# A decision support tool for the urgent surgeries assignment problem

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## Abstract

**Purpose -** In this paper, nonelective patients are assigned in an already existing operating block schedule, both respecting health and cost-efficiency objectives.

**Design / methodology / approach -** We designed and developed assignment strategies, in function of three patient classes: emergent, urgent, and work in case. The global objectives are both the assignment of the maximal amount of nonelective cases and global operating block overtime cost-efficiency.

**Findings** – The developed strategies have been tested and validated with a 4-operating-room block, with 5 specialties, with a 7-hour regular opening time, 2-hours- allowed overtime, on a 5-day planning horizon. Results show an improvement on both operating rooms capacity filling and supplementary hours overruns limitation.

**Research implications** – Strategies are independent on the benchmark test values. They are adapted to 3 patient classes, and on the objectives aimed for each class.

**Practical implications** – The decision support tool has been developed with and validated by a west European hospital surgical team. The strategies can be adopted by any other comparable hospital block.

**Social implications** – Developing the here presented strategies in developed countries hospitals could help them limit their health care budget overruns.

**Originality / value -** Scientific results obtained are twofold. Firstly, all proposed strategies have been validated and show effectiveness and relevancy for the addressed problem, in real time conditions. Secondly, the tool also assesses, for a given operating block, with a given provisional schedule, the number of nonelective surgeries that can be accommodated.

**Keywords:** Operating rooms scheduling; online scheduling; non-elective surgeries assignment; decision support tool; operating theater.

## Introduction

Budget reduction and significant increases in life expectancy put a substantial amount of strain on limited health care resources. Those phenomena highlight the need for hospital's administrators to use resources more effectively and lead managerial staff to examine more closely cost-effective activities. Computational tools have the potential to transform the fields of public health policy, by instilling decision makers with the willingness to adapt and accept new technologies, attitudes, information, and creative ways of thinking (Macario et al., 1995). The development of decision support tools helps them support decisions on complex dynamic problems (Van Oostrum et al., 2008). The operating theater is the hospital's largest cost and revenue center, because it consumes 40% of a hospital's resources (Brunner et al., 2009), and more than 60% of patients admitted to the hospital require a surgical intervention (Guerriero and Guido, 2011). Consequently, due to the economic environment that it represents, the sizeable impact on patients' safety and on the workflow of other departments, hospital managers consider the operating theatre department as their main source of concern.

In order to achieve a better use of operating theater resources, it is essential to firstly understand the type of patients treated, and then to analyze their resulting workload. Patients typically vary in a multitude of ways, among others: illness severity, recovery speed, diagnosis, medical complications and resource consumption. In this context, we are interested in two types of patient flows: elective and non-elective patients. These two patients' groups have different characteristics. In fact, elective patients are scheduled in advance, while non-elective cases turn up unexpectedly and cannot be scheduled in advance. Obviously, operating theater managers face a managerial conflict between elective and unpredictable surgeries. Electives have to be scheduled to achieve a high resource utilization and a high level of efficiency, while non-elective surgeries claim responsiveness and minimization of the generated disruptions for elective patients.

Within this framework, we propose an intelligent decision support tool to help operating theater mangers integrating urgent patients (non-elective) into the predefined schedule. These kinds of systems have demonstrated their convenience and efficiency (Kasie *et al*., 2017). In fact, throughout the planning horizon, the initial surgical schedule is adjusted in function of non-elective surgeries arrival. Usually, the manager realizes these adjustments, according his own experience, without necessarily considering optimization requirements (Berry *et al*., 2008). Thus, since it is hard for an operating room (OR) manager to handle this unpredictable flow of patients, we developed a decision support tool which supports the decision maker in the re-scheduling process. This tool was developed in the frame of a collaboration between our laboratory and the surgical team of the operating block of a west-European hospital. This surgical team has validated the decision support tool, as well as the results presented in this paper.

It is important to adapt the strategic manufacturing objectives to the clinical state of the patient (Chiarini, 2019). In a first time, we sort non-elective patients according to their medical priority. We essentially distinguish three non-elective patient's classes: emergent, urgent and work-in-cases. The main contribution of the second section of this paper is to provide online assignment strategies to each non-elective patient category. The proposed assignments are riskless on patient health. According to each non-elective surgery class, the proposed adjusted schedule minimizes different criteria such as patient's waiting time, deviation from firstly scheduled starting time of an elective surgery and the amount of resulting overtime for surgical teams.

In this paper, we describe, in the first part, the tackled problem along with a literature review. Then, the second part describes the methodologies we have proposed and developed to assign non-elective surgeries in an existing schedule, in function of their respective gravity. The third part presents the results we have obtained with these methodologies on real case schedules, along with discussions on these results. Finally, we give concluding remarks, along with a discussion of future possible extensions of this work.

## I. Problem presentation: Non-elective cases scheduling

This paper tackles non-elective surgeries scheduling problem. In this section, we firstly present an overview on how the problem of integrating non-elective patients in operating theatre schedule is treated in the literature. Secondly, we present a detailed description of the considered problem. In this work, non-elective patients were categorized into three main classes: emergent, urgent and work in cases. These three classes are defined are dedicated to provide a description of the assignment procedures proposed for each of non-elective patient classes.

### I.1. Literature review

The planning of operating rooms is a difficult process. Its real complexity results from various sources of variability. Due to non elective surgeries arrival, the operating room schedule has to be adjusted. Thus, the need for a decision support tool, guiding the operating room manager, to handle this unpredictable flow of patients, arises. To this end, effective tools are helpful for the management of an operating theater (Sangwa and Singh Sangwan, 2018), and lot of work has been done on electives surgeries scheduling, as well as for industrial management multi-team systems in an agile environment (Turner et al., 2019).

In this work, we try to assign non-elective surgeries in an existing schedule, with the aim of disturbing it the less possible, taking into account three emergency levels of gravity. The literature about how to include non-elective patients is scarce. Apart from taking this inclusion into account as a rescheduling problem (Essen et al., 2012), and a recent study performed with an intelligent task management platform (Ongenae et al., 2017), only a very limited research deals with non-elective patients scheduling. The few studies that dealt with this problem mentioned three policies for handling emergencies: dedicated, flexible and hybrid.

*The dedicated policy:* One or more operating rooms are dedicated for non-elective patients with the aim of separating flows of both patient categories. In such a case, arriving emergency patients are operated immediately, only if the emergency operating room is available. Otherwise, if all emergency operating rooms are occupied, non-elective patients have to wait until an ongoing surgery has finished.

Heng and Wright examined the effects of a dedicated room installation for non-elective surgeries (2013). They proved, on the one hand, that the dedicated operating room leads to fewer elective cancellations, and less overrun minutes in elective rooms. On the other hand, separating elective and non-electives is a way to reduce the flow variability.

*The flexible policy:* There is no separate operating room reserved for non-elective surgeries. Operating room time is shared between elective surgeries and emergencies. Several rules and strategies are used to manage the access for the two patient categories. Ferrand, Magazine and Rao mentioned three scheduling approaches for this policy in 2014:

- *Reserve some capacity:* With this approach, some operating room time is reserved for emergencies, so that some safety margin is dedicated for unexpected events. Clearly, reserved time decreases the operating room capacity assigned to elective patients. On the other hand, if the demand for emergency surgeries exceeds planned capacity, then it remains necessary to disrupt the elective schedule. The reserved capacity per operating room has been calculated as the average non-elective duration plus the variability in the elective and nonelective durations (Van Houdenhoven et al., 2007). A queuing model has been used to calculate the fixed amount of time to reserve in each operating room. If this time is not sufficient, electives are cancelled and become semi urgent, which needs to be served within the following two weeks (Zonderland et al., 2010).
- *Insert emergencies:* This approach allows emergency patients to be operated once an ongoing elective surgery has finished. Completion times of elective surgeries are called “Break In Moments” (BIM). The waiting time of emergency surgeries can then be reduced, by spreading the BIMs over a day. The problem can be considered at operational off-line level, when the arriving of nonelective surgeries is taken into account while sequencing and

scheduling elective surgeries (Van Essen et al., 2012). In this paper, the objective was to minimize the maximum distance between two consecutive BIMs in order to reduce the waiting time of non-elective surgeries. The aim of this work was to spread the BIMs as uniformly as possible over the day.

- *Insert slack:* Other than BIMs, it is also possible to assign "buffers" in which non-electives patients can be served if needed. This is different from reserving a certain amount of capacity (approach 1), since buffers are spread out over operating rooms and over the time and can be variable in size. These buffers protect against unforeseen nonelectives, but can also protect against duration variability.

*The hybrid policy:* It is a combination of both last policies. With this policy, not only some capacity is reserved for non-elective patients, but other operating rooms are also accessible by them. In 2009, Tancrez, Roland, Cordier and Riane examined the impact of a setting with one dedicated operating room and five or six flexible rooms. Nonelective surgeries are assigned in priority in the dedicated room. Otherwise, if the dedicated room is occupied, they will be assigned in flexible rooms. Authors argue that the decrease in capacity for the electives creates an increase of overtime or fewer planned surgeries within an acceptable overtime.

It's clear that both dedicated and hybrid policies generate a loss of flexibility, since one or more operating rooms are condemned for nonelectives that may not show up. Additionally, under a dedicated policy, despite a higher utilization rate of regular elective operating rooms thanks to disruptions reduction, utilization rate of a dedicated operating room is only about 37%, which is considered as a very poor utilization rate (Barlow et al., 1993). Moreover, according to Van Riet and Demeulemeester (2014), a size of less than ten operating rooms provides fewer possibilities to reserve a full operating room (OR) for nonelectives. Then, dedicated policy can only be adopted if operating theater size is the double of this amount.

Conversely, in flexible policy, no capacity is left open in this case; only a possibility for entering the schedule is created since they can access all operating rooms. The work presented in this paper has been realized in collaboration with a western Europe hospital, and its operating theater is composed of only six operating rooms. We assumed, with the operating theater manager, to adopt the flexible policy, considering all previously cited reasons. This means that operating rooms capacity will be shared between both patients' categories, elective and nonelective.

### I.2. Patients classes definitions

The second aspect to aboard, which concerns non-elective patients, is patient's categorization. In the patient scheduling literature, there is a lack of consistent designation of patient categories. Following terms are all used to describe patients who cannot be scheduled well in advance: emergent, urgent, add-on, semi-urgent and work in cases.

The categorization of non-elective patients can be done, based on several aspects. In this work, patients are categorized based on medical priority. Each non-elective patient is assigned a due time interval, in which his surgery is medically advised (Van Riet and Demeulemeester, 2014).

In the work presented in this paper, three types of non-elective patients are taken into consideration:

- *Emergent* surgeries are characterized by a high level of urgency. For some surgeries, the slightest amount of waiting time may be life threatening, and the first available operating room has to be requisitioned.

- *Urgent* surgeries represent emergencies that can support some waiting time, so that there would be time to determine which operating room can be used to perform the operation. These emergencies could wait for a couple of hours, but must be done before the end of current day, unless the patient would then have an increased risk by waiting longer.

- *Work in cases* surgeries concern the non-elective patients that need to be served within one week. In addition, some surgeries need to be scheduled in order to be conducted within a couple of weeks, but these would be considered electives, even if it leads to other electives being rescheduled.

The aim of the work presented in this paper is to propose scheduling procedures for each non-elective patient category. In fact, we developed a decision support tool that generates, to the operating theatre manager, an appropriate assignment of non-elective surgeries, respecting each patient medical safe interval.

## II. Proposed approach

We suppose that provisional schedule of current week is already defined. It defines the sequence of all elective surgeries that have to be performed, in each operating room, during the current week. Regarding nonelective patient's assignment, given their particular characteristics, we relax some constraints imposed for elective surgeries. During a day, all assigned surgeries into an operating room should have the same specialty. This constraint can be released, when necessary, to integrate a non-elective patient into the schedule. The second constraint which can be relaxed is the respect of regular opening time. For non-elective patients, another set of periods can be dedicated to an allowed overtime, for each operating room.

As mentioned above, we consider three types of non-elective patients, classified according to their medical priorities: emergent, urgent or work in case. They share some common characteristics with elective patient, such as the day and time of arrival, estimated duration, and specialty. We have defined and programed assignment procedures that aim to minimize relevant criteria in function each category of nonelective patients. For instance, for emergent patients, waiting time is minimized, while for urgent patients, two criteria are minimized: the amount of resulting overtime and the deviation from elective surgeries first scheduled starting time. We describe in this section all the assignment procedures we propose, for each non-elective patient category.

### II.1 Non-elective patients class 1: Emergent patients

The emergent patient's surgeries have to be performed without any impediment, otherwise there would be colossal risk to patient's life. For this reason, they have to be treated as soon as possible. Thus, the only objective is to minimize their waiting time.

At the arrival of an emergent patient, two situations can occur: (1) it exists one or more operating room where the surgery could be assigned, or (2) all operating rooms are occupied, even during the authorized overtime. We detail both cases hereafter.

*a. First case: It exists one or more operating room where the surgery can be assigned*

An operating room where the emergent surgery can be assigned is one where there are enough unoccupied periods to assign it. The operating room which generates the less waiting time for the emergent surgery before being assigned will be chosen.

In a first situation case, at the emergent surgery arrival period, it exists one (or more) unoccupied operating room. Then, the surgery can be directly assigned. Moreover, if we can choose among empty operating rooms, we choose the less occupied one. The postponed elective surgeries are rescheduled in the same order.

In the second situation case, all operating rooms are occupied, and we have to wait until the end of one of the ongoing surgeries. In this case, we compare each ongoing surgery completing times, in all operating rooms susceptible to be chosen. The emergent surgery will be assigned on the first available operating room. Thus, we guarantee the minimum waiting time for the patient.

*b. Second case: All operating rooms are occupied, even during the authorized overtime*

In this case, at the arrival of the emergent surgery, all the operating rooms are occupied even during the authorized overtime. In other words, assigning the emergent surgery will lead to exceedance of overtime authorized amount. Since emergent patient do not tolerate waiting time, we authorize exceptionally, for this type of non-elective emergency, and in this particular case, to postpone a surgery. The surgery to be delayed is a work in case surgery, since that the patient health tolerates some waiting days before the surgery deadline.

Thus, we first search for an already programmed work in case surgery (after the arrival of emergent surgery) during the day. If it exists, then it will be cancelled and the emergent surgery is integrated to the planning. The cancelled surgery duration, if found, plus eventual idle times, must be at least as long as the emergent surgery's duration. Obviously, if several work-in-cases surgeries are found, we choose the one having the nearest duration from the emergent one. Otherwise, if all preprogrammed surgeries are either elective or urgent, then we exceptionally authorize the exceedance of allowed overtime. Assignment procedure described above is detailed in ***Figure 1***. Note that all the cancelled work in cases will be re-assigned, if possible, into the schedule, during one of the next days of provisional schedule, at the end of the program, in the less occupied operating room. We use then the work in case assignment procedure.

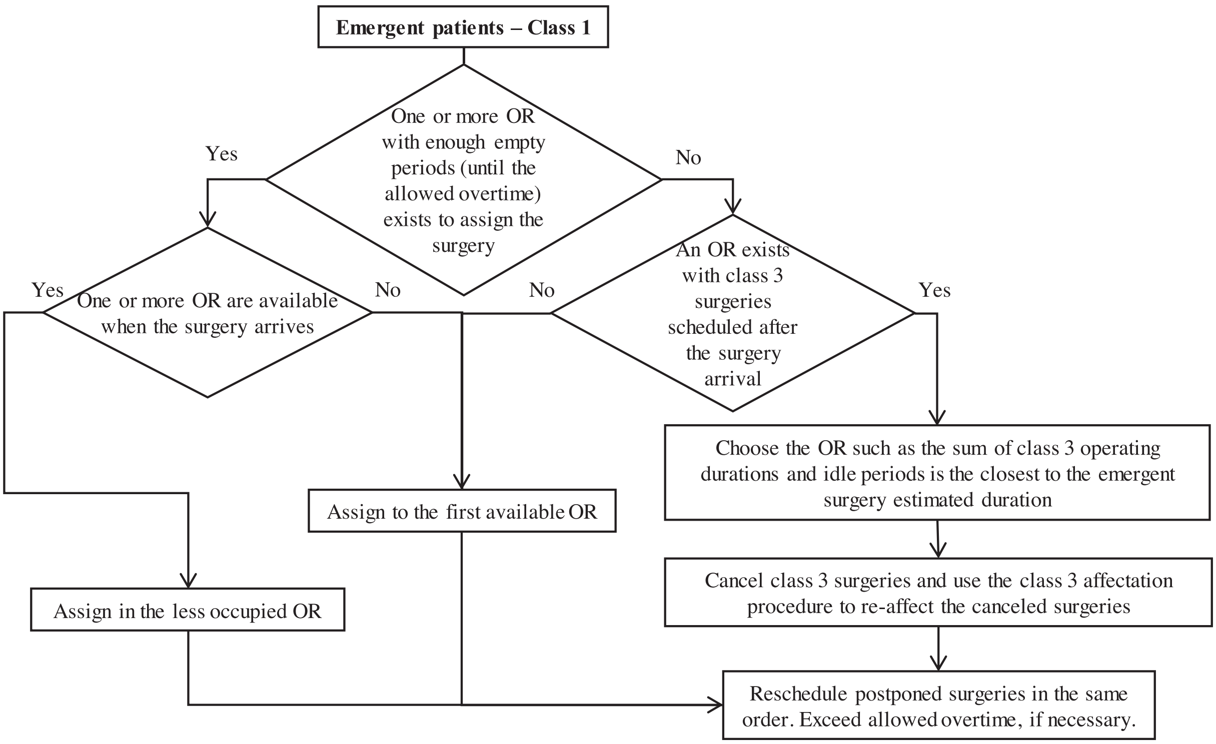


**Figure 1.** *Emergent –Class 1 surgeries assignment procedure.*

### II.2. Non- elective patients class 2: Urgent patients

In case of urgent admissions, patient condition can be stabilized, and it is possible to perform the surgery within a few hours, before the end of the current day. Due to the flexibility offered by this category of non-elective patients, the operating room manager can consider different assignment methods. We investigated on the suitability of four different possible assignment strategies:

- *Strategy 1:* Assign in an operating room where the same specialty as the urgent surgery is programmed. If all opened operating rooms, during the arrival day of urgent surgery, have a different specialty from the urgent one, then this strategy will not be adopted to assign the urgent patient.
- *Strategy 2:* Assign directly in the less occupied operating room, independently on the specialty assigned within it during the current day. If all operating rooms are occupied, even during regular overtime, urgent surgery will not be assigned with this strategy.

- *Strategy 3:* If, during regular opening time of operating rooms, a set of consecutive unoccupied periods, equal to or greater than the estimated duration of urgent surgery exists, then it will be assigned into them. Otherwise, urgent surgery will not be assigned with this strategy.
- *Strategy 4:* Urgent surgery is assigned at the end of the schedule, into the first available and less occupied operating room. If all operating rooms are occupied, even during regular over time, urgent surgery will not be assigned with this strategy.

Questions that arise are: which one of these strategies is the most appropriate to the class 2 non elective patients? Should the operating room manager decide only to consider one strategy to apply at each time an urgent surgery shows up? Or shall he choose between them, according to the current situation (e.g., operating rooms occupancy rate, urgent surgery arrival time) which one of the strategies to adopt? These questions and their impact on resulting overtime amount and the deviation from the scheduled starting time of elective surgeries are explored.

The assignment procedure we propose for class 2 emergencies is presented in figure 2. After each urgent patient arrival, four different schedules proposals are generated. They represent respectively the result of the four proposed assignment strategies. Each schedule is evaluated according to two performance criteria, the deviation from the scheduled starting time of a surgery, and the amount of resulting overtime. When no strategy gives any feasible solution, we are using a last one, which is proposed at the end of this section.

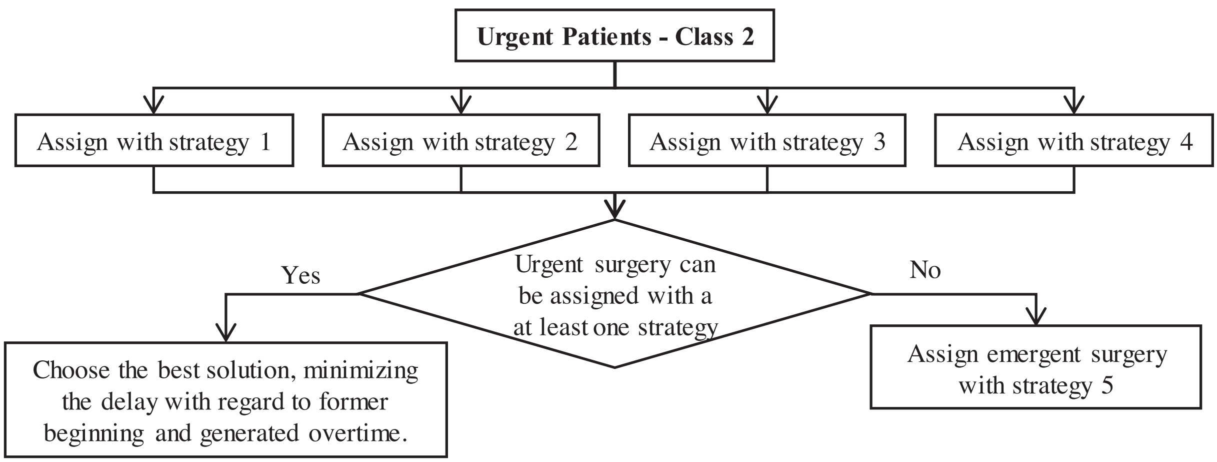


**Figure 2**. *Assignment procedure for urgent surgeries of Class 2.*

We offer to the operating theatre manager the possibility to choose the prioritized criteria: either to consider overtime or the deviation from the scheduled start time. Next subsections are devoted to present the four proposed strategies.

**a.** ***First strategy: Assign in an operating room with the same specialty as the urgent surgery***

The first step in this strategy is to find out whether during the arrival day of a non elective patient, the same specialty as the urgent surgery is already performed in one of available operating rooms. Thus, two situations are possible: (1) An operating room where the same specialty as the urgent case exists. (2) All operating rooms specialties are different from the urgent surgery's specialty. Figure 3 presents successive decisions taken in both cases of the first strategy.

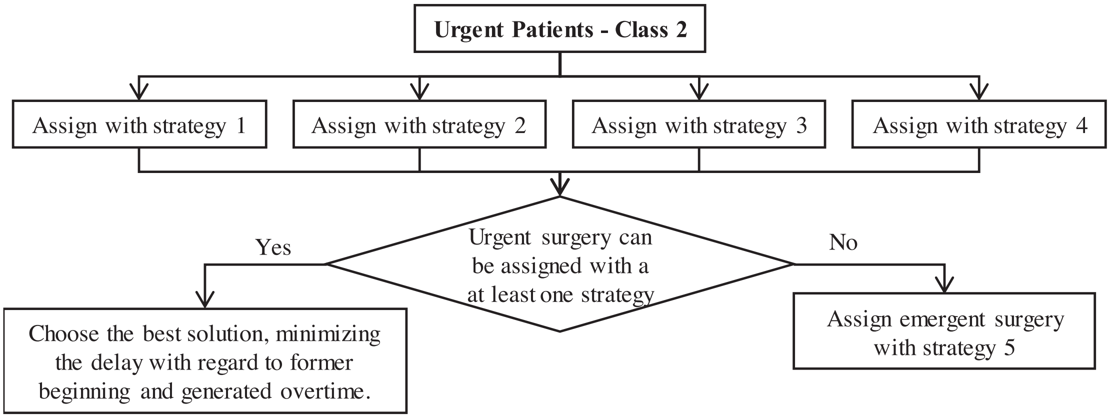


**Figure 3.** *Urgent – Class 2 surgeries assignment procedure – Strategy 1.*

**b.** ***Second strategy: Assign in the less occupied operating room***

Independently on current specialties performed in the operating rooms, urgent surgery will be assigned into the less occupied one. Figure 4 presents the successive decisions that are taken, when this strategy is adopted, to assign an urgent surgery.

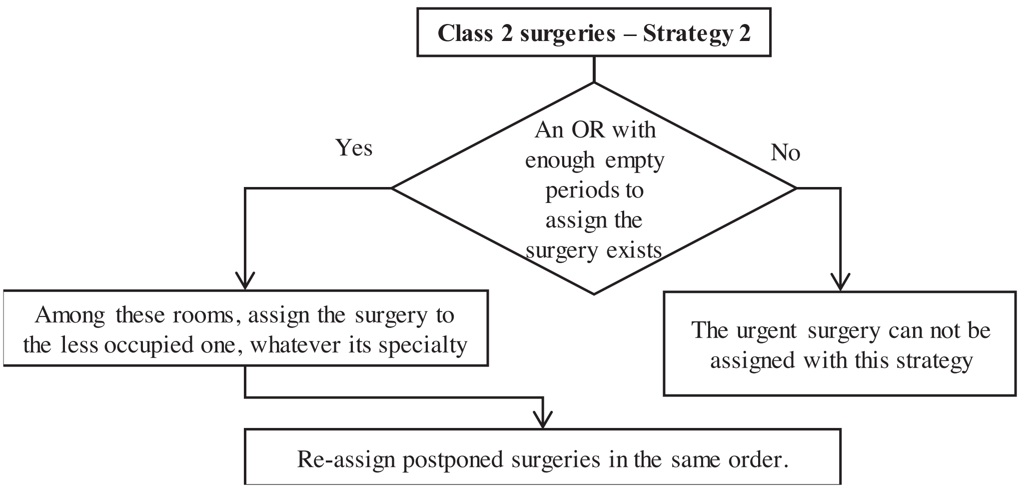


**Figure 4.** *Urgent – Class 2 surgeries assignment procedure – Strategy 2.*

**c.** ***Third strategy: Assign into consecutive empty periods during regular time if any exist or assign during the allowed over time***

When this strategy is adopted, the first step is to check if there are any consecutive unoccupied periods, during the regular time, where the urgent surgery could be assigned. Let $d$ be the estimated number of periods required to perform the urgent surgery. The amount of consecutive unoccupied periods, from the time at which the urgent surgery appears, should be equal to or greater than $d$.

Two major situations are possible: (1) $d$ consecutive unoccupied periods exist to assign the urgent surgery, or (2) it does not exist enough consecutive unoccupied periods to assign the surgery during regular time. In this case, surgery will not be assigned with this strategy. Figure 5 presents the decisions tree, in case of third strategy choice.

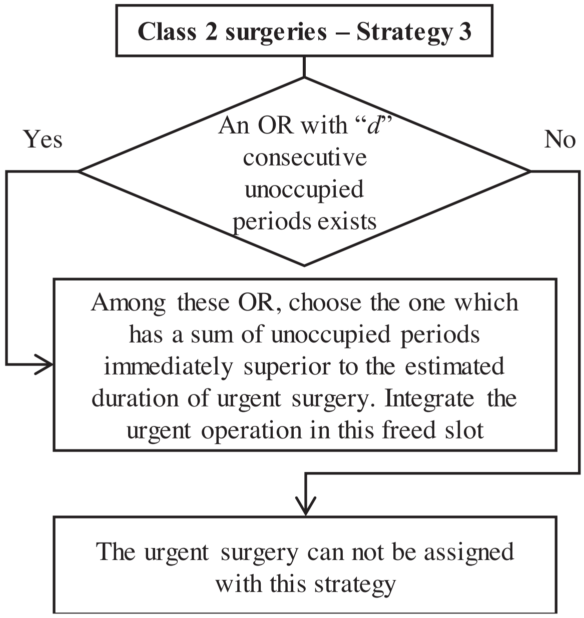


**Figure 5.** Urgent – Class 2 surgeries assignment procedure – Strategy 3.

**d. Fourth strategy:** ***Assign at the end of schedule in the allowed overtime***

For this strategy, surgery is directly assigned after the already programmed surgeries, in the first released operating room. Note that, if two operating rooms are released at the same time, the one where programmed surgeries have the same specialty as the urgent one is preferred, when it exists.

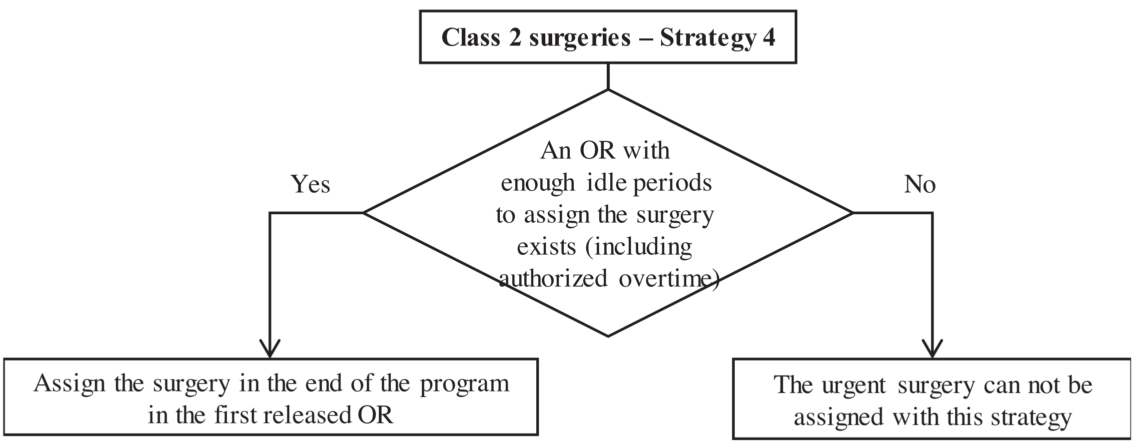


**Figure 6.** *Urgent – Class 2 surgeries assignment procedure – Strategy 4.*

**e. *Fifth strategy: Assign urgent surgery and cancel work in cases***

An urgent surgery can arrive while all operating rooms are occupied, even during authorized overtime periods. In this case, none of the aforementioned strategies will be used. For this reason, we defined a strategy for this special case, hereafter referred as strategy 5. As for emergent surgeries, we will exceptionally authorize, in this particular case, to cancel a set of work in cases such as the sum of their durations is enough, once cancelled, to integrate the urgent surgery into the schedule. The work in cases assignment procedure will be used to re-assign the set of cancelled surgeries. More details are given in figure 7.

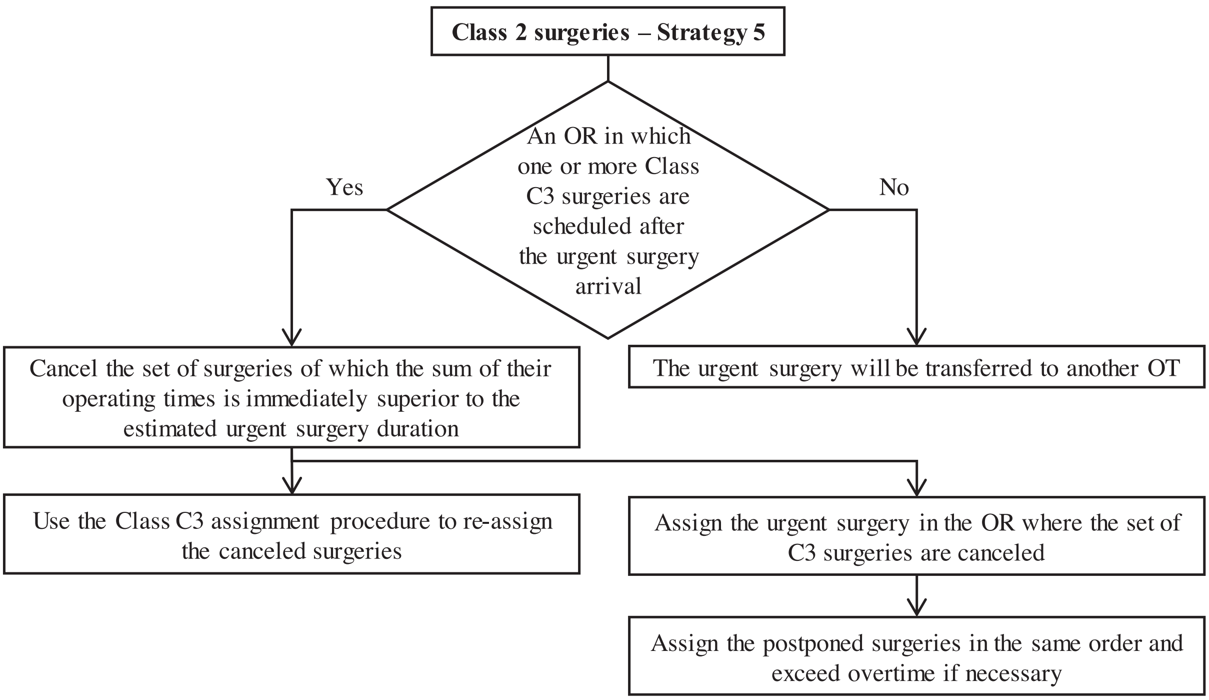


**Figure 7.** *Urgent – Class 2 surgeries assignment procedure – Strategy 5.*

## II.3. Nonelective patients class 3: Work in cases

The work in cases, also called the *add-elective cases,* are elective patients scheduled to fill up operating room time. Nevertheless, work in cases need to be served within one week.

From the arrival day of this patient category, until the end of planning horizon, we compare the amount of generated overtime when this surgery is assigned after the already scheduled surgeries in all the operating rooms. The chosen operating room is the one that leads to less overtime. If we obtain the same amount of overtime in two different operating rooms, we choose the first available one (assign the earliest in day) and where the same specialty is already performed (if exists).

Obviously, exceeding allowed overtime is not permitted. Then, if all operating rooms are occupied, even during allowed overtime periods, then the surgery will be transferred to another operating theatre or reported to next week (as an elective surgery), if patient conditions allow it. Figure 8 illustrates assignment procedure of the work in cases surgeries.

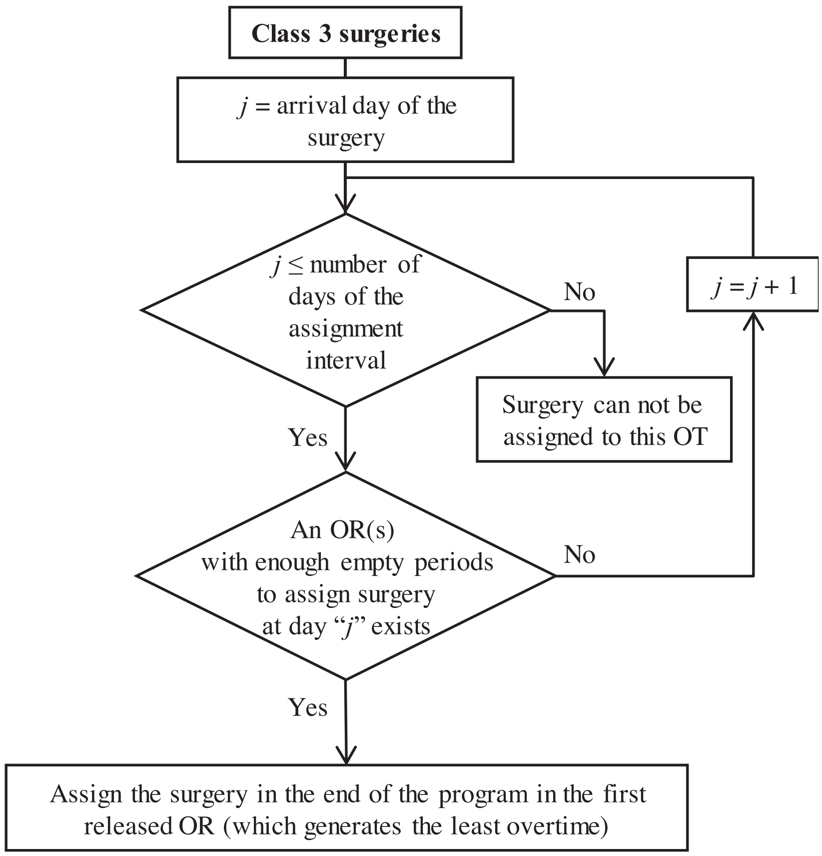


**Figure 8.** *Work in cases - Class 3 surgeries assignment procedure.*

## III. Computational experiments

Computational experiments presented in this section test and validate the proposed decision support tool. All proposed assignment procedures have been implemented, using Xpress-MP optimization software 3.10, and run on a PC with Intel Core i7 CPU 2.6GHz and 8 Go of memory.

Firstly, we randomly generated 5 instances of provisional operating theatre schedules. We consider the case of an operating theatre, composed of four operating rooms, in which are planned surgical cases with five specialties. The planning horizon is composed of five days. Regular opening time is constant over the planning horizon, and equal to 7 hours represented by 28 periods of 15 minutes. Allowed overtime periods set, which can be generated for nonelective patients' assignment, is of two hours, corresponding to eight time periods. Exceptionally, for emergent patients, we authorize exceeding overtime. Four supplementary time periods are then reserved to this aim. The five operating schedules have been generated with increasing occupancy rates, and are referred to as PO1, …, PO5 in the figures and tables of this section.

We also randomly generated 10 instances of non-elective sequences, for each of the 3 configurations with three different sizes, described on Table 1. The chosen configurations are respectively composed of 15, 20 and 25 nonelective surgeries, and are composed of instances of the three emergency classes. The number of emergencies of each class, in function of the configuration are also detailed in Table 1. For all emergencies, we randomly generate their arrival day, time, class and specialty. We also generate their operating time, in function of the distribution laws defined from statistic studies on past surgeries, depending on the emergency specialty.

*Table 1. Non-elective sequences generation.*

| Configurations | Total number of nonelective surgeries | Class 1 NbC1 | Class 2 NbC2 | Class 3 NbC3 |
|---|---|---|---|---|
| A | 15 nonelective surgeries | Between 0 et 4 | Between 0 et 7 | 15 – (NbC1 + NbC2) |
| B | 20 nonelective surgeries | Between 0 et 6 | Between 0 et 10 | 20 – (NbC1 + NbC2) |
| C | 25 nonelective surgeries | Between 0 et 7 | Between 0 et 13 | 25 – (NbC1 + NbC2) |

For each of the 5 provisional operating schedules, we analyzed the assignment impact of the 10 instances of non-elective occurring surgeries, for each of the three classes of instances presented on Table 1. In Table 2, we present the average occupancy rates before and after the non-elective cases assignments, as well as average percentage of urgent operations assigned, by emergency class. The occupancy rate is calculated in function to the regular opening time, without overtime.

The proposed tool succeeded in allocating 100% of emergent surgeries (vital), regardless of the number of emergencies integrated and the initial occupancy rate. This shows the assignment procedure effectiveness for this class. Indeed, its objective is to ensure an early assignment to avoid deterioration of the critical condition of the patients of these class.

For class 2 urgent operations, the percentage of affected operations varies between 95% and 100%. For the five provisional operating schedules, with an occupancy rate between 73% and 83%, it is possible to integrate 100% of the emergencies of this class for configurations with 15 emergencies. Beyond, for 20 and 25 emergency configurations, the percentage of class 2 assigned emergencies slightly decreases to 95% for the worst case.

The tool succeeds in assigning 100% of class 3 emergencies only for the first operating program (PO1) with an occupancy rate of 73%, and for a configuration consisting of 15 emergencies. From an occupancy rate of 76%, it becomes impossible to integrate all the operations of this class.

*Table 2. Occupancy rate variations after urgent surgeries assignments and percentages of assigned surgeries per emergency class*

| | | Occupancy rate **before** urgent surgeries integration | Occupancy rate **after** urgent surgeries integration | % Assigned C1 surgeries | % Assigned C2 surgeries | % Assigned C3 surgeries |
|---|---|---|---|---|---|---|
| 15 Urgent surgeries | PO1 | 0,736 | 0,907 | 100 | 100 | 100 |
| | PO2 | 0,762 | 0,945 | 100 | 100 | 98 |
| | PO3 | 0,78 | 0,961 | 100 | 100 | 96 |
| | PO4 | 0,802 | 0,987 | 100 | 99 | 94 |
| | PO5 | 0,834 | 1,022 | 100 | 99 | 94 |
| 20 Urgent surgeries | PO1 | 0,736 | 0,978 | 100 | 100 | 98 |
| | PO2 | 0,762 | 1,01 | 100 | 99 | 95 |
| | PO3 | 0,78 | 1,03 | 100 | 98 | 94 |
| | PO4 | 0,802 | 1,05 | 100 | 98 | 94 |
| | PO5 | 0,834 | 1,073 | 100 | 97 | 93 |
| 25 Urgent surgeries | PO1 | 0,736 | 1,024 | 100 | 98 | 95 |
| | PO2 | 0,762 | 1,056 | 100 | 97 | 93 |
| | PO3 | 0,78 | 1,074 | 100 | 96 | 93 |
| | PO4 | 0,802 | 1,092 | 100 | 96 | 92 |
| | PO5 | 0,834 | 1,119 | 100 | 95 | 89 |

We also observe, in Table 2, the occupancy rate variation after integration of nonelective cases. As expected, for a same initial occupancy rate, the more emergencies to be integrated, the higher occupancy rate after integration of emergencies. As well, for the same number of integrated emergencies, the higher the initial occupancy rate of operating programs, the higher the post-assignment occupancy rate increase. Similarly, the higher the preintegration occupancy rate, the lower the respective class 2 and class 3 emergency assignment rates.

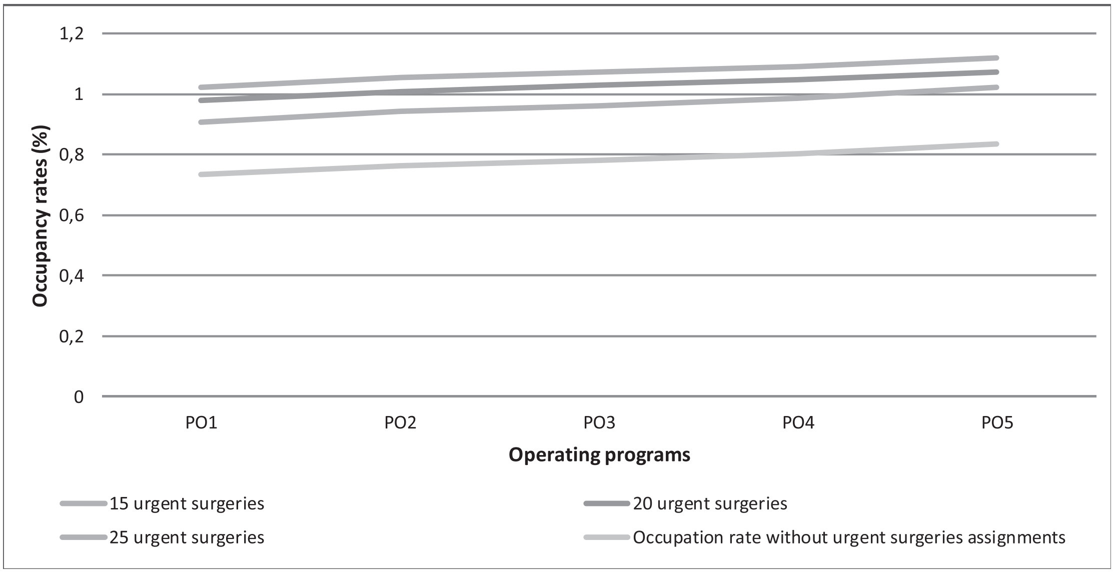


**Figure 9.** *Occupancy rate variation after all urgent surgeries assignments.*

In figure 9, we present the evolution of occupancy rates for the three emergency configurations (with 15, 20, and 25 emergencies), in function of the five initial operating schedules. Initial occupancy rates are recalled. This figure allows to estimate, for a given initial occupancy rate, from which number of emergencies an operating schedule is likely to generate overtime and exceed regular working time. Therefore, in addition to the real-time solution proposal, this tool can also estimate the capacity of an operating unit to accommodate emergencies, in function of the current situation.

This real time forecasting ability can be very useful in the case of a big highway accident, when a high number of injured people have to be healed in a short time period, and in a rather same time. A good estimation of the number of non-elective cases that can be treated at a time can reveal very useful. More recently, the terrorist attacks that took place in Europe give another example of a case where the estimation ability of this tool might be very useful. In the following paragraphs, we present the results we have obtained for the three emergency classes.

## III.1. Results obtained for emergent patients - class 1

For a vital emergency, the patient's condition requires rapid management. Therefore, the most relevant indicator for this class is the pre-assignment waiting time (column (1) of Table 3).

The waiting time averages are respectively of 32, 38 and 44 minutes for the three configuration sizes (15, 20 and 25 emergencies), and total average waiting time before a vital emergency assignment is 38 minutes. As expected, patients waiting time increases with the number of emergencies.

*Table 3. Results for emergent surgeries - Class 1.*

| | | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|---|
| 15 Urgent surgeries | PO1 | 0,45 | 0,6 | 0 | 1,8 | 0 | 0 |
| | PO2 | 0,52 | 0,68 | 0 | 1,9 | 0 | 0 |
| | PO3 | 0,51 | 0,69 | 0,02 | 1,98 | 0 | 0 |
| | PO4 | 0,61 | 0,88 | 0,01 | 2,03 | 2 | 2 |
| | PO5 | 0,64 | 1,09 | 0,04 | 2,05 | 2 | 2 |
| 20 Urgent surgeries | PO1 | 0,52 | 0,9 | 0,01 | 2,03 | 2 | 2 |
| | PO2 | 0,66 | 0,85 | 0,02 | 2,07 | 2 | 1 |
| | PO3 | 0,62 | 1,03 | 0,02 | 2,12 | 1 | 1 |
| | PO4 | 0,68 | 1,08 | 0,03 | 2,19 | 2 | 2 |
| | PO5 | 0,71 | 1,17 | 0,03 | 2,22 | 3 | 2 |
| 25 Urgent surgeries | PO1 | 0,59 | 0,96 | 0,03 | 2,71 | 2 | 2 |
| | PO2 | 0,74 | 1,04 | 0,04 | 2,76 | 5 | 3 |
| | PO3 | 0,71 | 1,14 | 0,05 | 3,06 | 5 | 2 |
| | PO4 | 0,81 | 1,17 | 0,05 | 3,19 | 6 | 0 |
| | PO5 | 0,83 | 1,34 | 0,09 | 3,36 | 8 | 0 |

(1) Average waiting time (in hours)
(2) Average authorised overtime (in hours)
(3) Average exceeding overtime (in hours)
(4) Average gap between new and old surgeries starting time
(5) Total number of postponed Class 3 surgeries out of the 10 instances
(6) Total number of re-assigned Class 3 surgeries out of 10 instances

We can also point out some other results. For a same number of emergencies integrated into the different operating programs, the waiting time does not necessarily increase with the occupancy rate. We can take the example of operating programs 2 and 3 (Figure 10). Although the initial occupancy rate of PO3 is higher than that of PO2, the average waiting time for class 1 emergencies has decreased. A patient waiting time depends on the current situation in the block. If his arrival coincides with an operation completing time, his waiting time is zero. If it occurs while there are significantly long surgeries going on in the rooms, then the waiting time will be longer. Van Essen et al. proposed to minimize the distance between BIM (end dates of elective operations) and have managed to reduce nonelective operations waiting time with this method.

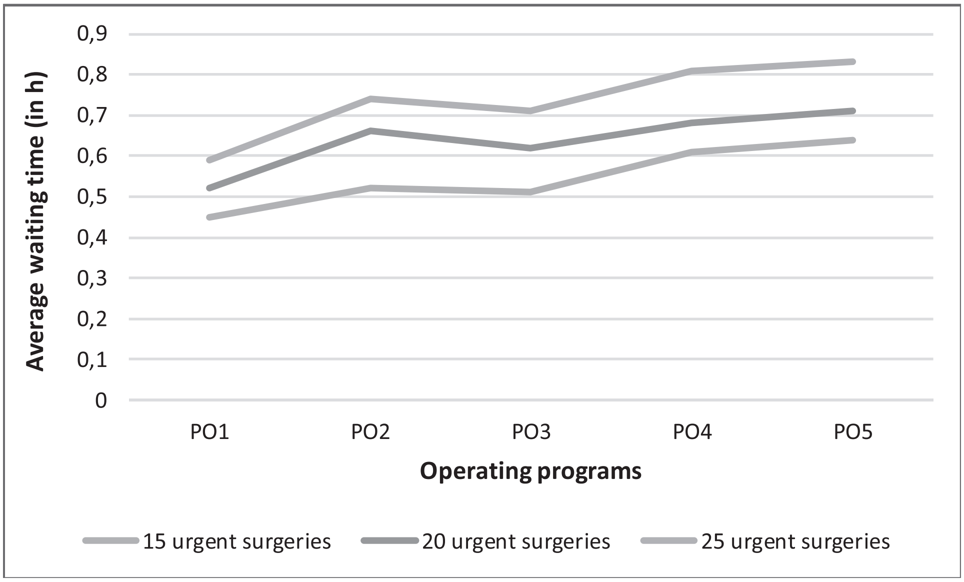


**Figure 10.** *Average waiting time variation of emergent surgeries – Class 1 before assignment.*

The average permitted overtime is 0.97 hours (58 minutes). Observing column (2) of Table 3, we note that the increase in authorized overtime depends on the occupancy rate of operating programs and on the number of emergencies to integrate. The same is for the offset from the old starting time (column (4) in Table 3). With this indicator, we have calculated the sum of the shifts in elective operations generated as a result of the integration of an emergency. The average value for all problems dealt with is 2.36 hours. This average is quite important, but can be justified by the vitality of the integrated emergencies.

Remember that for this category, we have exceptionally allowed the overtime allowed to be exceeded. On average, exceptional overtime is 0.03 hour (1.8 min), which is very low and can be easily absorbed in practice.

Column (5) shows the total number of class 3 operations carried over for the 10 instances performed for each size, and column (6) gives the number of class 3 operations that have successfully been reintegrated into the program. For the first subset of problems (integration of 15 emergencies), all deferred operations could be reinstated. For the second subset (integration of 20 emergencies), only two out of ten operations could not be reinstated. Finally, for the third sub-group, we note not only that the number of transactions carried over has increased significantly (26 compared to 10 and 4 in the first two configurations), but also that the decision support tool finds more In addition to difficulties in reintegrating these deferred operations (only 7 of the 26 postponed). There are two reasons for these non-assignments. The first is that the operating rooms are occupied and there are no more periods to incorporate these deferred operations. The second is that the cancelled operations on the last day of the week are not reinstated in the operative program considered, but postponed to the following week.

## III.2. Results obtained for urgent patients Class 2

The emergencies of this class tolerate an expectation until the end of the current day, as the condition of the patients can be stabilized. This gives the block manager a flexibility to find the best solution to integrate the emergency, while trying to disrupt at least the planned operating program. We have proposed four different assignment strategies for this class. We have also defined a fifth, which will only be used if the first four do not provide a solution.

The disruption of the operative program translates into overtime generated and shifting from the elective operations programmed in relation to their old start dates. As a result, the comparison of the solutions proposed by the different strategies takes place on the basis of these two criteria.

Upon the arrival of an urgent operation, a “provisional” solution is proposed by the strategies that succeeded in affecting the operation. The tool compares the number of overtime hours generated and retains the minimum overtime. If two strategies give the same number of overtime, the one with the least offset will be retained. The planned operating program will be updated with this solution.

In Table 4, we present the results obtained for the first four strategies. In the first column, we present the average number of overtime hours generated. The second shows the average lag in delayed elective operations relative to their old start dates. In the third column, we indicate the percentage of solutions proposed by each of the strategies. Indeed, the strategies are not able to propose results for all the emergencies to be assigned. For example, strategy 1 affects emergencies in a room of the same specialty. If there is no room of the same specialty, or if it exists but is occupied until the end of the authorized overtime, then this strategy will not be able to propose a solution.

*Table 4. Results obtained for Class 2 – urgent surgeries, with the first 4 strategies.*

| | | **Strategy 1** | | | | | | **Strategy 2** | | | | **Strategy 3** | | | | **Strategy 4** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (1) | (2) | (3) | (4) | Non-assignment percentage with this strategy (%) | | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) |
| | | | | | | SMSOQ | PSMS | | | | | | | | | | | | |
| 15 Urgent surgeries | PO1 | 0,64 | 1,62 | 57 | 22 | 67,4 | 32,6 | 0,19 | 0,96 | 95 | 34 | 0 | 0 | 47 | 16 | 0,44 | 0 | 93 | 28 |
| | PO2 | 0,74 | 1,67 | 52 | 21 | 67,86 | 32,14 | 0,22 | 1,31 | 93 | 32 | 0 | 0 | 45 | 17 | 0,48 | 0 | 91 | 30 |
| | PO3 | 0,88 | 1,75 | 50 | 21 | 76 | 24 | 0,25 | 1,4 | 91 | 33 | 0 | 0 | 40 | 16 | 0,51 | 0 | 90 | 30 |
| | PO4 | 0,9 | 1,82 | 42 | 21 | 80 | 20 | 0,27 | 1,44 | 97 | 31 | 0 | 0 | 40 | 18 | 0,59 | 0 | 95 | 29 |
| | PO5 | 1,08 | 2,33 | 40 | 16 | 82,86 | 17,14 | 0,58 | 1,88 | 90 | 38 | 0 | 0 | 17 | 9 | 0,86 | 0 | 88 | 35 |
| 20 Urgent surgeries | PO1 | 0,86 | 1,72 | 58 | 19 | 69 | 31 | 0,52 | 1,68 | 97 | 35 | 0 | 0 | 30 | 14 | 0,64 | 0 | 96 | 32 |
| | PO2 | 0,89 | 1,94 | 51 | 15 | 73 | 27 | 0,65 | 1,71 | 95 | 40 | 0 | 0 | 25 | 13 | 0,76 | 0 | 94 | 30 |
| | PO3 | 0,98 | 2,33 | 49 | 13 | 76,6 | 23,4 | 0,76 | 1,74 | 94 | 39 | 0 | 0 | 24 | 9 | 0,8 | 0 | 93 | 36 |
| | PO4 | 1,01 | 2,4 | 38 | 15 | 82,5 | 17,5 | 0,78 | 1,99 | 91 | 41 | 0 | 0 | 21 | 10 | 0,86 | 0 | 94 | 30 |
| | PO5 | 1,12 | 2,95 | 34 | 13 | 88,9 | 11,1 | 0,9 | 2,15 | 90 | 38 | 0 | 0 | 14 | 9 | 0,94 | 0 | 92 | 36 |
| 25 Urgent surgeries | PO1 | 0,91 | 1,78 | 48 | 17 | 64,58 | 35,42 | 0,64 | 1,69 | 92 | 35 | 0 | 0 | 29 | 11 | 0,69 | 0 | 92 | 32 |
| | PO2 | 0,95 | 1,99 | 42 | 14 | 74,07 | 25,93 | 0,79 | 1,86 | 91 | 34 | 0 | 0 | 28 | 10 | 0,72 | 0 | 91 | 37 |
| | PO3 | 1,05 | 2,37 | 45 | 16 | 70,59 | 29,41 | 0,88 | 1,94 | 91 | 28 | 0 | 0 | 19 | 12 | 0,85 | 0 | 91 | 37 |
| | PO4 | 1,25 | 2,43 | 43 | 14 | 76 | 24 | 0,95 | 2,12 | 85 | 28 | 0 | 0 | 15 | 8 | 0,92 | 0 | 85 | 42 |
| | PO5 | 1,4 | 3,02 | 35 | 12 | 71,67 | 28,33 | 1,19 | 2,17 | 77 | 26 | 0 | 0 | 14 | 6 | 1,15 | 0 | 83 | 46 |

(1) Average overtime (in hours)
(2) Average gap between new and old surgeries starting time
(3) Proposed solution (%)
(4) Chosen strategy (%)
SMSOQ : OR of the same specialty as the urgent surgery are full-occupied (%)
PSMS : An OR of the same specialty as the urgent surgery does not exist (%)

Similarly, strategy 3 affects emergencies in successive periods of time, the sum of which is greater than or equal to the duration of the emergency, before the permitted overtime. If these periods do not exist, then no solution can be proposed with this strategy. The different solutions proposed by the four strategies, if they exist, are compared. We then calculate the percentage of times each strategy was adopted (column (4) in Table 4). In the following, we detail the results of this table.

In Figure 11, we give the percentage of times each strategy was successful in providing a solution (column (3) of Table 3 on the total number of Class 2 emergencies to be assigned. For all configurations tested, strategies 2 and 4 are the ones that offer solutions most often. For these two strategies, a solution is proposed in 91.3 and 91.2% of cases respectively. The first strategy proposes solutions only in 45.6% of cases. The third strategy is the one that offers less often solutions, in 27.2% of cases.

In Figure 12, we compare the average overtime generated for strategies 1, 2, and 4. Strategy 3 does not generate overtime, and then is not represented. Overtime is the first criterion for which a strategy is adopted to integrate the emergency.

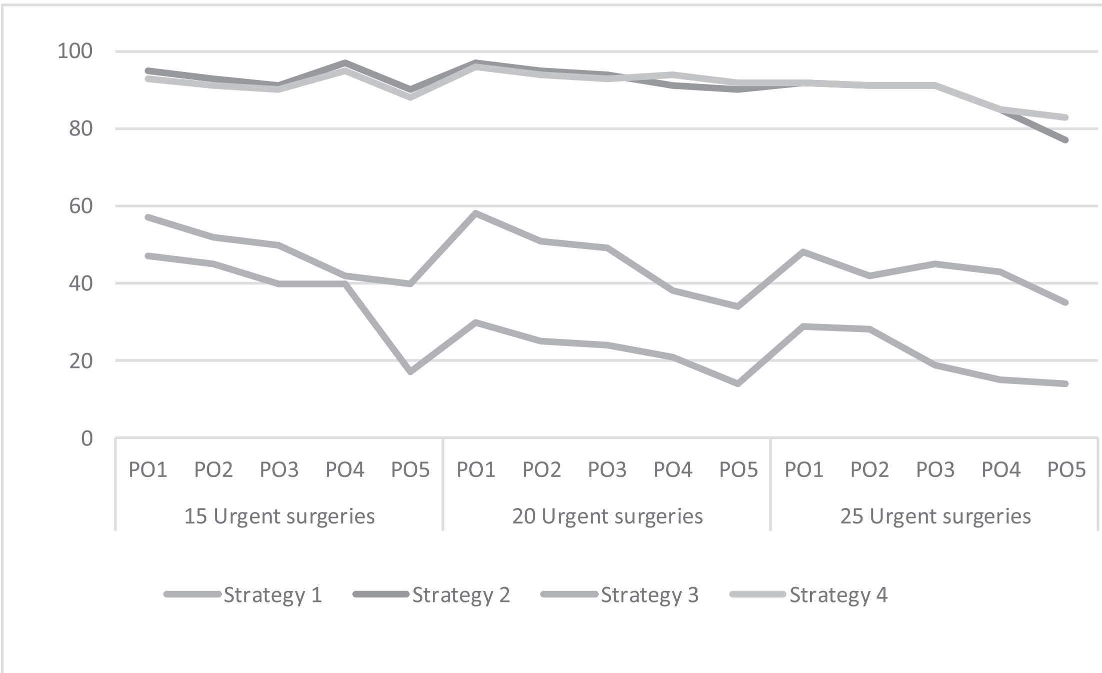


**Figure 11.** *Percentages of times a strategy is proposed a possible solution.*

Observing the evolution of this criterion, we note that the first strategy generates the most overtime for all problems (0.97 hour or 58.2 minutes). This explains the fact that the percentage of times that this strategy was chosen (column (4)) is lower than that of strategies 2 and 4 (16.6% versus 34.06% and 34%), respectively. The average number of overtime hours for this strategy is more important because we require that the emergency be assigned to a room of the same specialty. This is not always timely in terms of overtime or lag (on average 2 hours and 14 minutes).

We looked at why this strategy is not capable of providing as many solutions as strategies 2 and 4. There are two main. The first is that there is a room of the same specialty in the operating program, but this room is occupied until the end of the authorized overtime (SMSOQ). So the strategy has no solution. The second reason is that there is no room of the same specialty open on the day of the arrival of the emergency (PSMS). In columns 7 and 8 of Table 4, we give the percentage for these two reasons. We note that in general, the first strategy is not able to propose a solution because the same specialty rooms are occupied in 74.7% of the cases on average.


**Figure 12.** *Average overtime for strategies 1, 2, and 4.*

Moreover, it should be noted that, for the same configuration (15, 20 or 25 emergencies), the higher the rate of occupancy of the operating programs, the higher the percentage increases. Similarly, for an equal occupancy rate, the greater the number of emergencies to be assigned, the higher this percentage increases.

Strategy 3 does not generate overtime. It must have been the most chosen. However, it is only selected in 11.9% of cases. This is due to the fact that strategy 3 is the one that offers less often solutions, only in 26.5% of cases for all configurations. Indeed, the objective function of the mathematical model used to define the forecast operating programs consists of two parts. The first maximizes the occupancy in the operating rooms, and the second minimizes the downtime between programmed operations, in order to schedule them at the earliest. This second part makes that there are few or no unoccupied periods in the operative program. Therefore, it is not often possible to integrate emergencies using this strategy.

Strategies 2 and 4 are those that generate the least amount of overtime. The numbers of overtime generated by these two strategies are quite close. On average for all configurations, we have 0.63 hours (38 min) for strategy 2 and 0.74 hours (44 min) for strategy 4. In particular, in the case of the third configuration of tested data (25 emergencies to be integrated), these two strategies yield almost identical average results.

In figure 13, we give the frequency of selection for each of the five strategies (columns (4) in Table 4). From this figure, we can see the usefulness of proposing several assignment strategies for this emergency class. Depending on the current situation in the operating room, the tool can choose the most appropriate strategy to use.

While it is more appropriate for the head of the block to affect the emergency in a room of the same specialty, the decision support tool shows that this is not always the best solution and that this can lead to quite significant disturbances in the planned operating program.

The third strategy is the least used (on average in 11.9% of cases). However, since it does not cause any disturbance in the operating program (zero overtime and zero shift), it is worth considering it.

The second and fourth strategy are very close. These strategies offer the most solutions (respectively 91.3% and

91.2% of the cases) and are chosen as the best strategy in respectively 34.1% and 34% of the cases. We can see that when the occupancy rate, after integration of emergencies, is close to 100%, strategy 2 is best adapted. However, as soon as this rate exceeds 100%, these two strategies become equivalent.

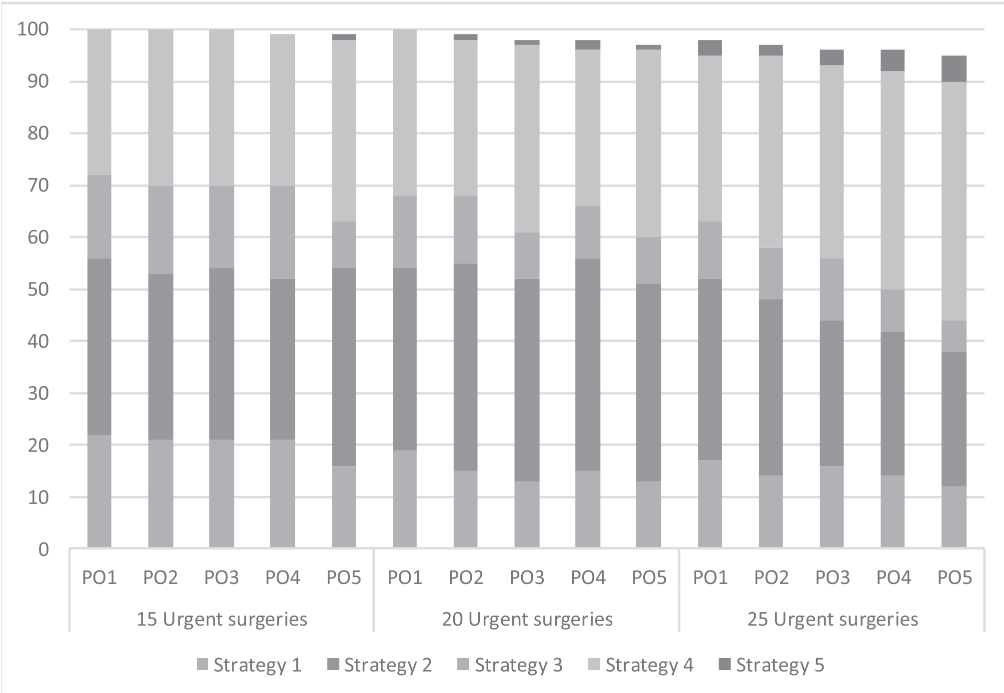


*Figure 13. Selection frequency for each strategy (in %).*

In Table 5, we present the results related to strategy 5. The greater the number of emergencies to be integrated, the more important the use of this strategy (column (1) of Table 5). This strategy is not able to provide a solution every time it is used. Indeed, in some cases there are no scheduled class 3 operations, or those programmed have a duration inferior than the emergency one. As we do not allow overtime exceed for this emergency class, the urgency is not programmed.

We also calculate the number of overtime hours generated as a result of the emergency assignment using this strategy 5. On average, this generates 0.44 hours (26 min). The use of this strategy implies the postponement of class 3 operations in order to be able to affect the urgency. The higher the number of emergencies to be assigned, the more the number of class 3 operations carried over increases: 2 operations carried over for the first configuration, 10 operations for the second configuration, and 23 for the third configuration. The number of deferred operations that have been successfully reassigned varies from one problem to another. It depends on the occupancy of the operating rooms and the day the operation was cancelled. If this is the last day of the operative program, then the operation will be reassigned only the following week.

*Table 5. Results of strategy 5 for class 2 emergencies.*

| | | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|---|
| 15 Urgent surgeries | PO1 | 0 | 0 | 0 | 0 | 0 |
| | PO2 | 0 | 0 | 0 | 0 | 0 |
| | PO3 | 0 | 0 | 0 | 0 | 0 |
| | PO4 | 1 | 0 | 0 | 0 | 0 |
| | PO5 | 2 | 1 | 0,5 | 2 | 1 |
| 20 Urgent surgeries | PO1 | 0 | 0 | 0 | 0 | 0 |
| | PO2 | 2 | 1 | 0,5 | 1 | 1 |
| | PO3 | 3 | 1 | 0,44 | 2 | 0 |
| | PO4 | 4 | 2 | 0,63 | 3 | 1 |
| | PO5 | 4 | 1 | 0,38 | 4 | 0 |
| 25 Urgent surgeries | PO1 | 5 | 3 | 0,44 | 3 | 1 |
| | PO2 | 5 | 2 | 0,35 | 3 | 1 |
| | PO3 | 7 | 3 | 0,35 | 3 | 2 |
| | PO4 | 8 | 4 | 0,58 | 5 | 3 |
| | PO5 | 10 | 5 | 0,67 | 9 | 3 |

(1) Use of strategy 5
(2) Solution proposed by the strategy 5
(3) Average overtime (in hours)
(4) Total number of class 3 surgeries reported over the 10 instances
(5) Total number of class 3 surgeries re-assigned over the 10 instances

### III.3. Results for work-in-case patients Class 3

This class includes patients whose status tolerates a wait of a few days, but must be programmed before the end of the current week. The integration of these operations should not lead to changes in the current operating program. We then proposed to integrate them at the end of the operative program. We also ensure that they generate the minimum amount of overtime. In Table 6, we present the results for this operation class. In the first column, we give the evolution of the average number of overtime hours. In the second column, we present the average wait time before their assignment in days.

*Table 6. Results for class 3 surgeries.*

| | | (1) | (2) |
|---|---|---|---|
| 15 Urgent surgeries | PO1 | 0,24 | 1,1 |
| | PO2 | 0,29 | 1,49 |
| | PO3 | 0,31 | 1,53 |
| | PO4 | 0,39 | 1,65 |
| | PO5 | 0,47 | 1,78 |
| 20 Urgent surgeries | PO1 | 0,27 | 1,25 |
| | PO2 | 0,33 | 1,86 |
| | PO3 | 0,37 | 1,9 |
| | PO4 | 0,42 | 1,98 |
| | PO5 | 0,56 | 2,06 |
| 25 Urgent surgeries | PO1 | 0,33 | 1,53 |
| | PO2 | 0,39 | 2,17 |
| | PO3 | 0,41 | 2,22 |
| | PO4 | 0,52 | 2,25 |
| | PO5 | 0,63 | 2,31 |

(1) Average overtime (in hours)
(2) Average waiting time before assignement (in days)

For the set of configurations tested, the assignment of class 3 operations generates, on average, 0.39 overtime (24 min) (column 1 of Table 6). For the same configuration, the more the occupancy rate increases, the more overtime it generates. On average, for configurations A, B and C, the overtime generated is 20.4, 23.4, and 27.4 minutes, respectively. Similarly, for the same operating program and different configurations (15, 20 and 25 emergencies), the overtime generated increases with the number of operations to be integrated.

For the average waiting time before assignment (column 2 of Table 6), for the first configuration, the operations are assigned, on average, after one and a half days. The waiting time for the second configuration increases, compared to the first. For the third configuration, operations are only assigned after 2 days.

**Conclusion**

In this paper, we have addressed the hard strategic issue of urgent surgeries assignment in an existing and in course operating schedule. Obviously, in practice, nobody let die an injured people, but non-elective surgeries insertions generate overtime costs in an operating theater. To answer this strategic concern, we took into consideration three non-elective patient classes, and designed scheduling assignment strategies, both answering to the medical needs of patients and to the overtime costs concerns of the hospital.

The proposed approaches have been explained and justified, in function of antagonist standpoints of patient and hospital. They have also been illustrated with synthetic and pedagogical diagrams. Then, they have been programmed and the computing results have been discussed in the last part of this paper, in function of each of the three classes of patients. Our hospital partner, has discussed and validated the presented approaches, as well as the results presented in this paper.

Two main and significant outcomes of this work are to point out, from our standpoint. The first is the realization of what we first addressed at the beginning of this work, a correct assignment of non-elective surgeries, which takes into account overtime concerns and significantly reduces overtime, but nonetheless accurately assigns the emergencies in the real time of an in course schedule. The second interesting point revealed by this work is an “offline” interest. The results presented in this paper show that we are able to forecast rather accurately the quantity and the quality of non-elective surgeries that a given operating block can accommodate, without endangering its exceeding schedule possibilities.

The perspectives we intend to give to these research works are twofold. In a first direction, we will further develop the existing operation tool, with our partner and other ones, which will take interest in reading this paper. We are particularly interested in computing the strategies developed in this paper with bigger operation theaters schedules. The second direction in which we are interested to continue our research works is the forecast possibilities on an operating block schedule. Indeed, if we succeed in giving relevant and real time information for operating theaters to the people in charge of answering to emergency calls, we could further improve the non-elective patients support.

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