number of surgeons complicated the problem, success was achieved in reaching the nearest solution. The increase in the number of operating rooms makes the problem more complex because of increases the number of constraints but it also facilitates the placement of the surgeries with increasing total placement area. So, the problem reach the closest solution. In the literature, selection methods such as roulette wheel, tournament method, and rank selection method are the most important selection methods for the operating room. In this study, the roulette wheel selection method was determined as the most appropriate method and the results obtained showed the accuracy of the selection. In very limited NP-Hard type problems such as operating room scheduling, the Repair Operator directly affects the solution because it corrects the genes that have been corrupted, lost, and lost their usual sequence after genetic operators. In cases where the Repair Operator is not implemented, it has been shown that generations progressing towards deadlock occur and the obligation of this operator to use.

In the program, in addition to the known genetic operators; The Repair Operator, which must be applied specifically for complex problems with a high number of constraints such as Operation Room scheduling, was used.

Further Works

It is possible to further enhance the study by methods such as some improvement, changing some methods or developing a new algorithm. In the elitism method, only the best individual is transferred to the next generation. According to population size, transferring more healthy genes to the next generation, is one of the methods that can be tried to improve the problem. When developing the application, the crossover and mutation methods used for the algorithm are multi-point. Better results can be achieved by using a block crossover and mutation methods or by testing with a new methods. Apart from the roulette wheel selection method used in the algorithm, a new selection method that can be developed specific to the problem will increase the success of the algorithm. By using a different meta-heuristic algorithm such as a new algorithm that called epigenetic algorithm, Particle Swarm Optimization, Simulated Annealing etc., it can be considered to make a success comparison when the same constraints are applied.

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