How to deal with Emergency at the Operating Room

Research Paper Business Analytics

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Preface

In March and April 2012 I worked on this Research paper Business Analytics about how to deal with emergency at the operating room. The Research paper is one of the final parts of the master Business Mathematics & Informatics.

The aim of this paper is to combine all three aspects of the study BMI on a literature study of a real problem. The aim is to combine Mathematics and Informatics on a research of a real business problem, which the student may select.

I would like to thank Rene Bekker for his help and critical insights during this research. I would also like to thank Alex Roubos for his Matlab tips.

I hope you enjoy reading this paper.

Summary

Hospitals have to make their health care delivery process more efficient. Hospitals have to reduce their costs and generate more revenues, but without a decrease of patient satisfaction. The Operating Rooms (OR's) is one of the most expensive parts of a Hospital.

There is much uncertainty in planning and scheduling of the OR. This because two types of patients arrives at a hospital, elective and emergency patients. Elective patients are the patients who are known and scheduled in advance, while emergency patients just arrive at some moment and must be helped quickly.

There are different methods to deal with emergency patients. There are hospitals, who have so called dedicated OR's. That are separate OR's only available for emergency patients.

A second option of to deal with emergency patients is the so called "white spots" method. This method reserves some capacity at the different Operating Rooms in case an emergency patient arrives.

A third option is a combination of the two methods. In this so called mixed method you have dedicated OR's for the emergency patients, but you also allow emergency patients to break in at the elective schedule in the elective OR's.

The different studies come with different results. A research of [12, Wullink et al] comes to the conclusion that you should use the "white spots" method. Another research of [13, Ferrand et al] on the other hand comes to the conclusion that you could better use dedicated OR's for your emergency cases. They even conclude that it is optimal to use 5 dedicated OR's.

The best policy depends on the performance measures you want to optimize. If you want to minimize the waiting time for an emergency patient, you should use the mixed policy. On the other hand if you want to optimize the overtime and utilization, you should use a "dedicated OR" when you have more than 20 OR's, otherwise the "white spots" policy is the best.

If you want to optimize all those three performance measures the best policy is the "white spots" policy. It has a slightly worse waiting time than the mixed policy, but has a slightly better overtime and utilization than the mixed policy. When you have 20 or more OR's the dedicated OR policy has in general a slightly better overtime and utilization than the "white spots", but the "white spots" policy has a much better average waiting time. When the number OR's is less than 20, then the "white spots" policy has in general a better average waiting time, a better overtime and also a better utilization when the number of OR's is equal or lower than 10.

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1.   Introduction

At the time of economic crisis and increasing competition, hospitals have to make their health care delivery process more efficient. To do so hospitals should reduce their costs and generate more revenues, but this all without a decrease of patient satisfaction. One of the major cost item of a hospital is their Operating Rooms (OR's).Therefore it is not strange, that in the past few years many studies have focused on this.

Operating room management is large research field, which we roughly divide in two levels: scheduling and planning. According to [1, Cardoen et al] scheduling is "defining the sequence and time allocated to the activities of an operation. It is the construction of a detailed timetable that shows at what time or date jobs should start and when they should end". Planning is "the process of reconciling supply and demand".

Scheduling the OR is one of the most challenging problems for hospitals. In the literature [2, Hans et al] the following reasons are given. The first reason why scheduling the OR is so difficult is because of conflicting interests. You have surgeons, OR personnel, patients and also management which all have different interests. A second reason is the complexity of scheduling because of the uncertainty of the occurrences and the durations of the surgeries. A third reason is the conflicting performance measures. High planned utilization is more efficient for the hospital, but may lead to overtime and long waiting times and sometimes to cancellation of surgeries, which lead to decrease of patient satisfaction.

The main reason why there is so much uncertainty in OR planning and scheduling is because you have two types of patients who come to a hospital, elective and emergency patients. Elective patients are the patients who are scheduled in advance, so they can be planned, while emergency patients just arrive at some moment and must be helped quickly [2, Hans et al].

There are different ways to deal with emergency patients [2, Hans et al]. Most hospitals have a so called dedicated OR. That is a separate OR for only emergency patients. An advantage of this is that the emergency patients do not affect the elective schedule on the other OR's. A disadvantage is that the dedicated OR has a low utilization, which leads to high costs. Another disadvantage is that when the dedicated OR is in use, it is not immediately available for another emergency patient.

A second option of how to deal with emergency patients is to "reserve" some capacity at the different Operating Rooms in case an emergency patient arrives. An advantage of this method is that you do not have those low utilized dedicated OR's, but your elective OR's have a lower utilization, because of the reserved capacity. A disadvantage of this policy is that it can lead to long waiting times for emergency patients and this policy may lead to cancelled elective surgeries.

This paper mainly focuses on how to deal with emergency patients. In this paper it is studied if it is better to have a separate dedicated OR, or to reserve some capacity at all the different Operating Rooms or whether a mix of the two is optimal. Furthermore it studies whether the results depend on which performance measure you want to optimize or on the number of OR's you have?

The paper is organized as follows. In the next chapter a literature of other researches is given on this and related topics. In the third chapter different simulation models to analyze the OR are described. In the fourth chapter the results of the simulations are given and in the last chapter I give a conclusion.

2.   Literature

In this chapter literature on OR related topics is discussed. The first section is about the types of patients that arrive at the OR, based on [1, Cardoen et al] and [3, Visser]. In the second is about how different hospitals deal with emergency. In the third section I describe what a standard operating process looks like. The fourth section gives an overview of different performance measures which can be used to evaluate the planning of the OR. Finally I describe some studies on the optimal order of the operations.

2.1   Patient characteristics

In the literature, most of the time two types of patient are considered: elective patients and emergency patients. Sometimes a distinction is made between inpatient and outpatient patients [3, Visser]. Where inpatient patients are those who stay more than a day and outpatient patients are those who leave the hospital the same day. The inpatient patient is divided into two types, namely scheduled and non-scheduled. Scheduled patients are the elective patients and the non-scheduled are the emergency patients, sometimes also called the non-elective patients. In the literature they sometimes also use the term urgent patients, who are patients that need help immediately, but most of the times they include these patients in the emergency patients.

Given these different types of patients a hospital needs admission planning to decide how many patients they should admit for each specialty at each day. In each specialty there are also differences between the patients based on their requirement of resources, such as capacity, nurses and equipment.

2.2   Emergency

In this section the different policies, which hospitals use to deal with emergency cases in the OR, are described.

In the literature there are two policies suggested for how to deal with emergency patients. The first option is the so called dedicated Operating Room and the second involves so called "white spots". In figure 1 you see a graphical representation of the two policies:
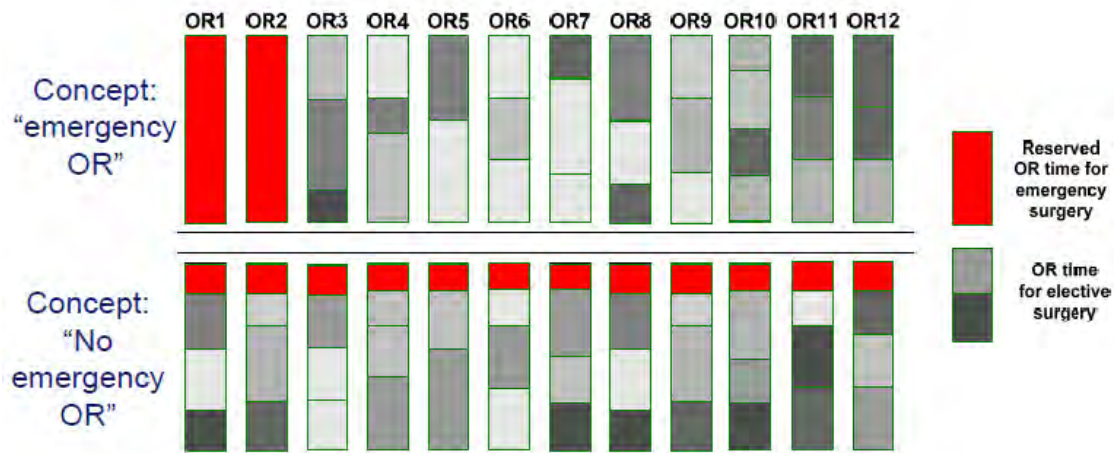
Figure 1: Different policies for emergency cases [10, Hans]

In figure 1 you see twelve different OR's. Each bar represents the total time available at one OR. In each bar you see different colours, which represent the different surgeries at an OR. The upper figure shows the so called dedicated OR's. Here you have two OR's (the red coloured bars) that are only for emergency cases. In the lower image you see the "white spots" at all the OR's (the red parts in all bars). So the policy of "white spots" reserves some time at all of the OR's in case emergency cases arrive during a day.

As I already mentioned in the introduction, the advantage of the dedicated OR's is that you need not to worry about the emergency cases in the other OR's. Another advantage with this policy is that an emergency arrival does not have to wait till an elective operation is finished at one of the other OR's. A disadvantage of the dedicated OR's is that you have low utilizations at those rooms, which lead to high costs. Another disadvantage is that when the dedicated OR's are "busy", you cannot help another emergency case until the operation at the "dedicated OR" is ended [2, Hans et al].

An advantage of the "white spots" is that you do not have the low utilizations of the dedicated OR. A disadvantage of the "white spots" is the risk that you have to cancel surgeries of elective patients, which is not good for patient satisfaction.

A third policy which - as far as I know - is not studied in the literature, is a mix of both "dedicated' OR's and "white spots". With this policy you have a dedicated OR, but you also allow emergency patients at the elective OR's. With this policy you do not have the problem that you cannot help another emergency case when the dedicated OR is "busy". The disadvantage of the low utilization at the dedicated OR has not been solved with this policy, but nevertheless it can be a good policy.

So it is interesting to investigate which policy is optimal under which scenarios.

2.3   Operation process

This section, based on [4, Guinet], describes what an operation process looks like and which optimization problems occur during the planning of surgeries. This process helps to understand the problems at the OR better.

The first step of the operation process is a medical examination with a surgeon and an anaesthesiologist to see if an operation is needed and if an operation is possible. If an operation is necessary and possible the next step is to set a hospitalization date for the patient. The date should be eligible for the patient and the surgeons, but there must also be an OR available. When the date has been established the surgeons do not want to change anything about that date anymore, because that would inter alia not be good for the patient satisfaction. Most often the hospitalization date is one day before the intervention. To schedule the intervention of the patient, the physician, nurses, and the operating room have to be planned one or two weeks in advance.

Scheduling a team of nurses, a physician, etc. and planning the patient interventions at the operating room is too complex to solve simultaneously and that is why these problems are solved separately. In the literature the scheduling process is often solved with a linear program under the constraints of fixed working hours.

Planning the interventions at the Operating Rooms is a more complex problem. To see this, let's first look closely at the intervention. At the intervention date, the patient has two procedures. One is the anaesthetic procedure and the other is a surgical procedure. The procedures must be finished within a certain time interval, because every patient has an intervention deadline.

Furthermore it is not easy to give very accurate operating times, because this depends on the patient pathology, which might not be known in advance, and the surgeon's expertise.

When the intervention is finished the patient is brought to the recovery room. The activities at the OR and the recovery rooms must be planned in such a way that it matches with the team of specialists. Furthermore, an intervention can only be planned when there is a free bed at the recovery room, because after an intervention the patient has to go immediately to a bed in the recovery room. So optimizing the whole Operating Room planning is very complex. According to [4, Guinet] it is an NP hard problem, which means that there is not yet an algorithm found, which can solve the problem in polynomial time.

[4, Guinet] gives an exact formulation of the problem and gives a so called Primal-Dual Heuristic, to solve the problem with a solution that is at most α times the optimal solution.

2.4 Performance Measures

In all optimization problems which are studied in the literature of OR planning, the results depend on which performance measures are used to evaluate the quality of the OR. In many studies combinations of different performance measures are used to get an optimal solution. In this case the optimal solution also depends on the weight that is given to the different performance measures, which depends on how important the hospital finds each performance measure. This section gives an overview of the different performance measures that are studied. [1, Cardoen et al] describes eight performance measures which are related to the quality of the OR's: waiting time, throughput, utilization, levelling, makespan, patient deferrals, financial measures and preferences.

2.4.1 Waiting time

The first performance measure we consider is waiting time. Waiting time could be seen as the time that an emergency patient has to wait (emergency waiting time), but also as the time an elective patient has to wait till he/she is helped, because of an emergency arrival (elective waiting time). Waiting time is generally one of the most well known performance measures, because it is one of the biggest problems in health care. Many people complain about the long waiting lists in health care, whereas long emergency waiting times can be dangerous for an emergency patient. Therefore it is not strange that many studies have been carried out on how to minimize the waiting time of patients.

2.4.2 Throughput

The second performance measure we look at is the throughput. This measure is strongly related to waiting time. The relation between those two measures lies in a mathematical law, named Little's Law. Little's Law says that the average number of customers in a stable system is equal to the average rate at which customer arrive multiplied by the average time a customer spends in the system [5, Little]. Here the long term average effective arrival rate is better known as the throughput. Note that the average time a customer spends in the system is the waiting time plus the so called process time, also known as the service time.

The performance measure throughput is a measure that you want to maximize. You want to maximize the number of patients that are treated on a day, because this leads to shorter waiting lists.

2.4.3   Utilization

A third performance measure is utilization. With utilization you have to find a balance between a high and a low utilization. On the one hand you want to maximize the utilization, because then you help the largest number of patients, which increases the throughput and shortens the waiting list. It also gives you high revenues, which is also important for a hospital. But with high utilization you have a small time-buffer to deal with uncertainty, such as an emergency arrival or a longer than planned intervention. This all may lead to overtime, which is very expensive for a hospital. It can also lead to cancellations of surgeries, which is not very good for patient satisfaction. On the other hand it is clear that a low utilization is also not very desirable. So the goal is to find a good balance between high and low utilization.

2.4.4   Levelling

Another measure is the levelling of resources, in particular the occupancies of different resources in the hospital. This measure aims at minimizing the probability that we have a capacity problem when something unexpected happens, like an emergency arrival or a longer surgeon time. To ensure this, we want a smooth occupancy of the resources, thus avoiding peaks at some moment in time. In the next section more about this topic is given.

2.4.5   Makespan

A fifth measure is the makespan. This measure is originating from the industry, where they aim is to minimize the maximum completion time of a machine. In a hospital the goal is to minimize the completion time of the last patient. So you can define the makespan for a OR as the time between the first arrival of a patient and the completion of the last patient.

2.4.6   Patient Deferrals

The sixth measure is patient deferrals or refusals. As indicated in Section 2.4.3, you prefer a high utilization, because that minimizes the waiting time, but you also prefer a low probability of patient deferrals or refusals, which may increase the elective waiting time of other patients. So these measures clearly need some weight to indicate how bad you think a deterioration of one of the measures is.

2.4.7 Financial Measures

The penultimate measure is the financial objective. Reducing the costs is one of the most important measures, because the Operating Room is already very expensive.

2.4.8 Preferences

The last performance measure is the preferences of the different parties. Surgeons and patients may have conflicting preferences. On the first sight it may look that this is not a very important measure, but it is shown that there is a relationship between the efficiency of health care and the schedules that take into account those different preferences [1, Cardoen et al].

2.5 Scheduling of the operations

There are many studies that study the problem in which order it is optimal to assign the operations at the OR. Different studies come with different conclusions, which depend on the performance measures they use to evaluate the schedule.

In [6, Denton, et al] a two-stage stochastic programming is used to find the optimal schedule that minimizes the weighted sum of the expectations of the waiting time, the idle time and tardiness. Tardiness is an alternative measure for makespan and is a measure for the overtime of a schedule. If you say that the quality of the schedule is measured by these three measures, it is optimal to schedule the operations in increasing standard deviation.

[7, Bekele et al] concludes that it is optimal to order the operations in decreasing order of duration. If you schedule the operations in decreasing order you have the lowest chance that you have patient refusals and you have the highest utilization.

Striking enough [8, Ali] concludes the opposite. They say it is better to schedule the operations in increasing order of duration, while they look at the same performance measures.

[9, Chew] investigated all kind of different heuristics and she comes with the following conclusion: If your performance measures are high utilization, overtime and flow, than it is optimal to schedule the operations in decreasing operation time. We talk about flow, when the next operation cannot be finished before the end of the day, so it is cancelled. Thereby the last operation of that day ends before the end of the day. If you want to minimize the waiting time and the number of patient's refusals, you can better schedule the operations in increasing order and increasing standard deviation. For all the heuristics and models about this topic I refer to the BMI paper of Chew [9].

3.   Simulation and assumptions

In this chapter a simulation of the OR is described. In the first section some models from the literature are introduced. In the second section the structure, assumptions and parameter choice of my own simulation model are described.

3.1   Models

I start with the model of [12, Wullink et al], who did their research at the Erasmus MC in Rotterdam. The next model described is from [13, Ferrand et al].

3.1.1   Model Erasmus MC

[12, Wullink et al] investigates which of two policies, dedicated OR and "white spots", is best for the Erasmus MC. They assume they have 12 OR's per day. In their model there is 450 minutes of OR staff available at each OR and each operation can be performed on each OR.

To model the process a discrete-event simulation model is used. They simulate the policies and the days independently from each other. As input for the discrete-event model a schedule with elective cases is used. The schedule is made by a so called first-fit algorithm. This algorithm assigns each surgical case for each surgical department to the first available Operating Room. The result is a schedule for each Operating Room with elective cases that are performed there. The duration of each of the elective cases are lognormal distributed, with a mean based on the historical data from the Erasmus MC. Next they assume that the emergency patients arive according to a Poisson process. Finally it is not clear what they assume about no-shows and abou if the patients arrive on time or not, but I think they just assume that there are no-no shows and that every patient arrives on time.

The data from the Erasmus MC is summarized in Table 1 [12, Wullink et al]:

Table 1 Aggregate descriptive statistics of the OR in Erasmus MC

Description	Number
Number of different surgical procedure types	328
Mean number of elective cases per day	32
Mean case durations (minutes)	142
Standard deviation of the case duration (minutes)	45
Mean number of emergency cases per day	5
Mean emergency case duration (minutes)	126
Standard deviation of the emergency case duration (minutes)	91

It is seen that on average an elective case takes 142 minutes, while an emergency case takes 126 minutes on average. It is also seen that the emergency arrivals occur with a mean of 5 per day. The emergency patients are served on a FCFS (first-come-first-served) basis. So depending which policy you consider, the next patient is served when the dedicated OR is free, or when you consider the "white spots" policy the next patient is served when one of the operation at one of the twelve OR's is ended. Next they assume that there is no delay in starting the emergency cases caused by the unavailability of surgeons and OR staff. Finally, they assume that after an emergency case the schedule of the elective patients is followed again, also if this might result in overtime.

For the simulation they used the sequential procedure to get the right number of simulation runs, which was 780 days.

3.1.2   Model of University Cincinnati

[13, Ferrand et al] also investigates which of the two policies, dedicated OR versus "white spots" is the best. As performance measure they take the emergency waiting time and the hospital-staff overtime. In their model they also investigate what the optimal number of dedicated OR's is.

In their model they assume they have 20 OR's and that an elective patient is surged in one of the OR's. So every elective patient can be surged in each OR. Furthermore, they assume that every patient can leave the operating room after the surgery and that an operation day has 8 hours, with possible overtime.

They also assume that at the beginning of the day the OR is empty and idle. In their model they took the schedule of elective patients as input for the model. They assume that the elective patients arrive in a batch within a fixed time interval, with the first batch at time zero. Furthermore they assume that there are no no-shows and that patients arrive on schedule. To do a fair comparison between the two policies they fix the number of elective patients that are scheduled. Finally, they assume that the emergency cases arrive according to a Poisson process and the operation time is lognormally distributed.

This model uses historical data to get a good estimation of the arrival rate of the emergency patients and operation time. Based on the historical data they schedule 75 elective surgeries per day. From the historical data they assume they have on average 12 emergencies a day, so per hour there arrive on average 1.5 emergency patients.

Finally, they assume that the operation time for elective patients is 93 minutes and for emergency cases 125 minutes. Because they had no information of the variance of the operating times, they use the same variance coefficient as [12, Wullink et al].

To find the minimum number of replications needed to get suitable results, they consider the half width of the confidence interval. They found that they need at least 400 replications to get suitable results.

3.2   Simulation model

In this section the structure, assumptions and parameter choices of my own simulation model are described. We start with the structure and then the assumptions are described.

3.2.1   Structure

In this model the performance of the three policies (the "dedicated OR", "white spots" or a mix of both) is investigated. The performance measures are the emergency waiting time, average overtime of the OR's, and the utilization.

In my model different number of OR's are simulated (all 5000 times). In the basis scenario of this thesis we have consider 5, 10, 15, 20 and 30 number of OR's. This way you can see if the optimal policy depends on the number of OR's

The input of my model is an elective schedule

3.2.2   Assumptions

In the basis scenario the elective schedule is assumed to be symmetric, i.e. all the operations at each OR have the same expected operating time. The mean of the operating time of an elective case depends in this basis scenario on the number of OR's. The mean operating time is calculated by dividing 480 by the total number of OR's we have. So the mean of the operating time decreases when the number of OR's increases. This is done to ensure that in the "white spots" policy every OR reserves the same expected time for emergency cases.

In the "white spots" policy emergency patients are operated on FCFS basis at the first OR that becomes available. The rest of the elective schedule is followed again when the emergency patient is finished, also if this results in overtime. At the dedicated OR policy the emergency patient is operated at the first dedicated OR that is free. In the mixed policy the emergency patients are served at the first OR which is free.

It is generally assumed that the arrivals of emergency patients occur according to a Poisson process with parameter λ, which means that the time between successive arrivals is exponentially distributed with mean λ^{-1}. The popularity of this assumption stems from the fact that the exponential distribution is so called memoryless. This means that for the analysis you do not need to know what happened before the time you looked at the system, only the current state of the system is enough. Another important motivation for this assumption is that when you have a large population, where each person has a small chance of generating a request for the server, in our case for being an emergency patient, then when the size of the population goes to infinity the number of requests is Poisson distributed. So a Poisson distribution can be used to model the arrival rate when you have a

large population who can independently generate a request for your service [14, Koole], which is the case in our situation.

Another parameter involved in the simulation is the operating time. For mathematical convenience it is often assumed that the service time is exponentially distributed. In most of the systems this is also quite reasonable, but in health care it is not. [11, Strum et al] did a research with data from a large hospital to see which distribution fits the data of the operation time best. With the help of the Shapiro-Wilk test, they considered which distribution fits the data the best. They conclude that the lognormal distribution fits the data best.

Figure 2 show that the lognormal distribution is indeed the best distribution for this data:
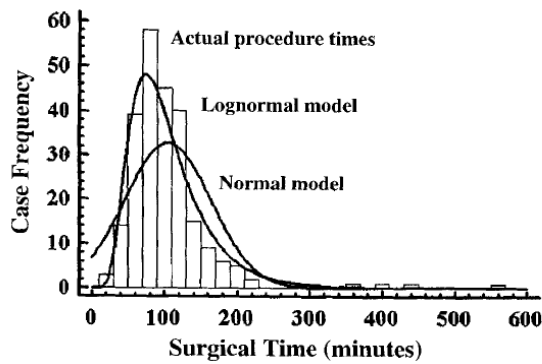
Figure 2: Empirical data with (log)normal distribution [11, Strum et al]

3.2.3   Parameter Choice

Table 2 shows the expected operating time for the different number of OR's in the basis scenario:

Table 2: Mean and standard deviation per OR in the basis scenario

number OR's	mean Elective (minutes)	std Elective(minutes)
5	96	30
10	48	15
15	32	10
20	24	7
30	16	5

In this basis scenario emergency patients arrive with a mean inter arrival time of 96 minutes and are operated with a mean of 126 minutes [12, Wullink et al].

4.   Results

In this chapter the result of the different methods are given. We start with the model of the Erasmus MC, then we consider the model of Cincinnati and finally we show the results of the model I made.

4.1   Model Erasmus MC

Table 3 shows the results of the Erasmus MC model [12, Wullink et al]. In Table 3 Policy 1 is the policy with the dedicated OR and Policy 2 the policy with "white spots". It is seen that Policy 2 is better at all the in chapter 3.1.1 predefined criterions (mean number of OR's was not a predefined criteria). Policy 2 has a lower total overtime (8.4 hours versus 10.6 hours), a lower emergency waiting time (8 minutes versus 74 minutes) and a higher utilization (77% versus 74%).

Table 3: Results Erasmus MC model for both policies

Emergency Policy	Policy 1	Policy 2
Total overtime per day (hours)	10.6	8.4
Mean number of OR's with overtime per day	3.6	3.8
Mean emergency patient's waiting time (minutes)	74 (+/-4.4)	8 (+/- 0.5)
OR utilization (%)	74	77

4.2   Model Cincinnati

Table 4 shows the results of the average and maximum overtime of the Cincinnati model against the number of dedicated OR's [13, Ferrand et al]. The overtime is, in this case, overtime caused by the elective schedule and overtime caused by emergency patients. It is seen that the average overtime is minimized with 5 dedicated OR's. So apparently it is optimal to have 5 dedicated OR's and 15 elective OR's. Then you have the optimal combination of not too much overtime in the dedicated OR and not too much overtime in the elective OR's.

Table 4: Overtime for Dedicated OR policy for different numbers of Dedicated OR's

Number of Rooms Dedicated to Emergency	Average number of overtime patients	Average overtime	Maximum overtime
7	19	78	659
6	15	70	659
5	12	58	659
4	11	62	659
3	11	79	703

Table 5 shows the results of the waiting time for the same numbers of dedicated OR's [13, Ferrand et al]. It is seen that you have the smallest waiting time with 5 dedicated OR's. The average waiting time of an elective patient with 3 dedicated OR's is a little less than with 5 dedicated OR's, but at the same time the average emergency waiting time is a lot smaller with 5 dedicated OR's than with 3 dedicated OR's. So the waiting time is minimized with 5 dedicated OR's.

Table 5: Waiting time for Dedicated OR policy for different numbers of Dedicated OR's

Number of Rooms Dedicated to Emergency	Elective (waiting more than 30 min.) Average Number	Elective (waiting more than 30 min) Average Wait Time	Emergency (waiting more than 30 min.) Average Number	Emergency (waiting more than 30 min) Average Wait Time
7	38	100	0.11	2
6	29	88	0.33	6
5	19	62	1	16
4	17	62	2	39
3	15	60	5	82

Table 6 and 7 show the results of the different policies on the performance measures waiting time, overtime and utilization [13, Ferrand et al]. Note that the emergency waiting time is here the waiting time longer than 30 minutes. So an average emergency waiting time of 0.28 is in fact an average emergency waiting time of 30.28 minutes. In these tables the Flexible-No emergency policy is the situation when there is no emergency at all. The Flexible policy is the "white spots" policy and the Focused policy is the Dedicated OR policy. It is seen that when you consider the average elective waiting time the Dedicated OR policy is better than the "white spots" policy, but when you consider the average emergency waiting time the "white spots" policy is better. Table 7 shows that average overtime is lower with the Dedicated OR policy than with the "white spots" policy. The Dedicated OR policy is also better when you look at the utilization.

Table 6: Different polices with performance measure Waiting Time

Policy considered	Average Elective Wait	Average Emergency Wait	Maximum Elective Wait	Maximum Emergency Wait
Flexible – No Emergency	8	NA	220	NA
Flexible	27	0.28	776	22
Focused (5-15)	20	4.76	272	192

Table 7: Different polices with performance measure Overtime and Utilization

Policy considered	Average Number of Overtime Patients	Average Overtime	Maximum Overtime	Room Utilization (min,max)
Flexible - No Emergency	4	30	215	(0.58, 0.77)
Flexible	12	78	717	(0.61, 0.91)
Focused (5-15)	12	58	659	(0.24, 0.75) Emergency Room (0.91,0.93) Elective Room

4.3   Model Freerk

Table 8 shows for the basis scenario the average emergency waiting time for the three policies for the different number of OR's, with their confidence intervals.

Table 8: Waiting Time for the different policies

Policy	Number OR's	Average Waiting Time	CI Waiting Time
White Spots	5	71.54	(69.54, 73.54)
Dedicated OR	5	143.73	(135.15, 152.31)
Mix	5	24.65	(23.343 25.95)
White Spots	10	20.05	(19.59, 20.52)
Dedicated OR	10	145.61	(136.91, 154.32)
Mix	10	5.28	(5.02, 5.54)
White Spots	15	9.56	(9.34, 9.77)
Dedicated OR	15	144.22	(183.08, 207.21)
Mix	15	2.29	(2.18, 2.39)
White Spots	20	5.45	(5.32, 5.57)
Dedicated OR	20	147.43	(138.51, 156.34)
Mix	20	1.24	(1.18, 1.29)
White Spots	30	2.54	(2.48, 2.60)
Dedicated OR	30	150.89	(141.78, 160.00)
Mix	30	0.54	(0.53, 0.57)

It is clear that the mixed policy has the lowest average waiting time in all cases. The "white spots" method also has a low average waiting time. The dedicated OR has in all cases the highest waiting time, but the difference with the other policies becomes smaller when the number of OR's decreases. Another thing that is seen is that the average waiting time of the "white spots" and the mix policy decreases when the number of OR's increases. This can be explained by noting that in this model the average elective operating time decreases when the number of OR's increases, because the average elective operating time was 480 minutes divided by the number of OR's. So increase of the number OR's, reduces the average elective operating time, which will reduce the average emergency waiting time. A second reason to explain that the waiting time of the "white spots" and the mix policy decreases when the number of OR's increases, is by noting that the chance that an emergency patient has to wait is lower when you have more OR's, which will result in a lower average waiting time. Finally it is seen that the number of elective OR's does not affect the waiting time of the dedicated OR policy. The different results for the different number of OR's by the dedicated OR policy is due to randomness in the simulation model.

Table 9 shows the average overtime and the utilization of all the three policies. Utilization is the percentage of the total OR time (including any overtime) that an OR is "busy". It is seen that the less OR's you have, the better the "white spots" policy becomes. When you have 5 or 10 OR's the "white spots" method is even the best policy to use, when considering overtime and utilization. When you have 20 or more OR's the dedicated OR policy is the best.

Table 9: Overtime and utilization for the different policies

Policy	Number OR's	Total Overtime	CI Overtime	Mean Utilization	CI Utilization
White Spots	5	176.14	(170.92, 181.36)	0.8010	(0.7983, 0.8037)
Dedicated OR	5	248.98	(243.03, 254.93)	0.7882	(0.7858, 0.7906)
Mix	5	270.95	(264.90, 277.00)	0.7812	(0.7790, 0.7835)
White Spots	10	282.22	(275.92, 288.51)	0.8755	(0.8743, 0.8766)
Dedicated OR	10	311.88	(305.94, 317.83)	0.8750	(0.8737, 0.8762)
Mix	10	346.32	(340.13, 352.50)	0.8690	(0.8679, 0.8701)
White Spots	15	373.53	(366.17, 380.89)	0.9083	(0.9077, 0.9090)
Dedicated OR	15	378.72	(372.57, 384.88)	0.9107	(0.9099, 0.9115)
Mix	15	421.17	(414.63, 427.72)	0.9056	0.9049, 0.9063)
White Spots	20	428.29	(420.45, 436.13)	0.9242	(0.9237, 0.9247)
Dedicated OR	20	412.89	(406.59, 419.20)	0.9278	(0.9272, 0.9285)
Mix	20	457.09	(450.38, 463.90)	0.9237	(0.9232, 0.9243)
White Spots	30	502.83	(494.64, 511.03)	0.9402	(0.9399, 0.9405)
Dedicated OR	30	452.28	(445.96, 458.60)	0.9452	(0.9448, 0.9456)
Mix	30	499.29	(492.58, 506.01)	0.9422	(0.9418, 0.9426)

Table 10 shows what happens when the mean of the operating time is increased. The mean operating time is now 160 minutes and the standard deviation is 50 minutes. For the white spots policy this means that the elective schedule is not symmetric anymore. Now we have 6 OR's with 2 operations and the other OR's have 3 operations. So the "white spots" are now localized at the 3 OR's who have now only 2 operations.

Table 10 shows what happens with the average emergency time under this new situation. It is seen that the average waiting time of the "white spots" and the mix policy has been increased. This can be explained by the fact that the mean operation time has been increased. So when an emergency patient arrives it will take longer on average till an elective patient is finished in one of the OR's. Although the waiting time of the "white spots" and mix policy has been increased, it is still lower than the average waiting time of the Dedicated OR policy. The waiting time of the Dedicated OR did not change, because this policy does not depends on the elective operation time. Due to randomness of my simulation model you do not get exactly the same results as in Table 8. The waiting time of the "white spots" and the mix policy still decreases when the number of elective OR's increases, but now the only reason for this is that the chance that an emergency patient has to wait is lower when you have more OR's, which will result in a lower average waiting time.

Table 10: Waiting Time for the different policies under the new situation

Policy	Number OR's	Average Waiting Time	CI Waiting Time
White Spots	10	87.69	(85.32, 90.06)
Dedicated OR	10	146.25	(137.45, 155.05)
Mix	10	14.98	(14.14, 15.83)
White Spots	20	57.93	(56.25, 59.61)
Dedicated OR	20	145.04	(136.74, 153.33)
Mix	20	7.50	(7.07, 7.94)
White Spots	30	50.18	(48.66, 51.70)
Dedicated OR	30	148.38	(139.78, 156.98)
Mix	30	5.14	(4.79, 5.49)

Table 11 shows the overtime and the utilization for the different policies in the new situation. It is seen that the overtime is higher and the utilization is lower in the new situation. The higher overtime can be explained by the fact that the standard deviation of the elective operation time is higher in this situation than in the original situation. The lower utilization can be explained by noting that in this scenario you have some OR's that are less fully planned, which result in a low utilization at those OR's.

Table 11: Overtime and utilization for the different policies under the new situation

Policy	Number OR's	Total Overtime	CI Overtime	Mean Utilization	CI Utilization
White Spots	10	400.27	(393.23, 407.31)	0.8596	(0.8582, 0.8610)
Dedicated OR	10	451.69	(444.53, 458.85)	0.8560	(0.8547, 0.8574)
Mix	10	462.36	(455.23, 469.50)	0.8542	(0.8529, 0.8555
White Spots	20	787.59	(778.81, 796.37)	0.8940	(0.8932, 0.8948)
Dedicated OR	20	805.24	(796.63, 813.85)	0.8946	(0.8938, 0.8954)
Mix	20	816.04	(807.50, 824.58)	0.8936	(0.8929, 0.8944)
White Spots	30	1158.83	(1148.34, 1169.31)	0.9067	(0.9061, 0.9073)
Dedicated OR	30	1162.04	(1151.83, 1172.24)	0.9079	(0.9073, 0.9085)
Mix	30	1170.25	(1160.20, 1180.30)	0.9074	(0.9068, 0.9080)

In the next tables we consider another situation. Now we have a mixture of OR's with short operation times and OR's with long operation times. Only a situation with many OR's and few OR's is considered. The situation with few OR's has 10 OR's and 52 operations in total. In the "white spots" policy we now have 6 OR's with 2 long operations (mean operation time 160 minutes) and 4 OR's with 10 short operations (mean operation time 48 minutes). In the other 2 policies we have 4 OR's with long operations and 4 OR's with short operations (and 2 dedicated OR's). The situation with many OR's has 20 OR's and 110 operations in total. In this case we have 12 OR's with 2 operations (mean operating time 160 minutes) and 8 OR's with 10 operations (mean operating time 48 minutes)

with the "white spots" policy. By the other 2 policies we have 10 OR's with long and 8 OR's with short operations.

Table 12 shows the average waiting time of the policies for the two different situations. It is seen that the average waiting time is a little bit higher than in the original case. That can be explained by the same reason mentioned earlier that longer operation times in some OR's increases the time till an elective patient is finished in one of the OR's, which increases the average emergency waiting time. It is also seen that the average waiting time is much lower than in the situation with only long operations. This can be explained by the fact that you have less long operation is this case, which reduces the average emergency waiting time.

Table 12: Waiting Time for the different policies

Policy	Number OR's	Average Waiting Time	CI Waiting Time
White Spots	10	27.43	(26.71, 28.15)
Dedicated OR	10	143.34	(134.89, 151.80)
Mix	10	7.23	(6.88, 7.59)
White Spots	20	15.53	(15.10, 15.96)
Dededicated OR	20	143.68	(135.10, 152.26)
Mix	20	3.32	(3.15, 3.49)

In table 13 you see the overtime and utilization in this situation. It is seen that the overtime increased in comparison with the original situation. This has probably to do with the fact that we have some OR's that have a higher standard deviation in this situation. A striking result is that the "white spots" policy with 10 OR's has a higher overtime than in the situation with only long operations. This has probably to do with the fact that in this situation most of the emergency patients are operated at the OR with short operation time. The chance that an elective operation with a short operation time is finished earlier than an elective operation with long operation times is very high. So the emergency patients are more often operated at the OR's with short operating times. This causes much overtime at those OR's.

Table 13: Overtime and utilization for the different policies

Policy	Number OR's	Total Overtime	CI Overtime	Mean Utilization	CI Utilization
White Spots	10	465.72	(458.3463, 473.1022)	0.8562	(0.8550, 0.8575)
Dedicated OR	10	416.96	(410.3451, 423.5720)	0.8690	(0.8677, 0.8703)
Mix	10	446.28	(439.4946, 453.0740)	0.8640	(0.8628, 0.8652)
White Spots	20	728.15	(719.5582, 736.7332)	0.8978	(0.8971, 0.8985)
Dedicated OR	20	672.65	(664.7128, 680.5932)	0.9047	(0.9039, 0.9054)
Mix	20	695.36	(687.3912, 703.3265)	0.9026	(0.9020, 0.9033)

In the next tables we return to the original situation with a symmetric elective schedule, but now the arrival rate of the emergency patients and the number of Dedicated OR's is changed to see how this influences the results. We double and halve the mean interarrival time. When we double the interarrival times we halve the number of dedicated OR's. When we halve the interarrival time we double the number of Dedicated OR's. In the "white spots" policy more dedicated OR's means that we reserve more time for emergency patients. So the "white spots" are bigger with more dedicated OR's.

In table 14 the performance measures are changed a little bit. We now look to the average emergency waiting time per patient instead of the average total emergency waiting time. This is done, because in this case the total emergency waiting time is not very interesting to look at. Only a situation with many OR's and a situation with less OR's is considered. It is seen that for all the policies the average waiting time per patient decreases when the interarrival times decreases and the number of dedicated OR's increases. Apparently the number of Dedicated OR's has more influence on the waiting time then the increase of emergency patients.

Table 14: Waiting Time for the different policies when changing the arrival rate

Policy	Number Elective OR's	Dedicated OR's	Emergency	Average Waiting Time per patient	CI Waiting Time
White Spots	8	1	192	4.53	(4.39, 4.67)
Dedicated OR	8	1	192	71.62	(67.26, 75.98)
Mix	8	1	192	1.68	(1.59, 1.77)
White Spots	8	2	96	4.01	(3.92, 4.10)
Dedicated OR	8	2	96	29.12	(27.38, 30.94)
Mix	8	2	96	1.06	(1.00, 1.12)
White Spots	8	4	48	3.22	(3.15, 3.29)
Dedicated OR	8	4	48	10.77	(10.84, 11.44)
Mix	8	4	48	0.60	(0.57, 0.63)
White Spots	18	1	192	1.18	(1.15, 1.21)
Dedicated OR	18	1	192	68.51	(64.72, 72.54)
Mix	18	1	192	0.39	(0.16, 0.62)
White Spots	18	2	96	1.09	(1.06, 1.12)
Dedicated OR	18	2	96	29.49	(27.70, 31.27)
Mix	18	2	96	0.25	(0.24, 0.26)
White Spots	18	4	48	1.09	(1.07, 1.11)
Dedicated OR	18	4	48	10.89	(10.20, 11.59)
Mix	18	4	48	0.14	(0.135, 0.148)

Table 15 shows the overtime per OR and the utilization for different interarrival times. So again the performance measures are changed a little bit. Instead of the total overtime, we now look to the overtime per OR. It is seen that for all three policies the overtime per OR increases when the number of emergency patients and the number of dedicated OR's increases. However there is a larger increase with 18 OR's and 4 dedicated OR's, which is a striking result. For all the policies holds that the increase of the number of emergency patients has more influence on the over time, then the increase of dedicated OR's.

By all the policies the utilization decreases when the number of patients and the number of dedicated OR's increases. So here holds that the increase of dedicated OR's affects the utilization more than the increase of the number of emergency patients.

Table 15: Overtime and utilization for the different policies when changing the arrival rate

Policy	Number Elective OR's	Dedicated OR's	Emergency	Total Overtime per OR	CI Overtime	Mean Utilization	CI utilization
White Spots	8	1	192	24.48	(23.88, 25.08)	0.9121	(0.9113, 0.9130)
Dedicated OR	8	1	192	28.38	(27.81, 28.94)	0.9145	(0.9136, 0.9155)
Mix	8	1	192	30.74	(30.16, 31.32)	0.9103	(0.9094, 0.9112)
White Spots	8	2	96	28.22	(27.59, 28.85)	0.8755	(0.8743, 0.8766)
Dedicated OR	8	2	96	31.19	(30.59, 31.78)	0.8750	(0.8737, 0.8762)
Mix	8	2	96	34.63	(34.01, 35.25)	0.8690	(0.8679, 0.8701)
White Spots	8	4	48	31.59	(30.95, 32.23)	0.8268	(0.8252, 0.8283)
Dedicated OR	8	4	48	35.61	(34.97, 36.65)	0.8213	(0.8197, 0.8229)
Mix	8	4	48	39.31	(38.64, 39.98)	0.8152	(0.8138, 0.8166)
White Spots	18	1	192	17.17	(16.85, 17.49)	0.9478	(0.9475, 0.9482)
Dedicated OR	18	1	192	18.40	(18.13, 18.67)	0.9498	(0.9494, 0.9503)
Mix	18	1	192	19.86	(19.58, 20.13)	0.9470	(0.9466, 0.9475)
White Spots	18	2	96	21.41	(42.04, 43.61)	0.9242	(0.9237, 0.9247)
Dedicated OR	18	2	96	20.64	(40.66, 41.92)	0.9278	(0.9272, 0.9285)
Mix	18	2	96	22.85	(45.04, 46.39)	0.9237	(0.9232, 0.9243)
White Spots	18	4	48	30.54	(30.10, 30.98)	0.8761	(0.8750, 0.8773)
Dedicated OR	18	4	48	24.17	(23.83, 23.51)	0.8925	(0.8917, 0.8934)
Mix	18	4	48	26.77	(26.40, 27.10)	0.8879	(0.8871, 0.8886)

In the following tables only the number of Dedicated OR's is changed to see how this affects the results. For the elective schedule we use the schedule of the basis scenario. The results with 2 dedicated OR's is copied from tables 8 and 9. Table 16 shows that the average waiting time decreases when the number of Dedicated OR's increases. This can be explained by the reason that

when you have more OR's, the smaller the chance is that an emergency patient has to wait. The average waiting time of the "white spots" policy decrease when the number of dedicated OR's increase, because you have bigger "white spots" with more Dedicated OR's. So the original elective schedule is then spread over more OR's, which will reduce the waiting time.

Table 16: Average waiting time for the different policies when we change the number of Dedicated OR's.

Policy	Number Elective OR's	Dedicated OR's	Average Waiting Time	CI Waiting Time
White Spots	8	1	24.50	(23.96, 25.04)
Dedicated OR	8	1	864.67	(832.32 897.02)
Mix	8	1	13.69	(13.28, 14.10)
White Spots	8	2	20.05	(19.59, 20.52)
Dedicated OR	8	2	145.61	(136.91, 154.32)
Mix	8	2	5.28	(5.02, 5.54)
White Spots	8	5	10.76	(10.43, 11.09)
Dedicated OR	8	5	0.87	(0.60, 1.15)
Mix	8	5	0.12	(0.08 0.16)
White Spots	18	1	6.10	(5.96, 6.23)
Dedicated OR	18	1	846.66	(814.94, 878.38)
Mix	18	1	3.00	(2.91, 3.08)
White Spots	18	2	5.45	(5.32, 5.57)
Dedicated OR	18	2	147.43	(138.51, 156.34)
Mix	18	2	1.24	(1.18, 1.29)
White Spots	18	5	4.12	(4.01, 4.22)
Dedicated OR	18	5	0.73	(0.50, 0.96)
Mix	18	5	0.02	(0.016, 0.030)

Table 17 shows the overtime and the utilization when the number of Dedicated OR's is changed. It is seen that the overtime and the utilization decreases when the number of the Dedicated OR's increases. This can be explained by the fact that when there are more Dedicated OR's you have more capacity to handle the emergency patients, which decreases the overtime and also decrease the utilization of the OR's.

Table 17: Overtime and utilization for the different policies when we change the number of Dedicated OR's

Policy	Number Elective OR's	Emergency OR's	Total Overtime	CI Overtime	Mean Utilization	CI Utilization
White Spots	8	1	420.44	(412.62, 428.26)	0.9387	(0.9379, 0.9396)
Dedicated OR	8	1	451.29	(442.97, 459.61)	0.9349	(0.9341, 0.9358)
Mix	8	1	474.73	(466.81, 482.65)	0.9302	(0.9294, 0.9310)
White Spots	8	2	282.22	(275.92, 288.51)	0.8755	(0.8743, 0.8766)
Dedicated OR	8	2	311.88	(305.94, 317.83)	0.8750	(0.8737, 0.8762)
Mix	8	2	346.32	(340.13, 352.50)	0.8690	(0.8679, 0.8701)
White Spots	8	5	169.92	(164.93, 174.91)	0.6938	(0.6926, 0.6951)
Dedicated OR	8	5	275.62	(270.77, 280.48)	0.7486	(0.7467, 0.7505)
Mix	8	5	277.04	(272.15, 281.92)	0.7484	(0.7465, 0.7503)
White Spots	18	1	569.18	(560.66 577.70)	0.9563	(0.9559, 0.9567)
Dedicated OR	18	1	541.57	(533.40, 549.74)	0.9594	(0.9590, 0.9598)
Mix	18	1	580.79	(572.89, 588.70)	0.9555	(0.9551, 0.9559)
White Spots	18	2	428.29	(420.45, 436.13)	0.9242	(0.9237, 0.9247)
Dedicated OR	18	2	412.89	(406.59, 419.20)	0.9278	(0.9272, 0.9285)
Mix	18	2	457.09	(450.38, 463.90)	0.9237	(0.9232, 0.9243)
White Spots	18	5	265.29	(258.91, 271.68)	0.8203	(0.8197, 0.8209)
Dedicated OR	18	5	367.47	(362.49, 372.44)	0.8478	(0.8467, 0.8489)
Mix	18	5	369.04	(364.03, 374.05)	0.8477	(0.8466, 0.8487)

5.   Conclusion

The main question in this thesis was how to deal with emergency patients? Is it better to have a separate dedicated OR, or to reserve some capacity at all the different Operating Rooms or whether a mix of the two is optimal? Furthermore the question was whether the results depend on which performance measure you want to optimize or on the number of OR's you have?

The different studies come to different conclusions. [12, Wullink et al] comes to the conclusion that you should use the "white spots" method. On the other hand [13, Ferrand et al] comes to the conclusion that it is better to use dedicated OR's for emergency cases. They even say that it is optimal to use 5 dedicated OR's.

The best policy depends on the performance measure you think is the most important. If you want to minimize the waiting time for an emergency patient, you definitely should use the mixed policy in all the cases. The mixed policy is the policy with a dedicated OR, but where you also allow emergency patients on the elective OR's. On the other hand if overtime and utilization is most important, you should use a "dedicated OR" when you have 20 or more OR's, otherwise the "white spots" policy is the best.

If you find all those three measures equally important the best policy is the "white spots" policy. It has a slightly worse waiting time than the mixed policy, but has a slightly better overtime and utilization than the mixed policy. When you have 20 or more OR's the dedicated OR policy has in general a slightly better overtime and utilization than the "white spots", but the "white spots" policy has a much better average waiting time. When the number OR's is less than 20, then the "white spots" policy has in general a better average waiting time, a better overtime and also a better utilization when the number of OR's is equal or lower than 10.

As I mentioned in my paper there are many more performance measures to look at. In all three models those other performance measures are not considered, but might also be important to take into consideration and may result in different results. In further research it would be interesting to see if the optimal policy changes when you look to other performance measures.

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