Efficient scheduling of emergency surgeries by adjusting the schedule of elective surgeries

M. Yazdi\textsuperscript{a}, M. Zandieh\textsuperscript{b}, H. Haleh\textsuperscript{c} and S.H.R. Pasandideh\textsuperscript{d}

\textsuperscript{a}. Department of Industrial Engineering, Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran.

\textsuperscript{b}. Department of Industrial Management, Management and Accounting Faculty, Shahid Beheshti University, Tehran, Iran.

\textsuperscript{c}. Faculty of Industrial Engineering, Golpayegan University of Technology, Golpayegan, Iran.

\textsuperscript{d}. Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran.

* Corresponding Author. Tel: +982129905215, E-mail addresses: M_zandiyeh@sbu.ac.ir;
Abstract
The rapid growth of the population has resulted in an increasing demand for healthcare services, which forces managers to use costly resources such as operating rooms effectively. The surgery-scheduling problem is a general title for problems that consists of the patient selection and sequencing of the surgeries at the operational level, setting their start times, and assigning the resources. Hospital managers usually encounter elective surgeries that can be delayed slightly and emergency surgeries whose arrivals are unexpected, and most of them need quick access to operating rooms. Reserving operating room capacity for handling incoming emergency surgeries is expensive. Moreover, emergency surgeries cannot afford long waiting times. This paper deals with the problem of surgery scheduling in the presence of emergency surgeries with a focus on balancing the efficient use of operating room capacity and responsiveness to emergency surgeries. We proposed a new algorithm for surgery scheduling with a specific operating room capacity planning and analyzed it through a simulation method based on real data. This algorithm respects working hours and availability of staff and other resources in a surgical suite.

Keywords Surgery scheduling; Operating rooms; Emergency surgery; Break-In-Moments; Project scheduling.

1. Introduction

Most of the revenues and expenditures in hospitals are related to operating rooms (ORs) and ORs are known as the heart of hospitals. Due to the expenses of ORs, their efficient use in surgery scheduling is considerable. The quality of surgery scheduling directly affects waiting times and admission or rejection of patients since it has a crucial role in patient health.
Moreover, the work lives of surgeons, anesthesiologists, nurses, and other OR staff are also affected by how a schedule distributes staff workload.

The OR management consists of many decisions in OR capacity planning and scheduling. Some of these decisions from the viewpoint of the hierarchical pyramid of decision-making are strategic decisions (long-term), tactical decisions (medium-term), and operational decisions (short-term) [1]. Strategic decisions or case-mix planning initiate with demand forecasting for the long term. According to this forecasting, some surgery specialties (such as cardiothoracic surgery, neurological surgery) are selected for patient admission. Furthermore, the amount of OR capacity acquisition is determined. How many ORs to be constructed is based on a very long-term (one to five years) demand estimation. Which surgical specialties to be served is based on long-term (6 months to one year) estimation [2]. Decision making about how to divide the OR’s capacities among these specialties (OR time blocks) is part of the tactical decision-making. The medium-term demand forecasting influences OR time blocks [2]. These problems are known as master surgical scheduling in the literature. The OR time blocks determine the time duration and the amount of OR capacity that are accessible for patients from each surgery specialty. Finally, patient selection and sequencing of the surgeries, determination of their start times, and resource allocation in surgery cases are the problems at the operational level [3], [4]. The scope of this paper is only on the SSP at the operational level. That means only surgery requests for some surgery specialties are admitted and the determination of surgery specialties that should be selected for providing service to patients is not within our scope. Moreover, the OR time blocks that divide the OR capacity among surgery specialties are given and their determination is beyond the scope of our work. In this paper, we encounter the problem of determining a sequence of patient surgeries and assigning the resources to them and the determination of their start times. These patient surgeries are from various specialties. The resources are from various resource types (ORs, surgeons, recovery rooms, staff, and so on) and are available based on their working hour and OR time blocks

1.1. Elective and emergency surgeries
Hospitals consider the scheduling of two classes of elective and emergency surgeries. Elective surgeries are related to patients who are admitted a few days ago. On the contrary, emergency surgeries have specific characteristics: their occurrences are unexpected and often during the execution of the schedule of other surgeries. Moreover, emergency surgeries generally require rapid access to ORs [5]. Handling emergency surgeries is a complicated task for hospital managers. These surgeries often have high urgency. Sometimes, emergency surgeries need immediate access to an OR, but most of them can afford some waiting time. The amount of the tolerable waiting time for an emergency patient depends on the severity and kind of illness. Emergency surgeries can arise 24/7, the stochastic nature of emergency surgeries and their threats to patients’ lives, force managers to reserve some capacities of resources to handle emergency surgeries, which lead to particular resource planning.

Performing patient surgery needs access to multiple expensive resources such as OR and professionals simultaneously. That clarifies the difficulties of surgery scheduling in the presence of emergency surgeries. Furthermore, the arrival of emergency surgeries results in disturbing the prescheduled surgeries, which causes instability in staffing and shift scheduling in surgical suites. Besides, it causes reorganizing resources in surgical suites and even sometimes in other upstream and downstream units in hospitals [6]. Hospitals usually ask on-call surgery teams to attend within thirty minutes, and the problem of availability of professionals is dealt with in this way. Managers concern themselves about the OR capacity planning for handling emergency surgeries better.

**1.2. Various OR capacity planning**

In fact, balancing between responsiveness for saving the lives of emergency patients and effective utilization of expensive resources such as ORs is a challenge that every hospital manager encounters. Only a limited number of previous papers have dealt with the subject of emergency surgery scheduling [7], [8]. Flexible ORs and dedicated ORs are two main OR capacity planning that have been examined in the literature for encountering emergency
surgeries. In the flexible ORs policy, OR capacity is shared between elective and emergency surgeries. This OR policy can result in disruptions during the execution of the scheduled tasks and lead to higher waiting times and the cost of using resources’ overtime [9]. In order to avoid these disruptions, a dedicated OR policy is suggested in the literature [10], [11]. In the dedicated OR policy, ORs are divided into two separate groups. Each group of elective and emergency surgeries only can be scheduled in their ORs. This policy prevents disruptions from the arrival of emergency surgeries, but OR utilization is the drawback and it is a costly method [9], [12]. Dedicated ORs to emergency surgeries are never used by elective surgeries even when they are free for a long time, and many elective surgeries experience extra waiting times. “How to divide ORs capacity between emergency and elective surgeries” is an important question that in some papers like Persson and Persson, this subject is dealt with [13]. The selection of each OR policy can influence the efficiency of the resulted schedule. Furthermore, the selected OR policy affects the number of schedule disruptions and the amount of OR utilization [12].

As mentioned before, all the ORs are utilized for both elective and emergency surgeries in flexible OR policy. The authors apply different approaches for implementing flexible ORs policy. In the first category of papers, some fraction of OR time is reserved for inserting emergency surgeries. This fraction of OR time can be considered as an integrated time-space of OR availability interval or as various shorter slack times between elective surgeries in the schedule. These approaches utilize the partitioning OR capacity to handle emergency surgeries [9]. In some others, the scheduling of elective surgeries is done without any prior time allocation for emergency surgeries. In this approach, emergency surgery can be inserted in any free slack or replaced with elective surgeries in the schedule at moments when elective surgeries are expected to finish. This approach partitions the OR capacities between elective and emergency surgeries in real-time [9]. Consequently, the implementation of this approach is more complicated than the former category. The terminology of the break-in-moment (BIM) is the potential start times of emergency surgeries or the equivalent finish times of elective
surgeries [14]. Indeed, scheduling elective surgeries in this approach is done by concentrating on spreading the BIMs in OR intervals to reduce waiting times in emergency surgeries.

Figure 1. Scheduling elective and emergency surgeries under the BIM policy.

Figure 1. clarifies the insertion of an emergency surgery into the schedule of elective surgeries in three ORs. The OR policy is flexible, and emergency surgery is inserted to be scheduled at the BIMs.

The BIMs approach is implemented in a few papers. This approach is introduced by van Essen et al. [14]. Vandenberghhe et al. extended the BIMs approach for the case that surgeries durations are stochastic with known distributions [15]. Duma and Aringhieri also use the BIMs approach in their paper [16]. Another recent work proposes the combination of dedicated and flexible ORs (hybrid policy) in which some rooms are dedicated strictly to elective surgeries or emergency surgeries, and others are flexible to serve both of them [17].

Each of the previous OR policies (dedicated, flexible, and their subgroups) is utilized in the literature. The question about “which of these policies is better in a specific scenario” has no strict answer and strongly depends on the conditions of the hospital and other operational conditions [16].

1.3. The surgery scheduling problem literature review

Many researchers from the operation research community have been interested in the surgery scheduling problem (SSP) also named as OR scheduling problem. Plenty of the SSP works have been presented in the recent review papers [1], [18], [19], [3]. Generally, the number of SSP articles has been significantly increased in the current decade [18] also, recent studies on SSP has been tended to solve complicated problems [19].
In the literature, the authors consider SSP from different points of view. Pham and Klinkert suppose a flow of patients that moves through some hospital units. They have formulated the SSP as a generalized job shop-scheduling problem [20]. Van Essen et al. provide a decision support system that constructs schedules by considering patients and wards desirability as different stakeholders of the SSP [21]. Jung et al. consider a class of parallel machines scheduling for the SSP [22]. Aringhieri et al. cover the demands of some patients for surgery over the weekends and consider both the OR time blocking problem and the SSP together [23]. Moosavi and Ebrahimnejad consider the SSP when unscheduled surgeries defer to the next scheduling period [24]. Riise et al. suppose any patient surgery as a project, which consists of several activities. The execution of any activity requires some sets of resources (modes). Each resource can be available with the predefined capacity in some time intervals [25]. They propose a multi-project, multi-mode resource-constrained project-scheduling problem with generalized precedence relations for the SSP. The authors classify this problem as an NP-hard problem by referring to Hans et al. [26] and develop the generalized operational surgery-scheduling problem (GOSSP), which is a meta-heuristic algorithm for this problem. Santibáñez et al. focus on the interrelation master surgical scheduling and the feasibility of the schedules. The authors mention that because some post-surgical resources such as recovery rooms are limited and shared by all the patients, the capacity of them can make an OR time block impossible. They consider both of the problems (master surgical scheduling and scheduling of the patients at the operational level) jointly to create a feasible OR time block. They defined surgical groups in each surgery specialty. These surgical groups have the same resource requirements and consist of the same procedures. Then, they concentrate on scheduling surgical groups instead of scheduling surgeries [27]. The utilization of surgical groups is developed by Banditori et al. by adding the patient’s due dates and durations. The authors utilize mixed-integer programming and simulation methods and suggest an approach to determine which surgical specialties can serve in the ORs and determine OR time blocks in the surgery suite. In such a way, they solve strategic and tactical planning problems jointly [28]. Cappanera et al. integrate master surgical scheduling with patient selection and
sequencing problems and develop a multi-objective mixed-integer programming model [29]. Visintin et al. in their paper consider the master surgical scheduling problem jointly with managing some critical resources (surgical teams, operating rooms, and surgical units) [30]. Table 1 reports the main characteristics of some recent literature in the SSP.

1.4. Contributions

To our best knowledge, only Riise et al. [25], [31] have been utilized “a multi-project multi-mode resource-constrained project-scheduling problem with generalized precedence relations” as the optimization model for the SSP. Moreover, the implementation of the BIMs idea has only been used in a few papers and less dealt with in the literature. Riise et al. merely focus on elective surgery scheduling in their works [25], [31], and as a result, all the ORs are dedicated to elective surgeries. In this paper, we extend their work by considering emergency surgeries. Furthermore, to handle emergency surgeries, we consider the flexible OR policy and implement the BIMs idea for inserting the emergency surgeries.
Table 1. The main characteristics of some recent SSP literature.

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One of the difficulties of the SSP comes from the existence of uncertainty, such as the patient’s arrival uncertainty, duration’s uncertainty, failure of critical medical equipment [19]. In this paper, we ignore the equipment failure and the unpredictability in elective patient’s arrival. As it is mentioned by Riise et al., for dealing with the deviation of the duration time of surgeries, many hospitals use estimations [25]. Therefore, we assume that after any surgery referral (elective surgery or emergency surgery), an expert estimates all the possible modes for the activities. The expert estimates a duration for any activity in any mode, based on his or her prior experiences. These estimations help us to deal with the uncertainty in the durations that comes from the difference between various resources.

The rest of this paper is structured as follows. Section 2 provides an overview of the problem definitions, and section 3 discusses the proposed algorithm. Section 4 illustrates experimental designs and some computational experiments. Finally, section 5 addresses conclusions and some outlines for future works.

2. Problem description

This paper is about scheduling a set \( P \) of patient’s surgeries from some specialties such as cardiothoracic surgery, neurological surgery, and so on. These surgical specialties are determined previously, and the determination of them is not within our scope. Initially, this set only contains the elective surgeries, but during the execution of the schedule, the set changes to include some emergency surgeries. Performing a patient’s surgery needs allocating more than one resource type simultaneously.

2.1. Resources

The patient’s surgeries in the set \( P \) use a shared set of resources \( R \) that includes various resource types such as ORs, surgeons, etc. Any resource in \( R \) has a particular working hour or availability interval, and this resource is only available in these hours in some capacities. Any resource \( \forall r \in R \) has a set of non-overlapping availability intervals \( K^r = \{k_1, k_2, \ldots\} \) in
which $k_q \in K'$ refers to one of the availability intervals with the capacity $c_q$. This way of representing the availability of resources helps us to consider a continuous-time model for representing the availability and capacity of resources [25], [31].

The ORs are available for each surgery specialty according to the master surgical planning (OR time blocks). In other words, each time interval $k_q$ in any OR can only be assigned to a specific surgery specialty (see Figure 2).

Figure 2. An instance of OR time blocks.

It is assumed that the resources availability intervals, resource capacities in each availability interval, and OR time blocks are known and given. It is supposed that the restrictions, which come from OR time block only apply to elective surgeries. However, emergency surgeries can use any OR available interval without considering the OR time blocks.

2.2. Activities and activity modes

Performing each patient’s surgery $\forall p \in P$ consists of the execution of $N^p$ treatment activities, e.g., preparing the patient, preparing the OR, surgery, cleaning the OR, and recovery. Various precedence relations (including the maximum and minimum time lags) can be assumed between each pair of these activities in any patient’s surgery. As an instance, the maximum time lag can explain the extreme waiting time of a patient between a pair of activities. Usually, more than one set of resources or activity modes can be applied for the execution of activities. As discussed in the previous section, activity modes in surgery activity resulted from various combinations of different surgeons with the same specialty and different ORs. Each activity mode has its own set of resources and duration.

In any activity $i$ in any patient’s surgery $p \in P$, there is a set of activity modes $M^i$. The selection of one of the activity modes $m \in M^i$ is necessary for the execution of this activity.
This selection clarifies a set of resources \( R^m \), that the amount of \( \mu^m_r \) units of any of them \( r \in R^m \) is necessary for the execution of the activity. The simultaneous availability of all the resources in the activity mode is necessary for the execution of the activity.

Each patient’s surgery is considered as a project. The execution of this project means scheduling all of its activities. Remaining any of the project’s activities unscheduled makes scheduling other activities useless, thus, these activities must be removed from the schedule.

2.3. Inter-activity mode compatibility constraints and project modes

Some resources (such as OR and surgeon) are applied in more than one activity in a project. It is necessary to use the same resource in all the activities in a project. As an instance, if two activities in a project require resource OR, the same OR must be used in this project. Inter-activity mode compatibility constraints are a group of constraints to guarantee the usage of the same common resource between the activities of a project. Project modes are a set of various combinations of common resources in a project and are utilized for implementing these constraints. Inter-activity mode compatibility constraints limit the selection of activity modes to those modes, which are compatible with a project mode.

As an illustration, consider a sample project \( p_1 \) that consists of two activities \( P = \{ \text{Surgery, Cleaning} \} \). Activity Surgery is the predecessor of activity Cleaning with precedence relation \( FS^{\text{max}} (15) \) (activity Cleaning must start up to 15 minutes after the termination of the activity Surgery). The execution of Surgery activity requires one Surgeon and one OR and also the execution of Cleaning activity requires one OR and one Cleaner. It is supposed that resource type OR contains three resources \((OR_1, OR_2, OR_3)\). The inter-activity mode compatibility constraint says when resource \( OR_1 \) is used for activity Surgery in the project \( p_1 \) then, only \( OR_1 \) must be used for the activity Cleaning of this project. Project mode only
contains the OR resource type here and gets one of \( \{ OR_1 \} \), \( \{ OR_2 \} \) and \( \{ OR_3 \} \), that in the above example, \( \{ OR_1 \} \) is selected as the project mode.

Generally, to implement inter-activity mode compatibility constraints in any project \( p \in P \), some project modes \( W^p \) are considered. The selection of a project mode \( w \in W^p \) in any project \( p \in P \) leads to the fact that in any activity \( i \in N^p \) only a subset of activity modes \( M^i_w \subset M \) remains compatible with the selected project mode. Each activity mode \( m \in M^i \) has its activity duration that depends on some resource considerations such as surgeon's skills or whether the surgery is performed in training mode or not.

### 2.4. Project’s disjunction constraints

The project’s disjunction constraints prevent the usage of a common resource in other projects in the interval between the first usage of it in a project and the completion of the last usage of it in the same project. It means these constraints make a common resource after its first usage of it in a project as quarantined and unavailable for other projects. Only after the termination of the last usage of that common resource in the activities of the current project, the resource can be available for other projects. For more illustration of the project’s disjunction constraint, suppose another project \( p_2 \) with the same structure as \( p_1 \) discussed previously. Suppose the project \( p_1 \) is before the project \( p_2 \) in the schedule, moreover, in both of them, the project mode \( \{ OR_1 \} \) is selected (both of the projects require the usage of the same common resource). The project’s disjunction constraint says the activity Surgery in the project \( p_2 \) cannot start until the termination of the activity Cleaning of the project \( p_1 \), even if the resource \( OR_1 \) remains idle between the activities Surgery and Cleaning of the project \( p_1 \).

This problem is classified as a multi-project, multi-mode resource-constrained project-scheduling problem with generalized precedence in the literature that belongs to NP-hard
The mathematical model of this problem in the case of scheduling elective surgeries is presented as a mixed-integer linear programming model by Riise and Mannino [31]. Then, we extended that mathematical model by considering both elective and emergency surgeries when the BIMs approach in the flexible OR policy is implemented [32]. For scheduling elective surgeries in real size problems, Riise et al. presented the GOSSP algorithm [25].

In this paper, we develop a scheduling elective and emergency surgeries (SEES) algorithm. As mentioned in the introduction, scheduling emergency surgeries and the efficient usage of ORs are challenges for hospital managers. We implement the BIMs approach in the flexible OR policy and examine its efficiency in emergency surgery scheduling. We utilize a Norwegian medium-sized hospital's data that are available on the web for testing our algorithm [33]. The BIMs approach has the capability of scheduling emergency surgeries with efficient usage of ORs capacities. Moreover, this approach has been less dealt with in the literature. To our best knowledge, this approach has not been implemented before in an environment where surgeries are considered as projects. In this method, any emergency surgery is inserted into the schedule after terminating one of the currently undergoing surgeries or, in other words, at the BIMs. For minimizing the waiting time in emergency surgeries, it is necessary to minimize the interval of the sequential BIMs in the sequencing of elective surgeries. This problem is as minimizing the maximum interval between sequential BIMs [14].

As discussed earlier, our main contribution is to implement the BIM approach when each surgery is a project with multi-mode activities. The most important requirement for implementing the BIMs approach is to know the duration of OR usage in the projects. Although we only consider the problem in a deterministic state, we cannot estimate the duration time of surgery activities with distinct values. The first reason is that in the surgery activity of a project, the durations in different ORs are not the same because of the difference between activity modes. The second reason is that this variation of the durations in the activity surgery in a project is not negligible because of the large number of activity modes (in some projects there
are 36 activity modes for activity surgery). As discussed before, the main reason for this variation in durations is about some resource considerations. As an instance, the surgeon’s experience or whether the operation is in the training environment or not can change the duration of the surgery activity.

The GOSSP algorithm belongs to the class of NP-hard optimization problems [25]. Moreover, operating room planning with elective and emergency surgeries is a strongly NP-hard problem [34]. Furthermore, adjusting the BIMs is a strongly NP-hard problem, in the case that the number of ORs exceeds one [14]. Due to the difficulty of solving this problem, we extend the original meta-heuristic algorithm of the GOSSP conveniently to handle emergency surgeries at the BIMs. The next section presents scheduling elective and emergency surgeries (SEES) algorithm.

3. Proposed algorithm

The SEES algorithm is about scheduling elective and emergency patient’s surgeries. This algorithm initially provides a schedule of elective surgeries. Then, during the execution of this schedule, after the arrival of any emergency surgery, it tries to insert the emergency surgery into the schedule with rescheduling.

3.1. Constraints

Some constraints are the same in both of the problems of scheduling and rescheduling of elective and emergency surgeries. Scheduling a project requires satisfying all constraints mentioned in the previous section (such as availability of resources, precedence relations between activities, inter-activity mode constraints, project’s disjunction constraints). However, it is necessary to consider some aspects during the scheduling of elective surgeries to implement the BIMs idea. We develop a new heuristic for scheduling elective surgeries. Inserting elective surgeries to a partial schedule is bound to potential insertion of a possible coming emergency surgery up to a limited period to the schedule. Only after satisfying one of
the following conditions, each elective surgery can be inserted into the schedule. First, after the estimated start time in an elective surgery up to a limited period (maximum tolerable waiting time in the emergency surgeries), one of the ORs becomes free and remains available for a specific duration (the average duration of emergency surgeries). Second, after the estimated start time of the elective surgery up to a limited period (the maximum tolerable waiting time in the emergency surgeries), another elective surgery starts in one of the ORs. The possible coming emergency surgery can access an OR in a tolerable waiting time, because in the first case, one of the ORs becomes free, and in the second case, the emergency surgery is substituted instead of one of the elective surgeries in the schedule. However, these limitations do not apply to emergency surgeries. Providing their resources is the only condition for inserting emergency surgeries to schedule.

3.2. Objective components

Usually, scheduling all the projects is impossible. A feasible schedule results from the scheduling activities of a subset of total projects \( \bar{P} \subset P \). Selecting this subset depends on some objective components. For scheduling these selected projects ( \( \bar{P} \) ), it is necessary to select an activity mode \( m \in M^i \) and a feasible start time for any activity \( i \in N^p \) in each project \( p \in \bar{P} \). The selection of an activity mode \( m \) and determination of start time for each activity \( i \) should be compatible with the availability of all of the resources \( r \in R^m \) in the activity mode \( m \). Moreover, for scheduling the projects, all the previously mentioned constraints should be satisfied.

Various objective components by a linear combination of them are included in the SEES and it is supposed that minimization of the objective function is desirable. If we consider \( O \) as the objective function, then \( O^f \) is an objective component and \( \alpha_f \) is its corresponding weight. The next formula illustrates the SEES objective function:

\[
O = \sum_f \alpha_f O^f \quad (1)
\]
As will be discussed in the following, each of the objective components has a specific scale, a simple summation of the weighted objective components is not reasonable. Therefore, each of the objective components is normalized. The variable $O^t$ refers to the normalized objective component. In such a way, the effect of different scales is removed from the objective function.

In this problem, we consider many objective components. Some of them ('unscheduled surgeries', 'patient's waiting time', 'violation of scheduling children and patients with diabetes in the early day' and finally 'makespan' or finishing the schedule early in the day) come from the GOSSP. Moreover, we include some other objective components in the SEES as below.

The deviance for the start times of the elective surgeries between the final schedule (after inserting all emergency surgeries) and the initial schedule (that only includes elective surgeries) is calculated in the 'un-stability' objective component. This objective component is the summation of the violation of start times of elective surgeries in the final schedule from their start times in the initial schedule.

The problem includes various ORs, each of these ORs has its OR capacity, the ‘VORL’ objective component tends towards resource leveling through balancing the OR usage. The amount of this objective component is the difference between the maximum and minimum percentage of OR usage among various ORs in the schedule. As an instance, suppose a case in which there are three ORs, and in the final schedule 85% of the total available capacity of $OR_1$, 25% of the total available capacity of $OR_2$, and 70% of the total available capacity of $OR_3$ are consumed. In this case, the ‘VORL’ takes the value of 60 that is the difference between 85 and 25.

Any patient surgery has its due date, and it is desirable to start without any lateness to achieve its due date. Therefore, we consider the following objective components: ‘the number of electives that are scheduled with lateness’ (‘NElecL’), ‘the number of emergencies that are scheduled with lateness’ (‘NEmgL’), ‘the summation of lateness in electives’ (‘SLElec’) and ‘the summation of lateness in emergencies’ (‘SLEmg’).
We also consider some special objective components that are related to elective surgeries: ‘the number of unscheduled electives’ (’NUnElec’) and ‘average waiting time in electives’ (’AWTElec’). Similarly, for emergency surgeries, the following objective components are added: ‘the number of unscheduled emergencies’ (’NUnEmg’) and ‘average waiting time in emergencies’ (’AWTEmg’). In this paper, it is supposed that the entire patient surgeries should be scheduled in ordinary working hours. Only those emergency surgeries that remain unscheduled during ordinary working hours can be scheduled in overtime.

3.3. ACI function

The SEES algorithm is a constructive-improvement algorithm and consists of some functions. The main function of the SEES algorithm is ACI function or adaptive construction and improvement algorithm, which is an iterative search algorithm. The ACI function (Figure 3) uses a limited size pool for maintenance of schedules and their corresponding project insertion order (PIO). Each schedule has a PIO that keeps the order of insertion of each project to this schedule. For example, if we suppose the set of projects as \( P = \{ \text{Project}_1, \text{Project}_2, \text{Project}_3 \} \) then, the array \( PIO = (2,3,1) \) means that the first project for scheduling is \( \text{Project}_2 \) then \( \text{Project}_3 \) and finally \( \text{Project}_1 \). This function always updates the best schedule of the pool after any change in each iteration of the execution. In each iteration, a decision determines whether a new schedule should be constructed or one of the pool’s schedules should be improved. A roulette wheel sampling makes this decision. This roulette wheel works based on how much each of the two methods (construction of a new schedule or improvement of one of the existing schedules) has been successful in reaching a good solution.

The construction method creates a new schedule. Each project has a clinical priority that shows its importance for early scheduling. A roulette wheel sampling, which works based on these projects’ priorities, is applied to generate a PIO \( \pi' \). Then, the Schedule Creator function
that will be discussed later in this section uses the PIO $\pi'$ and a parameter to create a schedule.

This parameter has a critical role in mode selection (activity modes and project modes) during inserting projects into the schedule.

For scheduling each project, different project modes and different activity modes lead to the usage of different sets of resources and result in different duration times. Three parameters for scheduling a project are considered: 'the best objective function', 'the earliest finish time', and 'the first feasible mode'. Another roulette wheel sampling is applied for selecting the parameter, which works based on each parameter’s success to conduct good schedules. The Schedule Creator function finally generates the schedule $S'$ and adds this schedule $S'$ and its corresponding PIO $\pi'$ to the pool.

The improvement method improves one of the existing schedules of the pool, the selection is done randomly, but better schedules have a higher chance of selection. The Insertion Order Modification function tries to modify the PIO, $\pi$ of the selected schedule $S$ and gives the resulted PIO, $\pi'$.

If the new PIO, $\pi'$ remains the same as the previous $\pi$, then the algorithm tries to select another schedule from the pool. This step repeats until the modified PIO differs from its initial PIO. Then, the Schedule Creator function is called to generate a new schedule, $S'$ through the modified PIO, $\pi'$. Finally, the resulted schedule, $S'$ with its PIO, $\pi'$ replace by $S$ and $\pi$ in the pool.

After any change in the pool, the best schedule of the pool is updated. Then, the success of construction and improvement methods and the success of various parameters in reaching good solutions are updated in their learning mechanisms separately. Finally, the ACI function after completing its execution returns the best schedule of the pool as its output.

……………………………………………………………………………………………………………………..PLEASE PLACE FIGURE 3 HERE ………………………………………………………………………

**Figure 3.** Adaptive construction and improvement algorithm (ACI function).
In the SEES algorithm, initially, the \textit{ACI} function is executed for producing a schedule for elective surgeries or equivalently elective projects. That is offline scheduling, and the resulted schedule is valid before the arrival of the first emergency surgery. After the arrival of any emergency surgery, old projects take one of these three various states. The execution of some projects terminated before this arrival time, some of them are currently undergoing surgeries, but they are not complete, and the last ones are those, which have not started yet.

The SSP is non-preemption scheduling. Therefore, the first position for inserting the emergency surgery to the schedule is after the currently undergoing surgeries, but before the projects that do not start. Moreover, after the arrival of any emergency surgery, the state of resources must also be modified to consider the consumed and in-use capacities. After these changes, the \textit{ACI} function is called again for producing a new schedule. This process repeats after any emergency arrival, and it creates online schedules.

\textbf{3.4. Schedule Creator function}

In \textit{ACI} function, if the construction method is selected, then \textit{Schedule Creator} function creates a new schedule from a new PIO and a parameter. Figure 4 illustrates the algorithm of \textit{Schedule Creator} function. This function partially schedules the projects one by one, according to the PIO. Initially, a random activity order $\pi^p$ is generated for the set of activities $N^p$ in any project $p \in \pi$. In this activity order, all the precedence relations between activities are considered.

For initialization, the variable $w^*$ sets to null, this variable refers to the selected project mode, and the set \textit{feasiblews} is cleared, this set collects all the feasible project modes. The variable \textit{ProParam} initializes with the input parameter. This variable indicates the selected parameter for scheduling this project. Only in the case of emergency surgeries, the value of this variable changes to \textit{the earliest finish time} to consider the urgency of these surgeries.

Then, the algorithm searches among various project modes $w \in W^p$ to find the best project mode for scheduling the project $p$. For each project mode, the $SGS( S, p, w, \pi^p, \textit{ProParam})$
function tries to insert activities of the project \( p \) with the activity order \( \pi'' \) and project mode \( w \) into the partial schedule \( S \) with the parameter \( \text{ProParam} \). This function is the most complicated part of the Schedule Creator function because this function should satisfy all the constraints mentioned in the previous section during the insertion of the activities to the partial schedule. If the \( SGS \) function can schedule the project \( p \) then, it is investigated whether the project is an emergency surgery or not. The success of the \( SGS \) function is sufficient in the emergency surgeries, but the following conditions must be examined in elective surgeries for encountering probable coming emergency surgeries.

From the start time of using the OR in the elective surgery \( p \) until a specified time later (‘the predefined BIM interval’ (PBIMI)), another BIM must be found, or one of the ORs must be available. Moreover, that available OR must remain accessible for a specific duration (‘the mean surgery time for emergency surgeries’ (MST)). If the project mode \( w \) overcomes these conditions, then the project mode will be inserted into the group of feasible project modes.

\[ \text{Figure 4. ScheduleCreator Function.} \]

Then, this project is removed from the partial schedule and this process is repeated to examine the feasibility of other project modes. Finally, the best project mode is chosen for inserting the project into the schedule. This process is repeated for all projects in PIO. At the end of the algorithm, the Schedule Creator function returns the resulted schedule as its output.

\[ \text{Figure 5. Scheduling elective surgeries with respect to adjusting the BIMs.} \]

Figure 5 gives more explanation of the feasibility conditions of project modes in elective surgeries. For inserting Surgery\(_1\) into the schedule, OR\(_2\) is available at the BIM\(_2\). Since the distance between BIM\(_1\) and BIM\(_2\) is less than ‘PBIMI’ and OR\(_2\) is available for an interval as long as ‘MST’, this project is inserted into the schedule. In the second case, Surgery\(_2\) can be inserted into the schedule, because OR\(_1\) is available for an interval longer than ‘MST’.
However, in the case of inserting \( \text{Surgery}_3 \) to the schedule, none of these conditions is satisfied because none of the ORs becomes free during the interval of ‘\( \text{PBIMI} \)’, and none of the elective surgeries starts in this interval. Therefore, this project cannot be inserted into the schedule.

3.5. Insertion Order Modification function

The \( \text{ACI} \) function is based on the selection of one of the construction and improvement methods. In the improvement method, a roulette wheel selects a schedule and its corresponding PIO from the pool for improvement. The main idea for improving a schedule is that earlier projects in PIO have a higher chance to be scheduled better than the other projects.

………………………………PLEASE PLACE FIGURE 6 HERE ………………………………

**Figure 6.** InsertionOrderModification function.

Therefore, after recognizing the projects with more contributions to the objective function, the Insertion Order Modification function tries to move their position earlier in the project insertion order. The Insertion Order Modification function uses the vector \( \pi EP \) that keeps the earliest position in which each project has ever been in the schedule. Then, this function recognizes a set of projects with more contributions to the objective function or bad projects. These projects are sorted based on their earliest positions in \( \pi EP \) and their contributions to the objective function. After that, the Insertion Order Modification function tries to take their positions to one place earlier than their positions in \( \pi EP \). In the case that two projects compete for one place, one of these projects is randomly selected for that position and the other one takes place in the next position. Finally, this function returns the new PIO to the \( \text{ACI} \) function.

**Figure 6** illustrates the Insertion Order Modification function.
4. Computational results

4.1. Data specifications

We use real patients’ information in a Norwegian hospital that is available on the web [33] for testing our algorithm. We select the file w40-1 as the data source of elective surgeries. This file contains the availability information of resources and the details of 40 patients’ surgeries, including their activities, project modes, and activity modes. Then, we use file w40-2 as the data source for emergency surgeries so that this file includes the information of the other 40 patients’ surgeries. Except for disaster conditions, usually, the number of emergency surgeries is supposed as a specific percentage of the number of elective surgeries. Bowers and Mould found that the number of emergency patients is about 25 percent of the number of elective patients in the orthopedic department [35]. We suppose the number of emergency surgeries is 20 percent of the number of elective surgeries, and therefore, in each experiment, eight projects are selected randomly from file w40-2 as emergency surgeries.

4.2. Projects’ specifications

In our problem instance, each project consists of three activities: surgery, recovery, and cleaning \( p = \{\text{Surgery, Recovery, Cleaning}\} \). The surgery activity is the predecessor of the other two, and both of the recovery and cleaning activities can start simultaneously. Execution of activities in any project requires a subset of four resource types including ORs, surgeons, recovery rooms, and cleaners \( R = \{\text{ORs, Surgeons, RecoveryRooms, Cleaners}\} \). Resources are available in some capacities in some availability intervals. Because of the existence of OR time blocks, the OR resource in each availability interval is only usable by surgeries from a specific surgery specialty (such as urology). It is supposed that emergency surgeries can be performed in any available OR with no respect for OR time blocks. The period of scheduling is one week, and all the elective surgeries that cannot be scheduled in a week remain unscheduled. Only emergency surgeries that remain unscheduled will be scheduled in overtime.
4.3. Comparing methods

For the investigation of the efficiency of our proposed algorithm in facing emergency surgeries, we consider two different methods. In the first one, elective surgeries are scheduled without any respect to adjusting the consecutive BIMs interval (ordinary scheduling). In the second one, scheduling elective surgeries is tied up to adjusting the BIMs as discussed in Schedule Creator function (scheduling surgeries with the BIMs interval adjustment).

In the first method (ordinary scheduling), the only condition for the acceptance of a project mode in the Schedule Creator function is the success of the SGS function in inserting the patient’s surgery with this project mode to the schedule.

In the BIMs interval adjustment method (the second method), besides the above-mentioned conditions for scheduling elective surgeries, the existence of another BIM or another available OR is examined.

In both methods, after the arrival of emergency surgery, the PIO changes in a way that inserts the emergency surgery before all the projects that have not started yet. Then, an online rescheduling with this new PIO is done. Both methods are implemented in the Visual C++ environment and run under Windows 8.1 on a system with Intel Core i7, 2.2 GHz processor, and 8 GB RAM.

4.4. Quality measurements and main factors

We want to investigate if the BIMs interval adjustment has any role in decreasing the waiting time in emergency surgeries, and how this method influences other quality measurements. Initially, some factors that can affect the waiting time in emergency surgeries are recognized as follows: ‘the way of scheduling’, ‘emergency arrival times’, ‘emergency surgeries priorities’ (or their due dates for the operation). Moreover, in the second method of scheduling that adjusts the BIMs interval, two parameters ‘MST’ and ‘PBIMI’ can affect the scheduling of emergency surgeries. For facing these variability factors in our experiments, ‘emergency
arrival times’ and ‘emergency projects priorities' are randomized, and different levels are considered for 'MST' and 'PBIMI' parameters.

We utilize a Poisson process for modeling the emergency arrival process. For the reason that the weekly period consists of several workdays, ‘the emergency arrival times’ are adjusted in a way that can occur only during work hours. In the case of ‘emergency projects priorities’ or project’s due dates, it is supposed that the due date of each emergency surgery randomly takes one of the numbers 60, 120, 180, or 240 minutes with an equal probability (Table 2.).

Table 2. Priorities of emergency surgeries.

| Priorities | Value |
|------------|-------|
| Low        | 60    |
| Medium     | 120   |
| High       | 180   |
| Extra High | 240   |

For choosing the levels for ‘MST’ and ‘PBIMI’ factors, we suppose the first method is equivalent to the second method when ‘MST’ is zero and 'PBIMI' is 15000 that is greater than the scheduling period. In the second method, two levels of 100 and 300 minutes for the factor ‘MST’ and two levels of 60 and 90 minutes for the factor ‘PBIMI’ are chosen based on our data. Thus, the required experiments can be classified based on various levels of two main factors. Table 3. shows the details.

We consider seven different patterns of emergency surgeries, with the following discussion. These patterns are conducted by selecting eight projects randomly as emergency projects, eight arrival times from the Poisson process that are adjusted in the weekly working hours for emergency arrivals, and eight surgery priorities that are selected randomly based on Table 2. for the due dates of emergency surgeries.

Finally, our elective surgeries are scheduled based on various settings of two main factors and their levels are mentioned in Table 3. In each schedule, all the seven patterns of emergency surgeries are examined and the values of the response variables are collected. This step is repeated ten times. Table 4. shows the average of the response variables in each pattern. Table 5. refers to the mean of response variables in various levels of two main factors.
Table 3. Main factors and their levels.

…………………………………..PLEASE PLACE TABLE 3 HERE …………………………………………..

Then, these results are analyzed by Factorial ANOVA analysis in SAS software at the confidence level ($\alpha=0.05$). This analysis tests whether the mean of quality measurements are the same by varying the levels of effects. Factorial ANOVA cannot indicate which levels of the effect cause the difference in the mean of the response variable. Therefore, Tukey’s Studentized Range (HSD) test that is one of the most common ANOVA Post-hoc tests is used after the Factorial ANOVA analysis at the same confidence level.
Table 4. The average of response variables after 10 repeats.

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In this section, we investigate whether changing the levels of the effects ‘MST’, ‘PBIMI’, and their interaction effect are statistically significant in the mean of the response variables. The Factorial ANOVA tables summarize the information about the sources of variation in our quality measurements. The results of Factorial ANOVA for response variables related to emergency surgeries are presented in Tables 6 to 9. The amounts of the p-value in Tables 6, 7, and 8 do not identify any statistically significant factor. On the other hand, the p-value for the main effect of ‘PBIMI’ in Table 9 is less than the significant level (α=0.05). In this way, this effect is statistically significant, and we can reject the null hypothesis of the equality of the means of response variable ‘AWTEmg’. Tukey test is utilized to distinguish the mean of the response variable in which levels of ‘PBIMI’ is different from others. Table 10 shows the comparisons of the means of ‘AWTEmg’ between levels 90 and 15000 of ‘PBIMI’, and levels 60 and 15000 of ‘PBIMI’ which are statistically significant at the 0.05 level, but this comparison is not statistically significant in the case of the levels 60 and 90 of ‘PBIMI’. Thus according to Tables 10 and 5, we can conclude that the mean of ‘AWTEmg’ at levels 60 and 90 of ‘PBIMI’ are smaller than level 15000 of ‘PBIMI’.

**Table 10.** Tukey (HSD) test for ‘AWTEmg’.

| …PLEASE PLACE TABLE 10 HERE …….. |

In other words, we can summarize all of the above analysis about the quality measurements related to emergency surgeries as follows: The BIMs interval adjustment has a better performance in ‘AWTEmg’, but there is not any evidence that each of the methods has a better performance in ‘NEmgL’, ‘NUnEmg’, and ‘SLEmg’.
The results of Factorial ANOVA for response variables related to elective surgeries are presented in Tables 11. to 14. In the case of quality measurements related to elective surgeries, similarly, the following results are obtained. The p-value column in Table 11. that is related to ‘NElecL’ does not indicate any statistically significant factor. However, this column in Table 12. Indicates factors ‘PBIMI’, ‘MST’ and their interaction are statistically significant for ‘SLElec’. Since the interaction of the effects is present, our main effects do not have their usual interpretations. It is difficult to state how independent effects ‘PBIMI’ and ‘MST’ act because the nature and magnitude of each of the effects depend on the particular level of another effect. In the case of ‘NUnElec’, Table 13. shows the effect ‘MST’ is statistically significant. The Tukey test results (Table 15.) show that all the levels of ‘MST’ are statistically significant. Considering Tables 5. and 15. shows the mean of ‘NUnElec’ has its lowest value when ‘MST’ is at level 0, and on the other hand, ‘NUnElec’ has its highest value when ‘MST’ is at level 300.

Investigating the p-value column in Factorial ANOVA for ‘AWTElec’ (Table 14.) shows both the main effects ‘PBIMI’ and ‘MST’ are statistically significant. The results of the Tukey test in Table 16. verify that the difference between the means at levels 60 and 15000 of ‘PBIMI’, and levels 60 and 90 of ‘PBIMI’ are statistically significant. Tables 16. and 5. indicate the mean of ‘AWTElec’ gets its highest value at level 60 of the ‘PBIMI’ but, the results of the Tukey test
do not detect which levels of ‘MST’ can cause the meaningful difference between ‘AWTElec’.

Table 16. Tukey (HSD) test for ‘AWTElec’ (PBIMI).

Table 17. Tukey (HSD) test for ‘AWTElec’ (MST).

Table 18. Factorial ANOVA for Un-stability.

Table 19. Factorial ANOVA for VORL.

Tables 18. and 19. are related to ‘Un-stability’ and ‘VORL’. ANOVA Factorial analysis of ‘Un-stability’ in Table 18. shows the effect ‘PBIMI’ is meaningful, and its related Tukey test analysis in Table 20. indicates that the difference between the means at levels 60 and 15000 of ‘PBIMI’ is statistically significant. Tables 21. and 5. show the mean of ‘Un-stability’ when ‘PBIMI’ is at the level 60 gets a higher value in comparison with the case that ‘PBIMI’ is at the level 15000. However, ANOVA Factorial analysis of ‘VORL’ in Table 19. does not indicate any statistically significant factor.

Table 20. Tukey (HSD) test for ‘Un-stability’.

Finally, Table 21. shows the results of Factorial Analysis for ‘Objective Function’. In this table, the p-value column indicates that ‘PBIMI’ is statistically significant. Tukey test in Table 22. indicates that the comparison between the means at the levels 90 and 15000 and levels 90 and 60 are statistically significant. The investigating of Tables 22. and 5. verify that the ‘objective Function’ gets its lowest value when ‘PBIMI’ is at the level of 90.

Table 21. Factorial ANOVA for ‘Objective Function’.

Table 22. Tukey (HSD) test for ‘Objective Function’.

In this section, the efficiency of the ordinary method (the first method) and the BIMs interval adjustment method (the second method) are examined with some experiments using the real data.
Table 23. The Results of the comparisons between two methods in quality measurements.

In the case of the quality measurements related to the emergency surgeries, the second method is preferable because both of the methods have similar results in ‘NEml’, ‘NUEmg’, and ‘SLejm’ but the second method decreases ‘AWTEml’. However, by considering quality measurements related to the elective surgeries, the first method is better than the second method. Both methods have similar results in ‘NElecL’ but the first method gives better results in ‘NUNelec’, and then in the second method, the level 100 of the effect ‘MST’ acts a little better than level 300 in this quality measurement. In ‘AWTElec’ quality measurement, the second method gives the worst results when the ‘PBIMI’ effect is at the level of 60, but the difference between the level 90 (in the second method) and level 15000 (the first method) of the ‘PBIMI’ effect is not statistically significant.

Moreover, in the ‘Un-stability’ quality measurement, level 60 of the ‘PBIMI’ effect gives the worst results for ‘Un-stability’, but there is not any significant difference between the first method and the second method when ‘PBIMI’ is at the level 90. In the case of ‘VORL’ quality measurement, both methods have similar results.

Finally, the best value for ‘Objective Function’ is related to the level 90 of the effect ‘PBIMI’ in the second method. Table 23. gives a summary of the comparison between two methods according to various quality measurements.

The analysis results show that our proposed algorithm for the BIMs interval adjustment is more preferable than the ordinary method of scheduling elective surgeries. For this reason, decreasing the average waiting time in emergency surgeries and having equivalent performance in other quality measurements that are related to emergency surgeries. Our proposed algorithm for the BIMs interval adjustment gives a better objective function when
‘PBIMI’ is at level 90. Generally, when ‘PBIMI’ is at level 90 and ‘MST’ is at level 100, the BIMs interval adjustment has a better or similar performance in many of our quality measurements.

5. Conclusion and future works

In this paper, we proposed the SEES algorithm that is an improvement constructive meta-heuristic algorithm for scheduling elective and emergency surgeries. The SEES algorithm is an extension of the GOSSP algorithm by including the scheduling of emergency surgeries and developing the idea of the BIMs interval adjustment in the ORs. Our main contribution is implementing the BIMs interval adjustment in scheduling elective surgeries when surgeries are projects with multi-mode activities. To our best knowledge, in all previous works of the BIMs interval adjustment, the duration of using the OR is a determined value. Moreover, the set of elective surgeries in any OR is given. Despite the previous literature in the BIMs interval adjustment, here, we assumed that the algorithm determines which elective surgeries will be assigned to each OR. Moreover, surgery activity has multi-modes, thus, its duration depends on the selected mode during the execution of the algorithm.

To investigate the efficiency of this algorithm, we consider two methods of scheduling elective surgeries, the ordinary method, and the BIMs interval adjustment method. Then, some experiments for inserting the emergency surgeries to these two schedules were examined and various quality measurements were compared. The results of the analysis show that our algorithm gets better performance in quality measurements related to emergency surgeries. This algorithm can decrease the average waiting time in emergency surgeries and our algorithm gives better objective function in some levels of main factors. However, in the case of quality measurements related to elective surgeries, the ordinary method gives better results.

The most important point of our proposed algorithm is the ability to decrease the average waiting time in emergency surgeries without dedicating any OR to emergency surgeries while having a good performance in the objective function. Generally, the proposed algorithm in this paper is appropriate for OR departments with the following specifications: expensive
surgeries, the normal rate of emergency arrivals, and patients that can afford some waiting time.

The problem of scheduling surgeries at the operational level is dealt with in this paper. The structure of the proposed algorithm allows us to treat all the resource types as homogeneous entities that have some availability intervals with some capacities. Nurses are one of the resources, and their availability comes from the nurse rostering problem. This is a complicated problem because it requires considering many specifications of nurses such as their skills, qualifications, and being attentive to shift preferences, and contractual agreements. There are many papers on this in the literature. The nurse rostering problem and the SSP are two interrelated problems but a few papers have dealt with these problems together. We suggest an extension of our work by integrating it with the nurse rostering problem as future work.

In this paper, we supposed the information of the OR time blocks that determine the availability of ORs for each surgery specialty is given. These OR time blocks have a real influence on the quality of the schedules in the SSP. We also suggest the integration of our work with the problem of determination of the OR time blocks for future works.

After surgery, patients need to access some postoperative care resources. Recovery rooms, ward beds, and intensive care units (ICUs) are important downstream resources. These resources are the bottleneck resources of the surgery-scheduling problem because their unavailability can cause schedule disruption and cancellation of elective surgeries and other difficulties. As future work, we suggest the integration of our work and the problem of determination of the optimum capacity of important downstream resources.

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**Figure 2.** An instance of OR time blocks.

**Figure 3.** Adaptive construction and improvement algorithm (ACI function).

**Figure 4.** ScheduleCreator Function.

**Figure 5.** Scheduling elective surgeries with respect to adjusting the BIMs.

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Biographies

**Maryam Yazdi** is a Ph.D. Candidate in the Department of Industrial Engineering, Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran. She received her B.Sc. from Computer and IT Group of department of Electrical & Computer Engineering, Isfahan University of Technology, Isfahan, Iran. She obtained her M.Sc. in the Industrial & Systems Engineering Faculty Tarbiat Modares University, Tehran, Iran. Her research interests include scheduling, meta-heuristic algorithms, multi-objective optimization, and inventory management.

**M. Zandieh** accomplished his B.Sc. in industrial engineering at Amirkabir University of Technology, Tehran, Iran (1994-1998), and M.Sc. in industrial engineering at Sharif University of Technology, Tehran, Iran (1998-2000). He obtained his Ph.D. in industrial engineering from Amirkabir University of Technology, Tehran, Iran (2000-2006). Currently, he is a professor at industrial management and information technology department, Shahid Beheshti University, Tehran, Iran. His research interests are production planning and scheduling, financial engineering, quality engineering, applied operations research, simulation, and artificial intelligence techniques in the areas of manufacturing systems design.

**Seyed Hamid Reza Pasandideh** is an associate professor in the Department of Industrial Engineering at the Kharazmi University, Tehran, Iran. He received his B.Sc., M.Sc., and Ph.D. in Industrial Engineering from Sharif University of Technology, Tehran, Iran. Also, he conducted postdoctoral research on Cold Supply Chain at the University of Nebraska-Lincoln, Lincoln, US. His research interests include optimizing inventory control, multi-objective optimization and application of queuing theory. He
has published widely in those fields and is the editor of some journals such as International Journal of Supply and Operations Management (IJSOM).
Figure 1. Scheduling elective and emergency surgeries under the BIM policy.
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Figure 6. *InsertionOrderModification* function.
| Authors                        | Patient classification | OR capacity configuration | Solution technique | Optimization model formulation |
|-------------------------------|------------------------|---------------------------|--------------------|-------------------------------|
|                               | Elective | Emergency | Dedicated ORs | Reserved spaces or slacks | BIMs adjustment | Partially flexible ORs |                          |                              |
| Ferrand et al. (2014)         | ✓        | ✓         | ✓           | ✓                  | ✓         | ✓                      | Simulation               | Real time management model |
| Duma and Aringhieri (2018)    | ✓        | ✓         |             |                    |            |                        | Simulation               |                              |
| Duma and Aringhieri (2015)    | ✓        | ✓         | ✓           | ✓                  | ✓                      |                        | Hybrid simulation and optimization method | Real time management model |
| Jung et al. (2019)            | ✓        | ✓         |             |                    | ✓                      |                        | Hybrid simulation and mixed integer programming | Mixed integer programming |
| Banditori et al. (2013)       | ✓        |           | ✓           |                    |                        |                        | Hybrid simulation and mixed integer programming | Mixed integer programming |
| van Essen et al. (2012 a)     | ✓        | ✓         |             |                    |                        | ✓                      | Hybrid simulation and optimization method | Mixed integer programming |
| [21]                          |           |            |              |                    |                        |                        |                                 |                              |
| van Essen et al. (2012 b)     | ✓        | ✓         |             |                    | ✓                      |                        | Hybrid simulation, heuristics and mixed integer programming | Mixed integer programming |
| [14]                          |           |            |              |                    |                        |                        |                                 |                              |
| Hans et al. (2008)            | ✓        |           |             |                    |                        | ✓                      | Hybrid simulation and heuristic | Stochastic knapsack problem |
| Moosavi & Ebrahimnejad (2018) | ✓        | ✓         | ✓           |                    |                        |                        | Hybrid Mixed Integer Programming and heuristic Mixed integer programming | Mathematical programming |
| Cappanera et al. (2016)       | ✓        |           |             |                    |                        | ✓                      | Equivalent random method over simulation | Goal programming |
| Litvak et al. (2008)          | ✓        | ✓         |             |                    |                        | ✓                      | Overflow models in telecommunication systems |                              |
Table 1. The main characteristics of some recent SSP literature (continued).  

| Authors                   | Patient classification | OR capacity configuration | Solution technique                     | Optimization model formulation |
|---------------------------|------------------------|---------------------------|-----------------------------------------|---------------------------------|
|                           | Elective | Emergency | Dedicated ORs | Reserved spaces or slacks | BIMs adjustment | Partially flexible ORs |                                           |                                  |
| Lamiri et al. (2008)-stochastic | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and mixed integer programming | Stochastic mathematical programming |
| Persson & Persson (2010)   | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Simulation                                   | Bin packing model                 |
| Pham & Klinkert (2008)     | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and mixed integer programming | Generalized job shop scheduling problem |
| Santibáñez et al. (2007)   | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and mixed integer programming | Mixed integer programming           |
| Tancrez et al. (2013)      | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Simulation                                   | Markovian model                    |
| Tancrez et al. (2009)      | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Simulation                                   | Markovian model                    |
| Vandenberghe et al. (2019) | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and heuristic                | Stochastic mathematical programming |
| Visintin et al. (2016)     | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and mixed integer programming | Mixed integer programming           |
| Riise et al. (2016)        | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Heuristic                                    | A multi-project, multi-mode resource-constrained project-scheduling problem |
| Riise et al. (2012)        | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Mixed integer programming                     | A multi-project, multi-mode resource-constrained project-scheduling problem |
| Our Paper                  | ✓        | ✓         | ✓            | ✓                      | ✓                  | ✓                       | Hybrid simulation and heuristic                | A multi-project, multi-mode resource-constrained project-scheduling problem |
Table 2. Priorities of emergency surgeries.

| due-date (min) | 60  | 120 | 180 | 240 |
|----------------|-----|-----|-----|-----|
| probability    | 0.25| 0.25| 0.25| 0.25|
Table 3. Main factors and their levels.

| Factor A: | Factor B: | Description                  |
|-----------|-----------|------------------------------|
| PBIMI     | MST       |                              |
| 15000     | 0         | ordinary scheduling method   |
| Levels of |           |                              |
| factors   |           |                              |
| 60        | 100       |                              |
| 300       |           | the BIMs interval adjustment |
| 100       |           | method                       |
| 90        | 300       |                              |
Table 4. The average of response variables after 10 repeats.

| No. | PBIM1 | MST2 | NEmgL3 | SLEmg4 | NUnEmg5 | AWTEmg6 | NElecL7 | SLElec8 | NUnElec9 | AWTElec10 | Un-stability11 | VORL12 | objective function |
|-----|-------|------|--------|--------|---------|---------|---------|---------|---------|-----------|-------------|---------|-------------------|
| 15000 | 0 | 0.2 | 31 | 1.7 | 54.45189 | 1 | 1021.1 | 0.4 | 2964.011 | 19674.3 | 11.396 | 1.96E-04 |
| 60 | 100 | 0.6 | 13.9 | 1.8 | 26.5106 | 0.4 | 2965 | 1.8 | 3330.926 | 20027.9 | 12.422 | 2.34E-04 |
| 15000 | 0 | 0.2 | 5.1 | 1.5 | 44.5206 | 0.2 | 1031.4 | 1.7 | 3000.825 | 25846.4 | 11.718 | 1.99E-04 |
| 60 | 100 | 0.3 | 20.8 | 1 | 17.1419 | 0.4 | 1495.5 | 4.3 | 2876.971 | 26149.6 | 12.7133 | 2.03E-04 |
| 90 | 100 | 1 | 10.9 | 1.9 | 42.1469 | 0.5 | 4986.4 | 1 | 3024.604 | 13620.6 | 11.4084 | 2.29E-05 |
| 90 | 300 | 0.3 | 25.7 | 1.6 | 44.2418 | 0.7 | 1497.1 | 7.1 | 2950.443 | 22700.8 | 11.4557 | 3.29E-05 |
| 60 | 100 | 0.6 | 13.9 | 1.8 | 26.5106 | 0.4 | 2965 | 1.8 | 3330.926 | 20027.9 | 12.422 | 2.34E-04 |
| 15000 | 0 | 0.2 | 5.1 | 1.5 | 44.5206 | 0.2 | 1031.4 | 1.7 | 3000.825 | 25846.4 | 11.718 | 1.99E-04 |
| 60 | 100 | 0.3 | 20.8 | 1 | 17.1419 | 0.4 | 1495.5 | 4.3 | 2876.971 | 26149.6 | 12.7133 | 2.03E-04 |
| 90 | 100 | 1 | 10.9 | 1.9 | 42.1469 | 0.5 | 4986.4 | 1 | 3024.604 | 13620.6 | 11.4084 | 2.29E-05 |
| 90 | 300 | 0.3 | 25.7 | 1.6 | 44.2418 | 0.7 | 1497.1 | 7.1 | 2950.443 | 22700.8 | 11.4557 | 3.29E-05 |

1 PBIMI is the predefined BIM interval in the second method (the BIMs interval adjustment method), the level 15000 is used for referring to first method (ordinary scheduling)
2 MST is the mean surgery time for emergency surgeries in the second method (the BIMs interval adjustment method), the level 0 is used for referring to first method (ordinary scheduling)
3 NEmgL or the number of emergencies that are scheduled with lateness
4 SLEmg or the summation of lateness in emergencies
5 NUnEmg or the number of unscheduled emergencies in ordinary time that are scheduled in the overtime
6 AWTEmg or average waiting time in emergencies
7 NElecL or the number of electives that are scheduled with lateness
8 SLElec or the summation of lateness in electives
9 NUnElec or the number of unscheduled electives
10 AWTElec or average waiting time in electives
11 Un-stability is the summation of the violation of start times of electives in the final schedule (after inserting all the emergencies) from their start times in initial schedule (without any emergencies)
12 VORL or ‘violation from OR leveling’ is the difference between the maximum and minimum percentage of the OR usage among various ORs
Table 4. The average of response variables after 10 repeats (Continued).

| No. | PBIMI | MST | NEmlg | SLEmg | NUnEmg | AWTEmg | NElecL | SLElec | NUnElec | AWTElec | Unstability | VORL | objective function |
|-----|-------|-----|-------|-------|--------|--------|--------|--------|---------|----------|--------------|------|---------------------|
| 3   | 15000 | 0   | 0.3   | 42.2  | 2      | 42.132 | 0.4    | 1489.4 | 0.5     | 3008.248 | 29716        | 10.87798   | 7.28E-04   |
|     | 60    | 100  | 0.1   | 0     | 2      | 24.994 | 0      | 3987.8 | 3       | 3342.277 | 66792.3      | 11.489     | 2.79E-04   |
|     | 60    | 300  | 0.5   | 1.2   | 2      | 20.282 | 0.1    | 2467.8 | 9.6     | 3061.365 | 43941.6      | 7.9404     | 4.17E-04   |
|     | 90    | 100  | 1.2   | 0.7   | 2      | 46.414 | 0.1    | 5956.4 | 1.4     | 3142.13  | 38236.9      | 9.2584     | 1.46E-04   |
|     | 90    | 300  | 0.5   | 2.2   | 2      | 38.748 | 0.2    | 2499.6 | 8.3     | 2769.62  | 39654        | 8.7365     | 1.39E-04   |
|     | 4     | 15000 | 0   | 0.2   | 16    | 2      | 47.696 | 0.5    | 986.2   | 0        | 2915.261     | 7055.8      | 6.858     | 2.17E-04   |
|     | 60    | 100  | 0.3   | 13.8  | 2      | 30.249 | 0.4    | 2930.6 | 1.3     | 3502.799 | 26376.4      | 10.5744    | 2.45E-04   |
|     | 60    | 300  | 0.5   | 45    | 2      | 33.149 | 0.8    | 2530.6 | 5.4     | 3343.474 | 24974.8      | 11.48994   | 3.33E-04   |
|     | 90    | 100  | 1.0   | 20.2  | 2      | 41.883 | 0.5    | 4953.5 | 0.7     | 3085.512 | 11005.2      | 9.2545     | 2.32E-05   |
|     | 90    | 300  | 0.2   | 32.6  | 1.9    | 50.282 | 0.5    | 998.3  | 6.4     | 2928.979 | 24122.4      | 9.0995     | 1.34E-04   |
|     | 5     | 15000 | 0   | 0.6   | 1.1   | 0.2    | 58.162 | 0.1    | 2933.9 | 0.8     | 3073.144     | 23107.8     | 9.4294    | 4.51E-04   |
|     | 60    | 100  | 0.8   | 6.8   | 0      | 22.737 | 0.1    | 3938.5 | 5.6     | 3324.167 | 44578        | 12.934     | 1.24E-04   |
|     | 60    | 300  | 0.4   | 15.5  | 0.2    | 24.649 | 0.3    | 1999.6 | 7.6     | 3375.375 | 56762.2      | 11.5463    | 1.9E-04    |
|     | 90    | 100  | 1.0   | 0     | 0.1    | 25.088 | 0      | 5013   | 3.5     | 3190.673 | 36963.3      | 10.88335   | 9.15E-05   |
|     | 90    | 300  | 0.2   | 5.6   | 0      | 23     | 0.1    | 2005.9 | 7.9     | 3106.396 | 36820.4      | 12.0768    | 7.31E-05   |
|     | 6     | 15000 | 0   | 0.5   | 21.8  | 1.1    | 63.656 | 0.3    | 2419.8 | 1       | 3496.847     | 45124.3     | 14.2877   | 1.44E-04   |
|     | 60    | 100  | 0.6   | 6     | 1      | 32.142 | 0.3    | 3064.8 | 3       | 3532.152 | 49716.9      | 14.01048   | 1.77E-04   |
|     | 60    | 300  | 0.3   | 3.1   | 0.9    | 33.042 | 0.2    | 1532.1 | 8.9     | 3178.958 | 42986.1      | 12.1122    | 2.99E-04   |
|     | 90    | 100  | 0.1   | 28.2  | 1.1    | 46.124 | 0.5    | 5415.5 | 2.1     | 3143.474 | 36277.1      | 11.9657    | 6.86E-05   |
|     | 90    | 300  | 0.5   | 8.6   | 1.2    | 50.270 | 0.4    | 2506.3 | 8.4     | 2986.309 | 35778.3      | 9.2503     | 3.11E-05   |

Continued on next page
Table 4. The average of response variables after 10 repeats (Continued).

| No. | PBIMI | MST | NEml | SEmg | NEmg | AWTEmg | NElecL | SLElec | NUnElec | AWTElec | Unstability | VORL | Objective Function |
|-----|-------|-----|------|------|------|--------|--------|--------|---------|---------|-------------|------|-------------------|
| 7   | 60    | 100 | 0.2  | 15.7 | 1    | 14.01399 | 0.4    | 3435.2 | 3.5     | 3381.961 | 50912.3     | 10.6997 | 1.88E-04         |
|     | 60    | 300 | 0.5  | 3.7  | 1    | 9.3279  | 0.2    | 2483.5 | 8.5     | 3259.839 | 43868       | 9.7731  | 2.92E-04         |
|     | 90    | 100 | 0.1  | 7.3  | 1    | 20.78463 | 0.4    | 4990.2 | 1.8     | 3150.072 | 33034.4     | 9.4066  | 1.53E-05         |
|     | 90    | 300 | 0.4  | 24.1 | 1.2  | 17.93   | 0.4    | 2025.3 | 7.9     | 2809.2   | 38133       | 8.9339  | 3.01E-04         |
Table 5. The mean value table.

| PBIMI | MST | Number of observations | NEmgL | SLEmg | NUnEmg | AWTEmg | NElecL | SLElec | NUnElec | AWTElec | Un-stability | VORL | Objective Function |
|-------|-----|------------------------|-------|-------|--------|--------|--------|--------|--------|--------|-------------|------|-------------------|
| 1500  | 0   | 7                      | 0.3286| 19.4286| 1.3571 | 50.5948| 0.4714 | 1631.44| 0.8143 | 3030.94| 22998.80     | 10.5871 | 2.97E-04          |
| 60    | -   | 14                     | 0.4071| 12.1071| 1.2429 | 24.0784| 0.3071 | 2561.29| 5.4286 | 3254.91| 39505.05     | 11.3463 | 2.53E-04          |
| 90    | -   | 14                     | 0.4929| 14.1643| 1.2857 | 34.4632| 0.3500 | 3377.31| 4.7143 | 2978.43| 28947.98     | 10.3369 | 8.84E-05          |
| -     | 100 | 14                     | 0.5357| 12.4214| 1.2857 | 29.8746| 0.3214 | 4042.57| 2.5643 | 3200.77| 33559.10     | 11.4211 | 1.31E-04          |
| -     | 300 | 14                     | 0.3643| 13.8500| 1.2429 | 28.6670| 0.3357 | 1896.02| 7.5786 | 3032.57| 34893.93     | 10.2622 | 2.10E-04          |
Table 6. Factorial ANOVA for NEMGL.

| Source   | DF | SS   | MS   | F     | P     |
|----------|----|------|------|-------|-------|
| PBIMI    | 1  | 0.0514 | 0.0514 | 0.70  | 0.4105|
| MST      | 1  | 0.2057 | 0.2057 | 2.79  | 0.1054|
| PBIMI*   | 1  | 0.1729 | 0.1729 | 2.34  | 0.1364|
| MST      |    |       |       |       |       |
| Error    | 30 | 2.2143 | 0.0738 |       |       |
| Total    | 34 | 2.7269 |       |       |       |
Table 7. Factorial ANOVA for SLEmg.

| Source   | DF | SS    | MS    | F    | P    |
|----------|----|-------|-------|------|------|
| PBIMI    | 1  | 29.62 | 29.62 | 0.18 | 0.6755 |
| MST      | 1  | 14.29 | 14.29 | 0.09 | 0.7711 |
| PBIMI* MST | 1  | 4.32  | 4.32  | 0.03 | 0.8728 |
| Error    | 30 | 4974.35 | 165.81 |      |       |
| Total    | 34 | 5244.34 |       |      |       |
Table 8. Factorial ANOVA for NUnEmg.

| Source     | DF | SS    | MS    | F    | P     |
|------------|----|-------|-------|------|-------|
| PBIMI      | 1  | 0.0129| 0.0129| 0.03 | 0.8687|
| MST        | 1  | 0.0129| 0.0129| 0.03 | 0.8687|
| PBIMI* MST | 1  | 0.0014| 0.0014| 0.00 | 0.9560|
| Error      | 30 | 13.8743| 0.4625|
| Total      | 34 | 13.9497|       |      |
| Source      | DF | SS    | MS  | F    | P    |
|------------|----|-------|-----|------|------|
| PBIMI      | 1  | 754.907 | 754.91 | 5.90 | 0.0214 |
| MST        | 1  | 10.208  | 10.21  | 0.08 | 0.7796 |
| PBIMI* MST | 1  | 14.173  | 14.17  | 0.11 | 0.7416 |
| Error      | 30 | 3840.35 | 128.01 |      |       |
| Total      | 34 | 7166.03 |       |      |       |
| Comparison       | Difference Between Mean | Simultaneous 95% Confidence Limits |   |
|------------------|-------------------------|-------------------------------------|---|
| 15000 - 90       | 16.132                  | 3.22 29.043 ***                     |   |
| 15000 - 60       | 26.516                  | 13.605 39.428 ***                   |   |
| 90 - 15000       | -16.132                 | -29.043 -3.22 ***                   |   |
| 90 - 60          | 10.385                  | -0.158 20.927                       |   |
| 60 - 15000       | -26.516                 | -39.428 -13.605 ***                 |   |
| 60 - 90          | -10.385                 | -20.927 0.158                       |   |
### Table 11. Factorial ANOVA for NElecL.

| Source     | DF | SS    | MS    | F    | P     |
|------------|----|-------|-------|------|-------|
| PBIMI      | 1  | 0.0129| 0.0129| 0.22 | 0.6404|
| MST        | 1  | 0.0014| 0.0014| 0.02 | 0.8760|
| PBIMI* MST | 1  | 0.0057| 0.0057| 0.1  | 0.7552|
| Error      | 30 | 1.7314|       |      |       |
| Total      | 34 | 1.8657|       |      |       |
**Table 12.** Factorial ANOVA for SLElec.

| Source    | DF | SS    | MS    | F    | P     |
|-----------|----|-------|-------|------|-------|
| PBIMI     | 1  | 4.7E+06 | 4.7E+06 | 9.0  | 0.0054 |
| MST       | 1  | 3.2E+07 | 3.2E+07 | 62.3 | 0.0001 |
| PBIMI* MST| 1  | 7.5E+06 | 7.5E+06 | 14.5 | 0.0006 |
| Error     | 30 | 1.6E+07 | 5.2E+05 |      |       |
| Total     | 34 | 7.0E+07 |       |      |       |
| Source     | DF | SS   | MS   | F    | P    |
|------------|----|------|------|------|------|
| PBIMI      | 1  | 3.57 | 3.57 | 2.84 | 0.1025 |
| MST        | 1  | 176.00 | 176.00 | 140  | 0.0001 |
| PBIMI*MST  | 1  | 2.40 | 2.40 | 1.91 | 0.1775 |
| Error      | 30 | 37.77 | 1.26 |      |      |
| Total      | 34 | 321.24 |      |      |      |
| Source     | DF | SS    | MS    | F     | P    |
|------------|----|-------|-------|-------|------|
| PBIMI      | 1  | 535076| 535076| 15.2  | 0.0005 |
| MST        | 1  | 198023| 198023| 5.63  | 0.0243 |
| PBIMI* MST | 1  | 3823  | 3823  | 0.11  | 0.7440 |
| Error      | 30 | 1055352| 35178 |       |       |
| Total      | 34 | 1833432|       |       |       |
**Table 15.** Tukey (HSD) test for ‘NUnElec’.

| MST     | Difference Between Mean | Simultaneous 95% Confidence Limits |
|---------|-------------------------|-----------------------------------|
| 100 - 300 | -5.0143              | -6.0598  -3.9688                  | *** |
| 100 - 0   | 1.7500                | 0.4695   3.0305                   | *** |
| 300 - 100 | 5.0143                | 3.9688   6.0598                   | *** |
| 300 - 0   | 6.7643                | 5.4838   8.0448                   | *** |
| 0 - 100   | -1.7500               | -3.0305  -0.4695                  | *** |
| 0 - 300   | -6.7643               | -8.0448  -5.4838                  | *** |

Comparisons significant at the 0.05 level are indicated by ***.
Table 16. Tukey (HSD) test for ‘AWTElec’ (PBIMI).

| Comparison       | Difference Between | Simultaneous 95% Confidence Limits | Mean | Upper Limit | Lower Limit |
|------------------|--------------------|------------------------------------|------|-------------|-------------|
| 15000 - 90       | 52.51              | -161.53                            | 266.55 |
| 15000 - 60       | -223.97            | -438.01                            | -9.93 | ***         |
| 90 - 15000       | -52.51             | -266.55                            | 161.53 |
| 90 - 60          | -276.48            | -451.24                            | -101.71 | ***         |
| 60 - 15000       | 223.97             | 9.93                               | 438.01 | ***         |
| 60 - 90          | 276.48             | 101.71                             | 451.24 | ***         |
Table 17. Tukey (HSD) test for ‘AWTElec’ (MST).

| Alpha    | 0.05  |
|----------|-------|
| Error DF | 30    |
| Error MS | 35178.39 |
| Critical value of Studentized Range | 3.49 |

Comparisons significant at the 0.05 level are indicated by **

| MST | Comparison | Difference Between | Simultaneous 95% |
|-----|------------|--------------------|------------------|
|     | Mean       | Confidence Limits  |                  |
| 100 - 300 | 168.19  | -6.57              | 342.96           |
| 100 - 0    | 169.83 | -44.21             | 383.87           |
| 300 - 100  | -168.19 | -342.96            | 6.57             |
| 300 - 0    | 1.63   | -212.41            | 215.68           |
| 0 - 100    | -169.83 | -383.87            | 44.21            |
| 0 - 300    | -1.63  | -215.68            | 212.41           |
| Source   | DF | SS     | MS     | F    | P     |
|----------|----|--------|--------|------|-------|
| PBIMI    | 1  | 7.8E+08| 7.8E+08| 4.90 | 0.0346|
| MST      | 1  | 1.3E+07| 1.3E+07| 0.08 | 0.7815|
| PBIMI* MST | 1  | 9.2E+07| 9.2E+07| 0.58 | 0.4530|
| Error    | 30 | 4.8E+09| 1.6E+08|      |       |
| Total    | 34 | 6.4E+09|        |      |       |
Table 19. Factorial ANOVA for VORL.

| Source       | DF | SS    | MS    | F    | P     |
|--------------|----|-------|-------|------|-------|
| PBIMI        | 1  | 7.1322| 7.1322| 2.8  | 0.1049|
| MST          | 1  | 9.4016| 9.4016| 3.69 | 0.0644|
| PBIMI* MST   | 1  | 1.0607| 1.0607| 0.42 | 0.5239|
| Error        | 30 | 76.5122| 2.5504|      |       |
| Total        | 34 | 94.4694|       |      |       |
Table 20. Tukey (HSD) test for ‘Un-stability’.

| Alpha              | 0.05 |
|--------------------|------|
| Error DF           | 30   |
| Error MS           | 1.6E+08 |
| Critical value of Studentized Range | 3.49 |

Comparisons significant at the 0.05 level are indicated by ***.

| PBIMI Comparison | Difference Between Mean | Simultaneous 95% Confidence Limits |
|------------------|-------------------------|------------------------------------|
| 15000 - 90       | -5949                   | -20349 8450                         |
| 15000 - 60       | -16506                  | -30906 -2107 ***                    |
| 90 - 15000       | 5949                    | -8450 20349                         |
| 90 - 60          | -10557                  | -22314 1200                         |
| 60 - 15000       | 16506                   | 2107 30906 ***                      |
| 60 - 90          | 10557                   | -1200 22314                         |
Table 21. Factorial ANOVA for ‘Objective Function’.

| Source     | DF | SS     | MS     | F     | P     |
|------------|----|--------|--------|-------|-------|
| PBIMI      | 1  | 1.90E-07 | 1.90E-07 | 14.5  | 0.0007 |
| MST        | 1  | 4.41E-08  | 4.41E-08  | 3.36  | 0.0768 |
| PBIMI* MST | 1  | 1.15E-09  | 1.15E-09  | 0.09  | 0.7690 |
| Error      | 30 | 3.94E-07  | 1.31E-08  |       |       |
| Total      | 34 | 7.18E-07  |         |       |       |
Table 22. Tukey (HSD) test for ‘Objective Function’.

| Comparison   | Difference Between Mean | Simultaneous 95% Confidence Limits |
|--------------|--------------------------|-----------------------------------|
| 15000 - 90   | 2.0848E-04               | 7.8E-05                           | 0.00034    |
| 15000 - 60   | 4.3870E-05               | -8.7E-05                          | 0.00017    |
| 90 - 15000   | -2.0848E-04              | -0.00034                          | -7.8E-05   |
| 90 - 60      | -1.6461E-04              | -0.00027                          | -5.8E-05   |
| 60 - 15000   | -4.3870E-05              | -0.00017                          | 8.7E-05    |
| 60 - 90      | 1.6461E-04               | 5.8E-05                           | 0.00027    |

Comparisons significant at the 0.05 level are indicated by ** *. 
| Quality measurement | Comparison result |
|---------------------|------------------|
| **Emergency surgeries measurements** | |
| NEmgL               | Both methods act similarly. |
| SLEmg               | Both methods act similarly. |
| NUnEmg              | Both methods act similarly. |
| AWTEmg              | The BIMs interval adjustment method acts better. |
| **Electives surgeries measurements** | |
| NElecL              | Both methods act similarly. |
| SLElec              | The main factors and their interaction are statistically significant. It is difficult to judge which method is better. |
| NUnElec             | The ordinary method acts better, but in the case of the BIMs interval adjustment method, level 100 is preferable to level 300 in MST. |
| AWTElec             | The ordinary method acts similarly to the BIMs interval adjustment method when PBIMI is at the level of 90. Both of these acts better than level of 60 in PBIMI in the BIMs interval adjustment method. |
| **Others** | |
| Un-stability        | The ordinary method acts similarly to the BIMs interval adjustment method when PBIMI is at the level of 90. Both of them act better than level of 60 in PBIMI in the BIMs interval adjustment method. |
| VORL                | Both methods act similarly. |
| **Objective Function** | The BIMs interval adjustment method, when PBIMI is at level of 90 has the best result. |