# Software Application for Operation Planning in a Surgery Department

# MASTER THESIS

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This thesis is submitted as a full fulfilment of the Erasmus+ Program at Universidad de Zaragoza, along with the software application developed during the stay.


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# Abstract

Currently, the decision makers in a hospital spend more time in performing management tasks than taking care of the patients (the thing that they signed for when they first entered in the healthcare environment). Although some of them might be doing this for a long time which gives them experience in such decisions, the efficiency can be improved with the help of some technical solutions that are the result of advance research in planning and scheduling surgeries. Such technical solutions can also decrease the overtime hours and reduce the under/over utilization of some operating rooms.

This thesis' focus is to create such a solution that will help doctors to spend less time in managing tasks and have a better occupancy rate within the available capacity. It will also decrease the stress level and allow the doctor to offer more of his time to healthcare. The technical solution that comes next to this thesis is an implementation of algorithms studied and developed before [1]. It also has an in-built managing system for medical teams and patients and, the interface allows different levels of clearance, for a better security of the medical data.

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# Introduction

This thesis is a research about planning and scheduling in a medical department. There are already many studies in this field as there are many subjects to focus on also. Some of the studies come with a physical solution, not just a mathematical algorithm. Despite this fact, not many hospitals adopted such a solution that implements a decision model. This, plus the constant increasing of the waiting list forces the most expensive resource in a hospital to become a bottleneck, stop the hospital from getting the proper revenues and make the patients wait in a list that soon will seem endless.

In the next chapters of this thesis, I will talk about why this topic, what is it and how is it used, general aspects about the current algorithms, platforms that implement these algorithms and what directions are in the near future. I will also talk about the proposed algorithms and their models and how are they integrated in the software application I made. The app and its user interface, the algorithms and their simulation results will be also presented in the second half of this thesis, followed by some conclusions.

## Motivation

Technology is now everywhere. We all use it. Even if we just wash clothes, play video-games, drive the car, or construct robots to help us. We can find the latest available technology starting from smartphones to smart sidewalks or from smart cars to smart homes. Everything is technologized nowadays so, why not use this power to help ourselves? To give us more time with our family by enjoying the one we have instead of wandering every second if people from the hospital forgot to call us for the surgery or not.

The number of surgeries needed by the population increased in the last decades because of lifestyle, stress, technology, comfort, and so on. Many researches were made for improving and optimizing the results in medical departments. Some of them were focused on lowering the costs, improving the occupation rate or balancing the under and over time of the surgeons with the under and over utilization for the operating rooms.

From a management point of view, operating rooms are critical resources that needs to be occupied efficiently in order to obtain the maximum cost coverage. This also includes, along with a proper loading of the ORs, the used of medicines, medical instruments and devices and the human resources. From a patient's point of view, he is waiting for a surgery of a pathology that may or may not be critical than other patient's pathology. Furthermore, if the critical level of the pathology is under a certain level, they all wait in an ordered list. Both surgeons and patients want to keep this order for the surgeries as much as possible.

## History and previous research

Thousands of years ago, when surgeries as a practice were at the beginning, they were a terrifying thing for both patient and surgeon. Many people chose to die rather than go to a surgeon. Now, looking back at that time, it's understandable why people avoided surgeons. They didn't use any kind of pain reliever, although some of them used ice to numb the area. The patients, in all the cases were awake and seeing everything that was happening to them. Some of them needed to be hold by strong man because of the physical and mental pain they were in. Furthermore, the surgeons were not that caring about cleanness in the operation room. They were mostly protecting themselves from the patient's blood rather than using a clean and safe environment and instruments. That is a bit understandable when we think that back then, there were not too many knowledges about microorganisms. Because of this lack of knowledge and the environment was not safe for an open wound, causing a large number of deaths. The patients that survived the surgery (either they were lucky or they had a great immune system) did not have a supervised post-operatory recovery. In the mid-19th Century, surgeries had been done as fast as possible. For example, a leg amputation surgery could have been performed in 3 minutes or less, this of course, with the cost of accuracy. Although the anesthesia has been used since late 1800s, sterilizing the wound, air/room, and using clean white clothes and bed linings had been used starting with 20th Century. Even so, in around 4000 years since Egyptians were curing the migraine by drilling small holes in patient's head, in 3000 BC, the surgeries evolved very much, first by studying on animal body (16th Century) and then on dead human bodies (late 19th Century). Since then until nowadays, surgeries techniques and instruments kept improving thanks to all the studies and researches that were made in this field.

In year 2010, a paper called “Operating room planning and scheduling: A literature review” [2] was published as a review of current available papers. They studied over 246 manuscripts on operating room planning and scheduling that were published between 1950 and 2010. Nearly half of them were after January 1st, 2010, which shows an increasing research of this domain for helping and improving the medical system. All this research is made only to bring the system up to date and be able to help more efficiently the patients that are in need. The authors split the paper in 7 sections, studying the documents after the patients they considered, performance measurement, precision, type of analysis, solutions, uncertainty and applicability. It gives a good look of what is mostly the focus of researchers, where are the gaps in research and what might be a direction for future studies. The review above shows that more than half of the studies focus on elective patients, no matter if they are inpatients (patients that need to stay in the hospital after the surgery – with or without being in the hospital before the surgery) or outpatients (patients that usually come in and leave the hospital in the same day in which the surgery is scheduled). Elective patients are not considered emergencies. Emergencies patients are non-elective and therefore they cannot be foreseen. For emergencies patients are researches that use heuristic approaches to partial schedule resources. Elective patients are ordered in a list after the incoming date (the date in which the patient and the doctor decided the patient needs a surgery) and the critical level (low, normal or high). When a planning and scheduling is done, the selected patients for the current planning are announced that they have been scheduled for the surgery in a certain day. As in half of the papers reviewed in the article, this thesis is also considering only the operation theater alone, without using any other facilities from the hospital, like ICU. This is because we consider only non-emergency patients which have a lower probability of needing to use the ICU than the emergency patients. Another study focus in the previous researches was the waiting time, either it was considered for the patient or for the surgeons. This thesis considers only the waiting time for the patient because the medical teams will have assigned a certain operation room in certain days, so they will know from before, the time and operation room to use.

Other similar studies also show that the majority of research had been focus mainly on the surgical department due to high complexity of including other departments or even other facilities from the surgical department la PACU (Post Anesthetic Care Unit) or ICU. They also study the current problem from the view of time horizon involved in the scheduling. Some focus on the long and very long time planning (one year or more) while others focus on short and very short time planning (a few days to a few weeks). When using a long and very long time span the issue of capacity planning and allocation is addressed while in a short time span, a schedule can be constructed and executed with a predictable workload [3].

## Methods of application

Planning and scheduling a surgical operations is a process with 2 big steps. First step contains a plan (weekly or monthly) to assign a specific date to a specific patient. The second step is about ordering the patients scheduled on a certain day. In the first step, each patient is in a waiting list of a medical team. To assign a date to a surgery, we first need to assign an operation room to a medical team for each day in the current plan. After a medical team has an operation room assigned for each day of the plan, the patients from its waiting list can be scheduled. Also, in this step, a plan is not complete until all the patients that were scheduled confirm that they can be present on the specified date. The patients which do not confirm that they will be there on the allocated date, will be removed from the current plan and the next patients in the waiting list will be scheduled in their place. This step is repeated as long as there are free places in the current plan and there are patients in the waiting list who haven't been scheduled yet. The patients who were removed from the current plan because they cannot attend on the allocated date, they will be scheduled as soon as possible, manually, in a common agreed date or in a future plan. In the second step, each day from the current plan, will go through an ordering or sorting phase. This step allows giving a bigger priority to more urgent surgeries, complex/easy surgeries or children/old people depending on the surgeon preferences or even patient preferences. Also, people that will come to surgery from a longer distance, have the possibility to be scheduled after a certain hour. This project focusses on the first part. The second step will be completed by each medical team, manually, for the time being.

## Organizational structure of the medical department

The project is created to be applied (first, but not only) in the Orthopedic Surgery Department of the local hospital, "Lozano Blesa", Zaragoza, Spain. The targeted department is composed by a Head of Department (also a doctor) and 5 medical teams. Each team has a coordinator and each doctor has its own waiting list of patients. The waiting list of for each team is composed from all the waiting lists of the team members. The first patient in the list is the one that has the biggest waiting time and the last patient in the list is the last one added to one of the team members' waiting lists.

The medical department has available only 2 operating rooms per day for non-urgent surgeries. Each of them have an active schedule of, usually, 7 hours. Each OR is daily scheduled for only one team. The Head of Department has the following responsibilities: (1) assign teams for each available OR – one team per day, (2) assign teams for external consultations and (3) assign teams for emergency service. The assignment is made within a time horizon of two to six months. This way, the teams know in advance in which day they can use which OR. After the medical leaders know the scheduling for the OR, they start planning and scheduling the patients form the team's waiting list guided by his own intuition and experience. This planning and scheduling is also made manually as the team assignments made by the head of department. Studying the occupancy rate of the ORs from the last years, the average obtained was around 72% [1]. The structure of the department is also explained, in Figure 1.

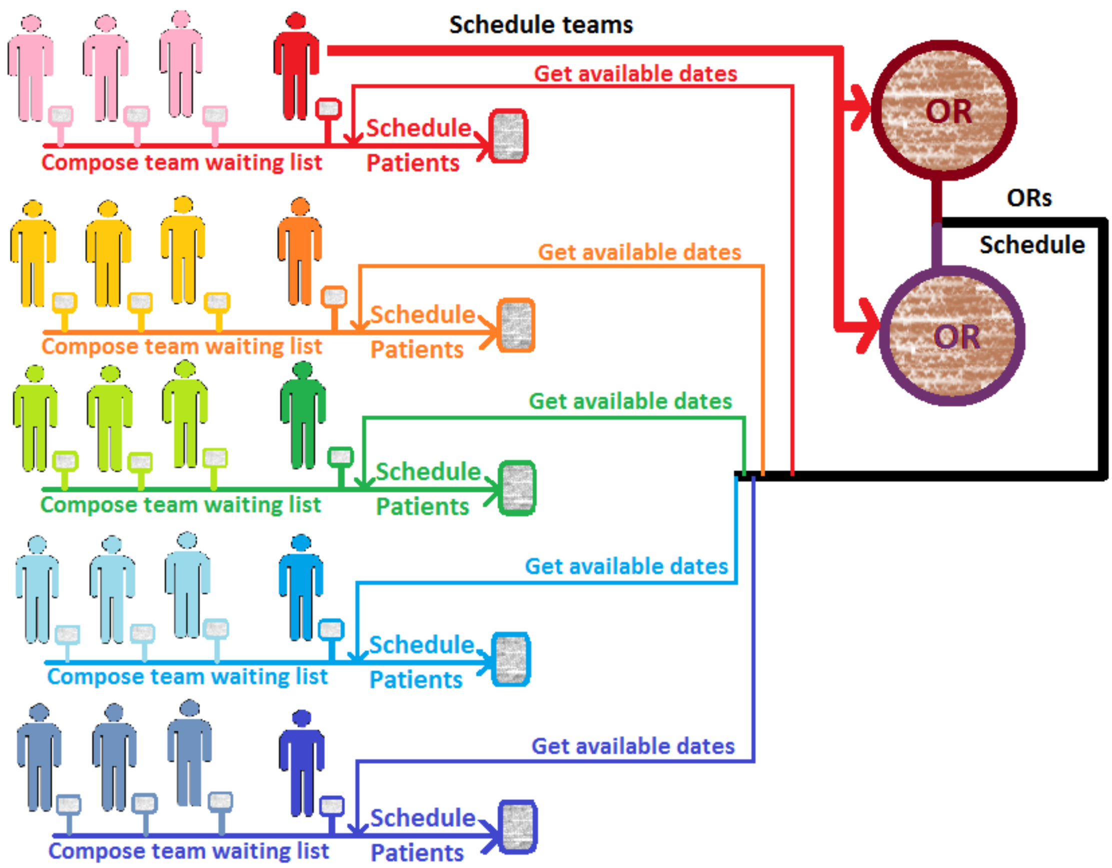


*Figure 1 Department workflow*

In Figure 1, each strong color represents a coordinator and the fade colors represent team members. The small squares are each doctor's waiting list. The circles are the available Operating Rooms. The red man is also the head of department so, he is scheduling daily medical teams in each OR. The coordinators (in strong colors) take the scheduled days for their team form the ORs' time table and create the planning and scheduling of the patients from the team waiting list (also composed by them), represented by the big squares.

## Project description

This project is made to be used by the medical stuff of the Surgery Department. Its interface is design to help managing the medical teams and patients in a more clear and easy way. It also gives a clearance level to every user so, not every user is allowed to do everything in the app. This way, it also offers a safe environment to work on. The application will be installed in a local computer in a hospital, orthopedic surgery department. This application is available in two different language versions (English and Spanish), option available in the login window. This application also has attached a database. So, every modification made will be saved and ready to be accessed and used in the current session or a future one, no matter the language preferred for the interface. The user will have to choose the desired language version in the login form and keep it until the end of the session. If he wants to change the language, the user must log out, switch the language, then to log in again. After the user has logged in, depending on the clearance, he can use the application for:

- Managing medical teams
    - Add/remove doctor from team or medical teams

- Move doctor to another medical team
    - Change the medical leader of the team or the team name
- Managing patients
    - Add/remove patients
    - Add/remove/change surgeries from patient's medical history
    - Manual schedule a patient to a certain medical team and doctor and to a certain day in which that team is available
    - Unscheduled a patient that cannot present himself to the hospital in the assigned day
- Managing operating rooms
    - Add/remove operating rooms from the operating theatre
    - Schedule a medical team in a certain day for each operating room
    - Change data in the current available time table
- Planning and scheduling patients from a certain waiting list for a given number of working days
- Adding the information of the performed surgery for each patient to whom the scheduled surgery is completed

Once a patient is unscheduled, because he cannot confirm the availability for the surgery, he will be added in the top of the list for the following planning. He can also be manually scheduled in another available day.

## Planning and Scheduling. General aspects

*Planning* is used in our lives daily. No matter if we are setting our goals as “pass the current study year with over 9 out of 10 CGPA” or “in this vacation I want to see the Black Sea and Alps”, we are making plans. This is a normal thing for humans because one of the executive functions of the brain is planning. Please notice that there is no time notion involved in planning. After we set a time and place to the entries in our plan, it becomes a *schedule*. In other words, scheduling is the process of arranging/ordering and optimizing the workload of a process/plan. Planning and scheduling, both together – as a team, have a major impact on the productivity. Their purpose is to minimize the allocated time, resources and costs. When making a plan, usually, we need to answer 3 questions: What? How? and Who?, but when we’re making a schedule the answer of other 2 questions is important: When? and Why?. *Planning* means taking the target (let’s say: cross platform adventure game) and braking it down to smaller pieces (for our example, they can be: User Interface, user connectivity to server, quests, items, levels). Every piece needs to be broken down in smaller parts as long as it cannot be explained short and clear. This is a top-down planning. Another approach can be bottom-up planning, but it is used when there is already at least another similar successful project. For a good planning, it is recommended to have: (1) a Work Breakdown Structure (WBS – braking the project into smaller pieces), (2) a project execution plan, (3) usage of resources and (4) project milestones. After everyone in the team has a good idea of what it should be in the end, the *scheduling* can be performed. [4] Scheduling means: (1) determining when exactly, the tasks from the previously determined plan will be performed (starting time and end time – based on a time estimation of the details found in each task’s description), (2) in what sequence will they be performed. To order the entries in a plan are usually used one of the following priority sequencing rules:

- First come, first served
- Earliest due date
- Shortest processing time first
- Longest processing time first

Depending on the process, accepted past due date time, the critical level of the tasks in the plan and dependencies, one of the above rules can be applied. If the plan is well structured, different rules for sequencing can be applied for different independent parts of the project. Though, if the plan includes more than one site or team than, a more complex solution should be considered. In this case, there are algorithms studied and developed ready to be implemented and used depending on the needs or the desired optimization. Almost in all cases, not all targets can be optimized. Therefore, each study focus on the most important tasks at the moment and compromise (but not too much) the optimization of the other tasks. Common scheduling failures (that occur usually to less experienced teams) are: lack of planning (there are tasks that haven’t been foreseen. That means there are tasks that haven’t been included in the planning, therefore they have not been included in the scheduling. This leads to delays), poor defined activities (it can lead to a misunderstanding of the task which will be reflected in delays), poor duration estimation (estimating less than the actual time, mostly caused by underestimating the complexity of the task).

## General aspects about surgery planning and scheduling

The surgery planning and scheduling started with the nurse rostering problem. This problem refers to finding an optimal way to determine shifts and holidays for nurses. Both nurses and hospital have their own constraints. The problem is described as finding a schedule that fulfils both types of constraints. Nowadays, this is not the only problem of hospitals as the number of surgeries increased but the number of human resources (nurses, doctors, anesthesiologists and so on), logistics (rooms, beds) and medical instruments are limited. Also, because of this increase, the management team of an operation theatre is now formed from surgeons, anesthetists and nurseries unlike before when nurses have been chiefly responsible for the daily function of the surgical suite. A good management of the operation theatre helps the doctors and nurses to focus only on the patient on the surgery day, without losing time and effort to compensate a poor management and compromising patient safety.

Operation room efficiency is of the most important constraint that the management team is trying to maximize. For these purpose, they use charts to analyze the under-utilized and over-utilized rooms as well as the overtime medical teams have. In operation theatres that have more than two operation rooms, it is possible to have under-utilized rooms and overtime for medical team. For example, we have 2 operation rooms, each with 5 hours of time spam, and the first operation room is used by a medical team for 3 hours and the second operation room is used by another medical team for 6 hours. That means we have 9 out of 10 hours occupied in the operation theatre (under-utilized operation theatre) and 1 hour of overtime performed by the second medical ream in the second operation room.

Another problem which can generate overtime is start-time tardiness. It means that from various reasons, one or more of the surgeries scheduled in one day (referring to elective patients) starts at a later time than the one established in the schedule. This will also generate an increasing waiting time for the following patients besides the overtime for the medical team. The increase number or repeated days with overtime will also increase the stress level of the medical team members which will reflect in a decreasing attention for the patient safety. Not only overtime is a current problem but also the case cancelation in the day of surgery which will generate under time and under-utilization of the operating room. This problem is as important as overtime or over-utilization of the operating room because all of them generate revenue lost for the hospital. Therefor management teams have to consider all the problems and find and apply an optimized solution that suites best. Many of the cancelations are due to non-medical problems like surgeon unavailability, full ICU or bad weather that stops the patient to come in the scheduled day. Depending on the region, country and geolocation, a hospital can deal more with overtime then cancelations or vice-versa. A good management team does not adopt an optimization plan only after the results obtained from simulations or from other hospitals but also regarding its own medical history. Unfortunately, it is hard to obtain charts with medical load in past decades due to late adoption of technology in many sites.

## Current available tools

An editorial on Artificial Intelligence planning and scheduling [5] shows a roadmap of the published research in Artificial Intelligence (AI) planning and scheduling, also giving some examples of prototypes. AI research in the field of planning and scheduling started to be very active in 1960s when many of the papers focused on the development of algorithms on planning as the only goal. In the mid ’70s the researchers started to consider the achievement of sub-goals favorizing the appearance of partial order planners. In the mid ‘80s, the models were expanded to consider time as a major factor in the planning process. By the end of 1990s, there were available prototypes. Some of the prototypes were meant to be uses in managing the chemical processes in plant operating procedures (CEP) or a planning and scheduling system used for mobile robots, beer production or military operation planning (Cypress). Also, for supporting physicians’ diagnosis and therapy planning, there were created tools like MYCIN or EXPERT. Current available software is basically focus on creating the time table for doctors and nurses. Some are available on mobile and permit tracking of working and vacation hours or comparing schedules[1] or web-based solution for managing teams and schedule shifts[2]. The existing solutions of planning patients are not used because they do not consider the patient’s preferences for a certain doctor or day. It is also available for the doctors. They are not available to choose the type of patients they want to have at a certain moment. Therefore, the return to pen and paper solution or not adopting a technical option was unavoidable.

In 2013 was conducted a study [6] as part of the Contingency Contractor Optimization project that had as a focus to determine if there are any available **Open-Source linear programming** (LP) solvers that can be used instead of commercial ones (solvers tied to a commercial product such as Matlab). They identified around 100 tools that were an add on in Matlab or Excel. From the stand-alone, open-source or low-cost available solvers, they identified, during two screenings, some LP solvers and compared them to each other. Moreover, while conducting the screenings, they also identified available Quadratic Programming solvers such as: CVXOPT, OOQP, LSSOL, CLP, PPL, MINTO and CBC, but they did.t focus on them. In the first screening, they selected 10 LP solvers that met the initial criteria: (1) free or low cost, (2) LP solver product, (3) uses exact algorithms (such as Simplex or Interior Point) and not heuristic algorithms (e.g. Monte Carlo), (4) the product is mature, (5) is a stand-alone product. In the second screening, they reduced the first list by applying other criteria. PCs solver was eliminated because it was not updated since 2006. Being not widely used was another reason to eliminate PPL and JOptimizer solvers. The last criteria that eliminated other 3 solvers (LiPS, CVXOPT and QSOPT) was: being developed for academic use and research, with no intention of using them in production. The solvers that completed all the requirements are: **CLP** (C++), **GLPK** (C and Java), **lp_solve** (C, C++, C#, Java and .NET) and **MINOS** (Fortan, C and Matlab). They were supposed under 201 tests (180 “easy” and 21 “hard”) and their results have been compared after many criteria, the most important being time of solving the problems. The reference results for the proposed problems were obtained using **CPLEX**.

In the proposed software solution, the patient will have a certain doctor and medical team assigned to each surgery for his medical history. If him or the doctor in charge want to change it, they are able to do it. Also, if the patient asks and the doctor in charge and medical team have a free slot in the allocated working ours, the patient can be scheduled for surgery in the day he desires.

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[1] Bio-optronics software – http://bio-optronics.com
[2] SEIDA – http://www.optimum-choices.com

## Next directions of development and possible use-cases in near future

A possible direction in the future was proposed by Sandberg in the paper published in 2005 [7]. He and his colleagues propose a design called “OR of the future (ORF)” where some of the preoperative and postoperative process can be done in parallel, if the OR have intake and recovery rooms. This way, the nonoperative time and the probability of overtime are reduced, by not being assigned to the OR occupation time. In this proposed solution, the anesthesia and other preoperative process are done in the intake room while the surgery room is prepared for the operation and, after the surgery is finished, a nurse will provide the early recovery attention in the post operatory room, while the surgery room can be prepared for the next patient that is in the intake room with the anesthesia personnel. Artificial Intelligence solutions might come in front in a near future by combining the studies and results from this field with the algorithms developed in the field of planning and scheduling, therefore making the planning and scheduling adaptable by learning from its own past decisions.

--- find at least another example… more recent ---

# Mathematical models, Algorithms & Platforms(Solvers)

Production planning problems, but not production scheduling, started to implement linear programming since 1940s [8]. One of the powerful and general techniques used in linear programing problems was the simplex method, invented by George Dantzig in 1947. Later, in 1950s, production scheduling problems led to researches into sequencing problems. This lead to creation of algorithms like: the earliest due date rule (EDD), shortest processing time rule (SPT). For solving more complex problems, in 1960s, appeared algorithms based on Branch-and-Bound techniques that allowed finding the possible solutions and determine the optimal one. Also, column generation techniques and constraint programming have been developed to solve integer programming problems. In early '70s, complexity theory showed that algorithms able to find the optimal solution in a reasonable time are unlikely to exists. That's why, in '80s and '90s, algorithms that could find a near-optimal solution became the focus in search algorithms.

---description of some algorithms form the 3rd article ----

## Mathematical models used in this project

In this project, we consider only the elective patients from the orthopedic department of the local hospital "Lozano Blesa", Zaragoza, Spain. There are 2 available operating rooms for the selected group of patients, each operating room being available for only one team per day. Also, the operating rooms' time table varies daily. Based on the history of completed surgeries in the department, a list of average durations of the performed surgeries has been computed and used in these mathematical models. The purpose of the mathematical models is to optimize the use of the operating rooms without exceeding the maximum available time per day and without making use of unnecessary resources. Because there still are uncertainties about the surgeries' durations due to unforeseen events of the different nature of the human bodies, and because the total day length of an operating room also includes the cleaning time, the optimal occupancy rate of each operating room, daily, is considered 80%. Before I came in the project's team, Daniel Clavel Villagrasa studied these details and composed the models implemented this project [1]. In order to obtain the desired occupancy rate, the first model offers an approach that makes use of integer programming (**MILP**) – a model that respects the desired occupancy rate with a specified tolerance and preserves the order of patients from the waiting list as much as possible. The patients from the waiting list have been ordered before adding them in the model, after some criteria established by the hospital (for example: date of adding in the list, critical level). The other approach uses quadratic constraints (**MIQCP** & **MIQCP-P**) – two models that computes the probability of overcoming the total time and offers a minimum confidence level for it.

The results of the first algorithm, MILP, (as they can be seen in the "Simulation results" chapter), show that *minimizing the <u>absolute</u> deviation* can also lead to a bigger percentage rate than the desired one. This will lead to overtime for the medical teams and overload for the operation room, which is not desirable. The second approach comes in order to obtain a safe planning – with a lower probability of overcome the total time in any of the day scheduled. Both models (MILP and MIQCP) use the duration of the surgeries and the cleaning time (time needed to clean any possible bacteria from the previous surgery and to prepare the operation room for the next surgery) as random variables with normal probability density function. MIQCP model will be used to obtain optimal solutions of the model. Using these data, we'll obtain a minimum confidence level of not overcoming the total time by computing the average occupation rate. The minimum confidence level obtained will be an input parameter of MIQCP-P model which will perform a safe schedule faster.

--- need to add more technical details ---

## Platform(Solvers) and algorithms chosen for this project

The algorithms chosen to solve them are: **MILP** – because of the binary variables defining the surgeries scheduled (or not) for each day and the real variables that describes the deviation from the desired output – and **MIQCP** because of the quadratic conditions from the second model. Regarding the study above about results of available solvers for these problems, **CPLEX** was the one that fit better with the requirements of the models. Also, it is cross-programming languages available and it offered us the possibility to reimplement the models in Java (before, being implemented in Matlab by my colleague), where we could also offer a graphical interface to the end-user.

## Platform: CPLEX

IBM is currently developing a platform that implements algorithm for solving linear programming problems and other related problems (for example: Quadratic Constraint Programming) and it is called "**IBM ILOG CPLEX Optimization Studio**" [9]. Currently, it offers libraries for the most used programming languages like C, C++, Java, .Net and Python available on Windows environments as well as on Linux environments. CPLEX is crated over Concert Technology which is a set of libraries that allows the programmer to embed CPLEX in the above specified programming languages. Concert Technology also makes use of Callable Library which is a C library that allows the programmer to embed CPLEX in any programing language that can call C functions. IBM describes CPLEX as "a tool for solving, first of all, linear optimization problems".

---- need some more details ----

## Algorithm: MILP

The first model designed for this problem was implemented using **MILP** algorithm and uses the following variables:

- *n* – number of patients in the waiting list
- *m* – number of days to schedule
- *order* – vector of size *n* with the preferred order of each patient in the waiting list
- $\mu_S$ – vector of size *n* with the average duration of patients' surgeries (for *n* patients to schedule, this vector will have *n* average duration values in the same order)
- $S_1, S_2, \ldots S_m$ – binary vectors of size n, that are used for planning and scheduling patients in each day of the current schedule. It is implemented as a matrix, *m* x *n*, each line representing a working day.
- $\alpha \in R^{m}_{\geq 0}$ a vector of absolute deviation in minutes for each day (size($\alpha$) = m), regarding the objective ($Obj = dayTime * \frac{occupancyRate}{100}$).

The conditions in the model are:

- It is mandatory that any patient to be scheduled once and only once in the whole plan. In other words, the sum of every column (from 1 to $n$, each of size $m$, to be less or equal with 1). This is implemented in the model as the following:

$$\sum_i S[i][j] \leq 1; \; \forall \, j = \overline{1, n}. \tag{1}$$

- Each element form the vector of absolute deviations is defined as following:

$$\alpha_i \geq \left|\sum_{j=1}^{n}(\mu * S[i][j]) - Obj\right|, \forall \, i = \overline{1, m} \tag{2}$$

The <u>objective</u> of this model is express by two contradictory smaller objectives: (1) obtain the desired occupancy rate and (2) maintain the order from the waiting list for the scheduled patients. If the accepted deviation from the desired occupation rate is 0, the requirement of keeping the order of the patient list cannot be fulfilled, and vice versa. To solve this, the main objective of the model was composed by a linear cost function with two terms. The first one is related to the desired occupancy rate and the second one, with the order of the scheduled patients. The two terms are balanced by parameter β which allows us to set a compromise between the two objectives. The objective is defined as following:

$$min(\sum_{i=1}^{m}[\alpha_i * (m - i + 1) + \beta * order * S_i * (m - i + 1)]) \tag{3}$$

The <u>size and complexity</u> of the model is defined as following:

- Number of variables: *(n + 1) x m*
- Number of constraints: *2 x m + n*

An implementation of this model with a schedule result of a random generated list can be found in the following <u>example</u>: number of patients ($n$) = 20, number of days to schedule ($m$) = 5, desired occupancy rate = 80%, working days of 7 hours and an accepted deviation of maximum 10% of the total day time.

*Table 1 Random generated list of patients to be scheduled*

| *Order* | *Patient* | | *Surgery* | *Average duration [min]* |
|---|---|---|---|---|
| | **Last Name** | **First Name** | | |
| *1* | Jacobsen | Paulita | Surgery_1 | 100 |
| *2* | Casio | Les | Surgery_5 | 194 |
| *3* | Harting | Lois | Surgery_3 | 77 |
| *4* | Wasielewski | Lorina | Surgery_7 | 184 |
| *5* | Sill | Teresa | Surgery_29 | 121 |
| *6* | Pratts | Laurice | Surgery_2 | 81 |
| *7* | Acebedo | Tamie | Surgery_6 | 97 |
| *8* | Ganley | Newton | Surgery_6 | 97 |
| *9* | Zollinger | Shelly | Surgery_6 | 97 |
| *10* | Walko | Sylvester | Surgery_10 | 85 |
| *11* | Rosado | Obdulia | Surgery_15 | 150 |
| *12* | Buonocore | Tamela | Surgery_25 | 153 |

| | | | | |
|---|---|---|---|---|
| *13* | Southern | Kellie | Surgery_6 | 97 |
| *14* | Raab | Clarissa | Surgery_15 | 150 |
| *15* | Ballengee | Walton | Surgery_6 | 97 |
| *16* | Difalco | Destiny | Surgery_15 | 150 |
| *17* | Gouin | Dana | Surgery_4 | 86 |
| *18* | Rabago | Ilda | Surgery_6 | 97 |
| *19* | Carbone | Margareta | Surgery_10 | 83 |
| *20* | Valliere | Aiko | Surgery_29 | 121 |

Desired occupancy rate of 80% from 7 working hours leads to a desired occupancy time of **336** minutes (out of 7[hours] * 60[minutes] = 420[minutes]). The obtained results for **β = 0.333** are (priority given to occupancy rate closer to the desired rate):

| *Day No.* | *Occupation time [min]* | *Occupation rate [%]* | *Order No. of Scheduled Patients* | *Absolute Deviation [min]* |
|---|---|---|---|---|
| *1* | 337 | 80.2381 | 4, 12 | 1 |
| *2* | 335 | 79.7619 | 1, 10, 11 | 1 |
| *3* | 344 | 81.9048 | 2, 14 | 8 |
| *4* | 338 | 80.4762 | 3, 6, 7, 19 | 2 |
| *5* | 339 | 80.7143 | 5, 8, 20 | 3 |

*Solution cost:* *146.227*
*Total time:* *2.69 [sec]*

The obtained results for **β = 2** (priority given to patient order list) are:

| *Day No.* | *Occupation time [min]* | *Occupation rate [%]* | *Order No. of Scheduled Patients* | *Absolute Deviation [min]* |
|---|---|---|---|---|
| *1* | 334 | 79.5238 | 4, 11 | 2 |
| *2* | 315 | 75.0 | 2, 5 | 21 |
| *3* | 330 | 78.5714 | 1, 3, 12 | 6 |
| *4* | 328 | 78.0952 | 6, 7, 14 | 8 |
| *5* | 332 | 79.0476 | 8, 10, 16 | 1 |

*Solution cost:* *610*
*Total time:* *0.63 [sec]*

## Algorithm: MIQCP

The second model, implemented with **MIQCP**, uses the following variables:

## Algorithm: MIQCPP

Almost the same thing but different…

# Project architecture

## Data Base

## Front-End. User Interface (UI)

## Back-End. Platforms & Dependencies

# Project implementation

## Data Base

## User Interface

## Platforms & Dependencies

## Back-End implementation (general project implementation with more details about some important classes and methods)

# Application. How to use it

## User type: Head of department

## User type: Medical team leader

## User type: Medic

## User type: Assistant

# Simulation results (Matlab and JAVA)

## Algorithm: MILP

## Algorithm: MIQCP

## Algorithm: MIQCPP

# Conclusions

# References


[1] D. Clavel, "Operation planning of Elective Patients with a minimal confidance level of not overcoming the total time," Zaragoza, 2016.

[2] E. D. J. B. Cardoen, "Operating room planning and scheduling: A literature review," *European journal of operational research,* pp. 921-932, vol. 201, no 3, pp. 2010.

[3] W. E. S. D. P. S. L. G. V. J. H. May, "The surgical scheduling problem: Current research and future option," *Production and operations management,* pp. 392-405, 2011.

[4] A. Godhawale, "Introduction to planning & Scheduling," projectcontrolsonline.com, London, UK, 2010.

[5] C. D. Spyropoulos, "AI planning and scheduling in the medical hospital environment," *Artificial Intelligence in Medicine,* pp. 101-111, 1 10 2010.

[6] K. L. A. R. J. D. J. D. D. K. A. J. N. M. J. L. Gearhart, "Comparision of Open-Source Linear Programming Solvers," Sandia National Laboratories, Albuquerque, 2013.

[7] B. D. M. E. W.S. Sandberg, "Deliberate perioperative systems design improves operating room throughput," 2005.

[8] J. A. Hermann, "A history of production scheduling," in *Handbook of production scheduling*, Springer US, 2006, pp. 1-22.

[9] IBM, CPLEX manual, 2014.