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SIMULATION FRAMEWORK TO ANALYZE OPERATING ROOM RELEASE MECHANISMS

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ABSTRACT

The block time (BT) schedule, which allocates Operating Rooms (ORs) to surgical specialties, causes inflexibility for scheduling outside the BT, which negatively affects new surgeons, new specialties, and specialties that have fluctuation in the number of surgeries. For this inflexibility, we introduce the concept of releasing ORs, and present a generic simulation and evaluation framework that can be used by hospitals to evaluate various release mechanisms. The simulation and evaluation framework is illustrated by a case study at Vanderbilt Medical Center and University (VUMC) in Nashville. The results show that introducing a release policy has benefits in decreasing the number of unscheduled patients and decreasing access time, without affecting the specialties originally assigned to the released rooms.

1 INTRODUCTION

Most hospitals assign Operating Rooms (ORs) to specialties (e.g., Orthopedics, Gynecology) using a Block Time (BT) schedule, where BT can be assigned to a specialty for the whole day or part of the day. This schedule is typically cyclical (e.g., cycles of 1 or 2 weeks). Hospitals want to make best use of their resources, conduct surgeries safely, and above all want to keep patient satisfaction high. Arrival rates of patients vary per specialty and over time. An exact fit between the number of patients and a cyclical division of BT is impossible without generating waiting lists. According to Baugh and Li (2012), when there are enough hospitals around, patients already walk away when the access time is higher than a couple of days. In order to reduce waiting times, specialties will have to go into overtime, even though there might be other specialties that do not have all their BT utilized.

To create more flexibility in the BT schedule, a release mechanism can be introduced. According to Dexter and Macario (2004), releasing a room can be defined as: making allocated but unfilled block time on the short term available to other surgeons or specialties. Releasing a room is a breech with the principal of BT scheduling where a specialty "owns" a block. Releasing the remaining time creates flexibility for specialties that have utilized all of their own BT without having to extend beyond their own BT into overtime. The patients also benefit from this practice since an earlier date for their surgery can be planned.

The motivation for this article is the request by Vanderbilt University and Medical Center (VUMC) to evaluate their current OR scheduling approach, to assess the limitations of the current system, and to propose interventions to improve it. VUMC has a 7 day release program that releases all unscheduled BT of specialties in the coming 7 days to all specialties.

To research, evaluate, and test other approaches for the releasing of ORs, we will use discrete event simulation. In the literature, there has been an increase in articles that describe simulation in healthcare (Fone, Hollinghurst, Temple, Round, Lester, Weightman, Roberts, Coyle, Bevan, and Palmer 2003, Günal and Pidd 2010) and, more specifically, simulation of OR scheduling (Ferrin, Miller, Wininger, and Neuendorf 2004, Lowery and Davis 1999). However, these models cannot easily be adapted towards other hospitals. Simulation model reuse is done infrequently (Robinson, Nance, Paul, Pidd, and Taylor 2004). The objective of this article is (i) to present a generic discrete event simulation (DES) framework to evaluate the scheduling of ORs with a releasing mechanism, and (ii) to apply this simulation framework to the case study of VUMC to provide insight into the effects of various release mechanisms.

In the remainder of this article we subsequently describe the problem (Section 2), the conceptual simulation model (Section 3), and the application of this simulation model to the case of VUMC (Section 4). We end with conclusions in Section 5.

2 PROBLEM DESCRIPTION

To demarcate the scope of our research, we use the framework for health care planning and control (Hans, Houdenhoven, and Hulshof 2011). Our scope is limited to the managerial area "resource capacity planning" and to the hierarchical fields "tactical and offline operational" control, i.e., we concentrate on the tactical and offline operational planning of resources, and therefore exclude the strategic and online operational decisions. On a tactical level we address the so-called operating room release policy, which determines when operating rooms are made available for scheduling elective patients. At the offline operational level we address the assignment of elective surgeries to (released) operating rooms. As our focus is on elective patient planning and scheduling, we leave emergency patients outside of our scope.

Dexter and Macario (2004) discuss when to release OR time based on maximizing efficiency. They describe eight conditions from previous work, which we summarize here. Here, we use the term case to denote a patient that will undergo surgery. Relevant conditions are: (i) allocate time to maximize OR efficiency; (ii) specialties with released BT should still be able to schedule additional cases; (iii) future OR allocations should not be affected by whether the OR is released; (iv) when a specialty has filled all its OR time, but wants to schedule another case, it is beneficial to perform this case in underutilized time of another specialty rather than in overtime, and only release a room if this is the case; and (v) room time should be released based on the expected under utilization on the day of surgery, because of different arrival rates between specialties.

According to Shaneberger (2003), at least four other hospitals in the US have a policy for releasing ORs and the policy differs from the suggestions made by Dexter, Traub, and Macario (2003) in the interview and his articles (Dexter and Epstein 2005, Dexter and Macario 2004, Dexter, Traub, and Macario 2003, Shaneberger 2003). In the literature, two ways to release ORs are discussed: (i) release the room on a certain day before surgery (Shaneberger 2003) and (ii) release the room that is the least utilized, or has the lowest expectation to be utilized when a new case needs to be scheduled outside the BT (Dexter, Traub, and Macario 2003). In this article, we review option (i), releasing ORs on a certain day before surgery, e.g., 7 days before the day of surgery (DoS). When scheduling according to the release policy is applied, there can be a request to schedule a case on a certain day that is pre-arranged with the patient (request day). Relaxing this request day is one of the possibilities, e.g., by scheduling a day sooner or later. These are strategies that can be evaluated in a simulation model and are bounded to the release policy.

In practice, scheduling happens with or without a waiting list, the presence or absence of a waiting list is not influenced by the absence or presence of a release policy, but depends mostly on country "preference" (Dexter, Macario, Traub, Hopwood, and Lubarsky 1999). In the US "Any workday" (Dexter, Traub, and Macario 2003) scheduling is usual, which means that the surgeon or surgeon scheduler, schedules the surgery with the patient in their office. In Europe it is usual that, in the clinic the surgeon determines that the patient needs surgery. The patient is then is placed on a waiting list. Waiting time or access time between countries varies significantly (Dexter, Macario, Traub, Hopwood, and Lubarsky 1999) also due to the strategy taken.

The use or absence of a waiting list has implications for the scheduling policies. To schedule the cases, "on-line bin packaging" (OBP) algorithms can be used (Dexter, Macario, Traub, Hopwood, and Lubarsky

1999). Online here means that the patient is given a surgery date the moment the surgery is requested. Dexter, Macario, Traub, Hopwood, and Lubarsky (1999) describe four possibilities: Next Fit, First Fit, Best Fit or Worst Fit. When making use of a waiting list in the simulation study, Regret Based Random Sampling (RBRS) (Hans, Wullink, van Houdenhoven, and Kazemier 2008) with an extra optimization via Random Exchange Method (REM) can be used to schedule the cases. The combination of a waiting list for elective cases and applying an OBP algorithm for the released cases without a waiting list is also a possibility or vice versa. This would mean that a waiting list is used for the elective patients and that when the rooms are released, the requested cases are planned directly by using the OBP algorithms.

In this paper, we consider the situation where the operating rooms (ORs) for the coming, say, 7 days are called “staged ORs”, and the ORs for all the subsequent days are called elective ORs. Surgeries scheduled in the staged ORs are referred to as staged surgeries, and the other surgeries are referred to as elective surgeries. The surgeon determines whether the patient is operated in the coming 7 days (staged surgery) or thereafter (elective surgery). A different scheduling policy is used for the staged cases than for the elective cases.

To evaluate various scheduling options (for both the elective cases and the staged cases), and various scenarios (maximum capacity, request day and scheduling policies) bounded to staged case scheduling, we use simulation. To evaluate the simulated scenarios, we use the following performance indicators:

- Utilization rate: total time available in the BT schedule divided by the total time required by the cases, including turnaround time.
- Overtime: total surgery time past the official closing time of the OR in the BT, including the cleanup or turnover time after the last surgery.
- Undertime: total non-utilized OR time within regular BT, which is not scheduled with surgeries.
- Access time: time between a request for surgery and the first possibility to schedule the case.
- Number of cases scheduled.
- Number of unscheduled cases: due to resource constraints some surgeries will be unable to accommodate in the schedule.

3 SIMULATION MODELLING

This paper proposes a generic DES framework for the performance evaluation of various ways of OR scheduling. In this model, we incorporate the possibility for a release mechanism. We describe the three main components of our simulation model: entities, resources, and processes. The entities will be represented by the patients that undergo the surgery. They are the moving parts through the simulation model. The resources will be represented by the physical resources in the hospital, e.g., operating rooms, the medical equipment, and medical staff. The processes describe how the entities and the resources are connected and how the patient is scheduled and undergoes the surgery. In the upcoming subsections, we present the individual components of our simulation framework (patients, resources, and processes), after which we present the complete framework.

3.1 Patients

The attributes of the patient determine when and where the patient will be scheduled. The main attributes of the patient are: the arrival process and the surgery type. To attribute a surgery type to a patient, we need to determine the case mix share of the specialty, and the surgery types performed by the specialties. The case mix share is used to determine the number of patients that need to be generated per specialty, and the number of surgery types per specialty is used to determine which surgery type to attribute to the patient. Per surgery type, a procedure time distribution can be generated.

To schedule and simulate the cases, we need the following information: number of cases per week, distribution of case times, turnaround time and arrival rate of the cases (Lowery and Davis 1999). Cases for different specialties have different arrival rates and differ in case time. More details are obtained when the distributions of case times are obtained on procedure level instead of specialty level, this can only be done when enough data is available to fit distributions per case type. For each case, we use the following attributes: ID (to track the case), arrival date and time, requested surgery date, specialty, surgery type of the specialty, surgeon, expected duration (time between wheels in wheels out), real duration, expected turnover time, real turnover time, delay and downtime, and patient type (inpatient or outpatient). Which case is generated, is based on the share the surgery type has within the specialty and which share the specialty has among the total specialties.

3.2 Resources

There are several resources bound to the ORs. We distinguish between: staff, rooms, and equipment. We distinguish three different staff types: anesthesia staff, OR nurses, and the surgeons. We assume that the anesthesiologists and the nursing staff are assigned to the ORs, and the surgeons are bounded to the OR where the surgery of their patient takes place. For the ORs, we assume there is a BT division between the different specialties in the hospital and that the opening hours per day of the week are known. Also limitations of certain OR rooms need to be taken into account. For example, certain surgeries can only take place in a negative pressure OR. This is also tied to the equipment: some ORs have fixed equipment needed for certain surgeries, whereas other equipment can be moved around between ORs.

As input we use the number of hours a surgeon or specialty has certain BT, and the number of blocks a surgeon or specialty has per week (Dexter, Macario, Traub, Hopwood, and Lubarsky 1999, Lowery and Davis 1999). In our case study at VUMC, the BT schedule repeats itself every week; the blocks are allocated per room, per day to a surgeon, and the ORs have different opening hours. The BT schedule also defines which rooms are allowed to be released (see Section 4.1).

3.3 Processes

Figure 1 shows the processes involved from the moment the patient arrives at the hospital to the moment the patient leaves the hospital. The patient initiates the scheduling process by either going to a clinic or to the ER. Next, the physician determines whether the case is urgent or elective. Urgent cases leave the elective scheduling system and are handled in the online operational planning processes, which are excluded from this simulation framework (see Section 2).

To include the release policy, we consider the decision to determine whether the case needs to be scheduled according to the release policy or that the case will be scheduled according to the regular BT scheduling. In Figure 1, we included also the option of using the waiting list. The waiting list can be used either to generate a list for the release policy or for regular elective BT scheduling.

For scheduling with or without waiting list, different strategies can be applied as discussed in Section 2. Also a different scheduling strategy can be used to schedule staged cases or elective cases, represented by the two different processes in Figure 1. The patient thereafter is notified and admitted for surgery according to the schedule. After the surgery is performed, the patient leaves the system, is discharged, or transferred (e.g., ICU and PACU).

The way the processes are organized in the hospital are used as input for the simulation model. Besides the regular processes of scheduling and surgery, we also include downtime and delays since they heavily affect the performance. According to Lowery and Davis (1999), 15-20% downtime is a realistic target in most operating rooms. In our model, the delay can be attributed to the patient or can be generated at the event trigger end task, as shown later on in Figure 2 and Figure 3.

3.4 Events

The simulation is driven by events, such as patient arrival, patient scheduling, surgery, and departure. To simulate the two main different approaches to scheduling, the situation with and without a waiting list, we present two versions of the model. In the two conceptual simulation models we made the trade-off

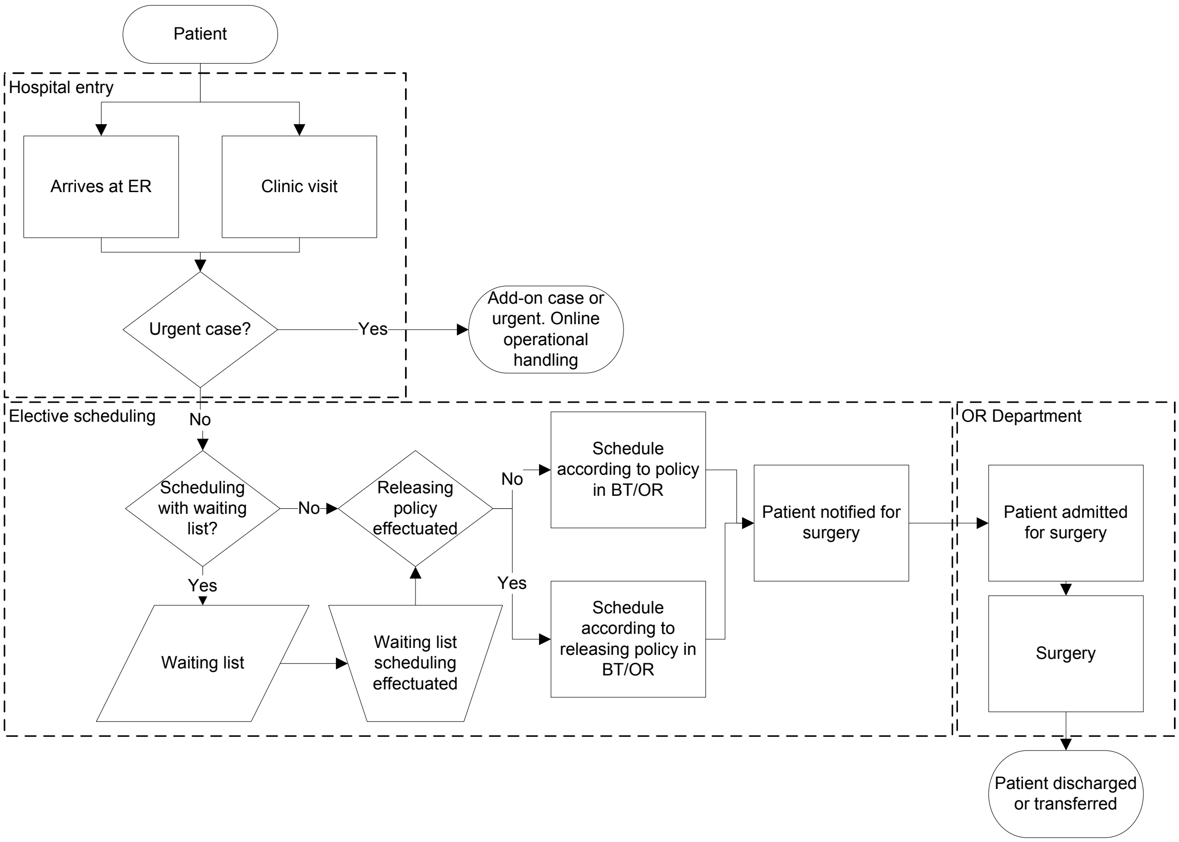

Figure 1: Processes for scheduling elective patients

between level of detail and generalizability. The conceptual simulation model is designed to support the comparison of various strategies for releasing rooms.

3.4.1 Conceptual Model with Waiting List

Following the framework from Mes and Bruens (2012), we identify four events that trigger processes or decisions: New Hour, New Patient, End Task and End Delay (Figure 2). The processes in Figure 2 are connected with solid lines; dotted lines are used to indicate information flow between processes and databases.

After a new hour has started, the event 'New Hour' checks whether the release policy is active, and ask whether it is time to schedule the elective waiting list or the staged waiting list. This event is ended when this decision is answered with 'No'. A waiting list can be scheduled, e.g., at the end of the day or at the start of a day. Every hour, the event New Hour checks whether it is time to schedule the elective waiting list and staged waiting list. When it is time to schedule the waiting list, the process 'scheduling elective patients into the schedule' or the process 'scheduling the staged cases into the schedule' is put into effect. This process saves the schedule, erases the scheduled patient from the waiting lists, and might consult the BT schedule to create the appropriate schedule.

The event New Patient triggers the process that creates attributes to this patient (see Section 3.1). The decision whether the release policy is active for this patient determines whether the patient is placed on the elective waiting list or the staged waiting list, and End event is called to close this process.

The End Task event is triggered every time the OR finishes a case. It determines whether a delay is required. It is critical that this delay or downtime is modeled accurately since it influences the outcomes

(Lowery and Davis 1999). When a delay is required, this delay is started, after which the End Delay event is triggered. When no delay is required, the process of calling the next patient from the schedule is initiated.

The End Delay event in Figure 2 triggers also the process of calling the next patient from the schedule. Using common random numbers, a time from the distribution is drawn that will be used to simulate the patient/case. The case is started and the End Task is called. The patient leaves the system when all its tasks are finished.

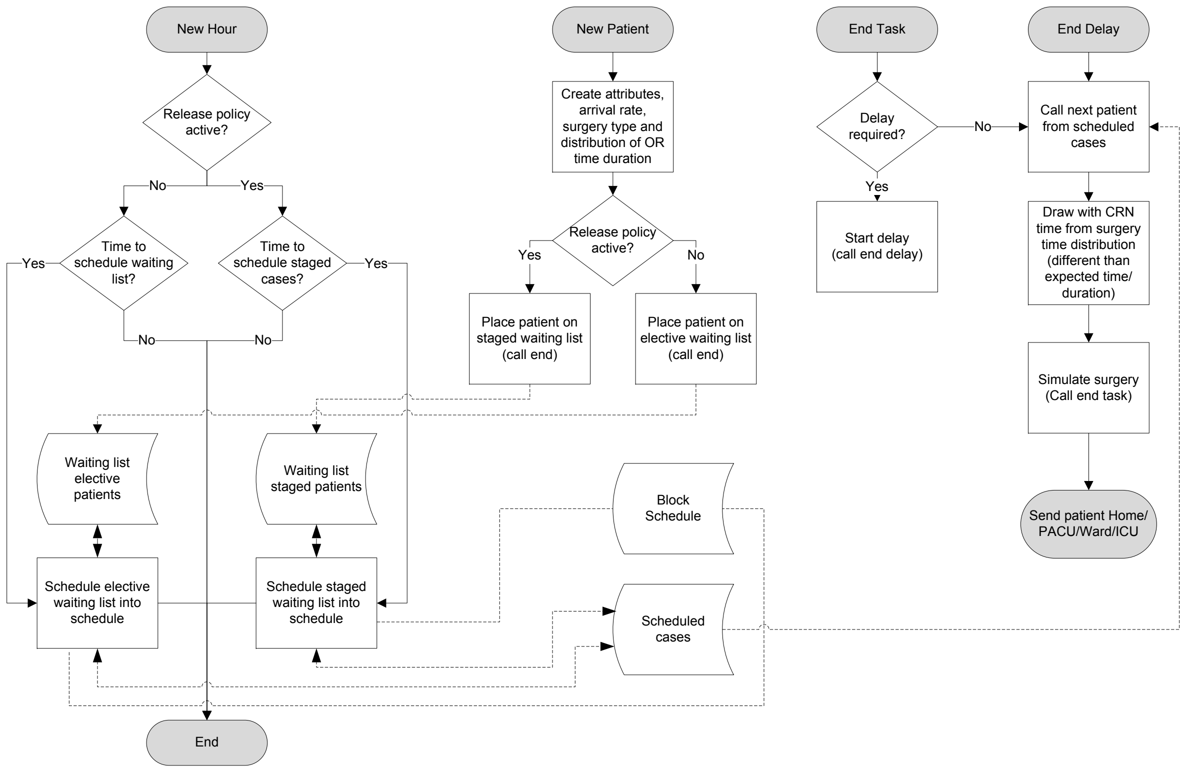

Figure 2: Scheduling with a waiting list

3.4.2 Conceptual Model without Waiting List

The conceptual model without waiting list, as shown in Figure 3, differs from the model with waiting list (Figure 2), in the process that takes place after the event New Hour or New Patient is triggered. When the decision whether the release policy is active is triggered at the event of a New Patient, the patient is scheduled directly into the schedule, and is stored in the table 'scheduled cases', it omits the waiting list as shown in Figure 2. The event new hour in Figure 3 triggers the decision whether the current schedule needs to be optimized.

4 A CASE STUDY

To illustrate the applicability of our simulation and evaluation framework, we perform a case study in VUMC. In the case study, we show that the input parameters and processes described are sufficient to simulate the OR department of this hospital. We first present the experimental settings (Section 4.1) after which we present the experimental results (Section 4.2).

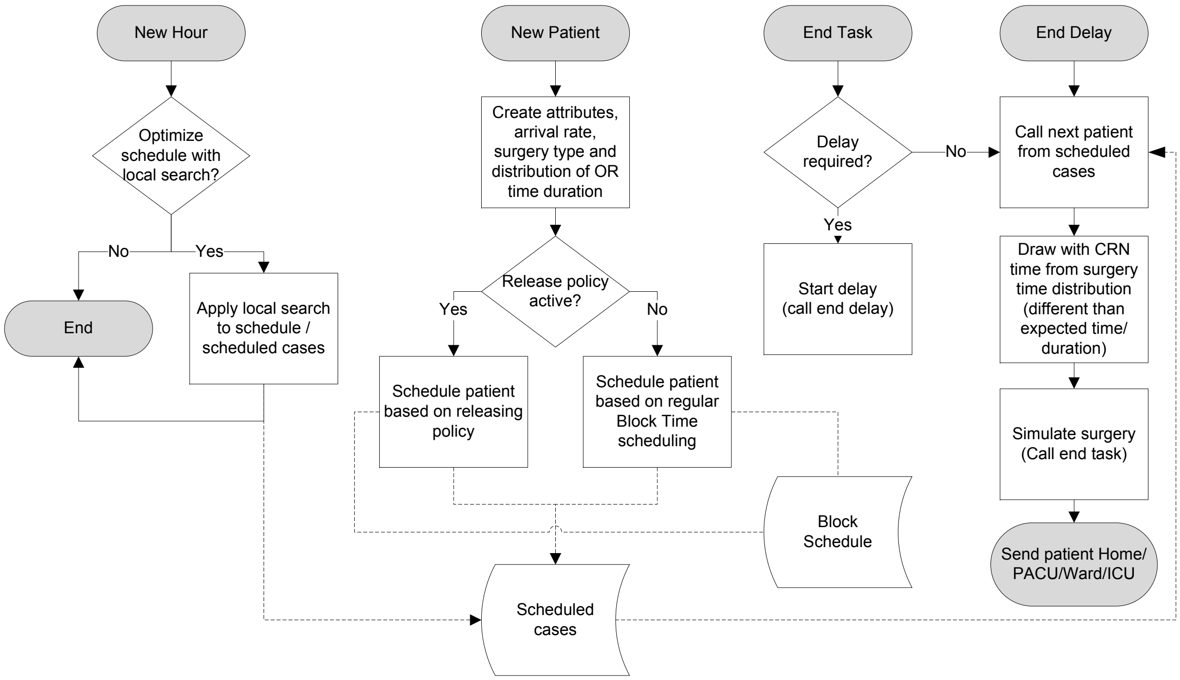

Figure 3: Scheduling without a waiting list

4.1 Experimental Settings

In VUMC, the elective scheduling is done according to the 'Any Workday' scheduling (Dexter, Traub, and Macario 2003) principle. The patient leaves the clinic with a date and time for surgery. VUMC is releasing the rooms 7 days ahead of the DoS. Releasing a room means blocking the ability to schedule directly in the specialty's own BT for the upcoming 7 days. Instead a day is requested for the surgery, and the cases are put on a staged cases list, and by the end of the day these cases are scheduled on a first come first served (FCFS) basis for the DoS. The staged cases list is scheduled at the end of the day. Scheduling cases longer than 7 days ahead of the DoS happens according to the regular BT scheduling, see also Section 2.

In this case study, we modeled the 50 ORs of VUMC that are 'on campus'. Of these 50 ORs, there are 47 inpatient ORs and 3 outpatient ORs (VUMC has more outpatient ORs but they are located 'off campus'). 11 ORs have limitations (see Section 3.2), which prevents them from being released under the release policy, e.g., cardiac surgery and orthopedic trauma rooms. Here, not releasing means the specialties are still allowed to plan cases in these rooms without having to put them on a staged case list. Other specialties are not allowed to perform surgeries in these rooms. The 11 ORs are not released because of equipment restrictions (e.g., cardiac surgery ORs) or because of arrival rate restrictions (orthopedic trauma rooms).

As described in Section 3.1, a distinction is made between inpatients and outpatients. The ambulatory outpatients are preferably scheduled in the outpatient rooms. Whenever this is not possible, they can be scheduled in the inpatient rooms, where the inpatient rooms function as a overflow. To determine the most common outpatient surgery types, we analyzed the surgeries performed in the outpatient rooms, based on this analysis we determined which surgery types are considered inpatient or outpatient.

In the simulation, we first create the OR schedule with the attributes assigned to a new patient event as shown in Figure 4. The top schedule of Figure 4 gives an overview of how the schedule looks like based on the scheduling heuristics applied, where the scheduling is done based on the expected duration. In the schedule, VOR13 and VOR8 are non released rooms, which show underutilized time. In the other ORs, we can clearly see that, after the specialty scheduled their own cases, the rooms were released and cases of a different specialty are added. For example, OR3 has two colors, first otolaryngology (OTO) cases in light green, then a plastic surgery case is scheduled in dark gray. The bottom schedule shows a realization of the schedule taking into account the stochastic nature of surgery durations. Due to variation in surgery duration and patient arrivals, we see delays before certain surgeries and some ORs run into overtime (the black arrows indicate the regular time for various ORs).

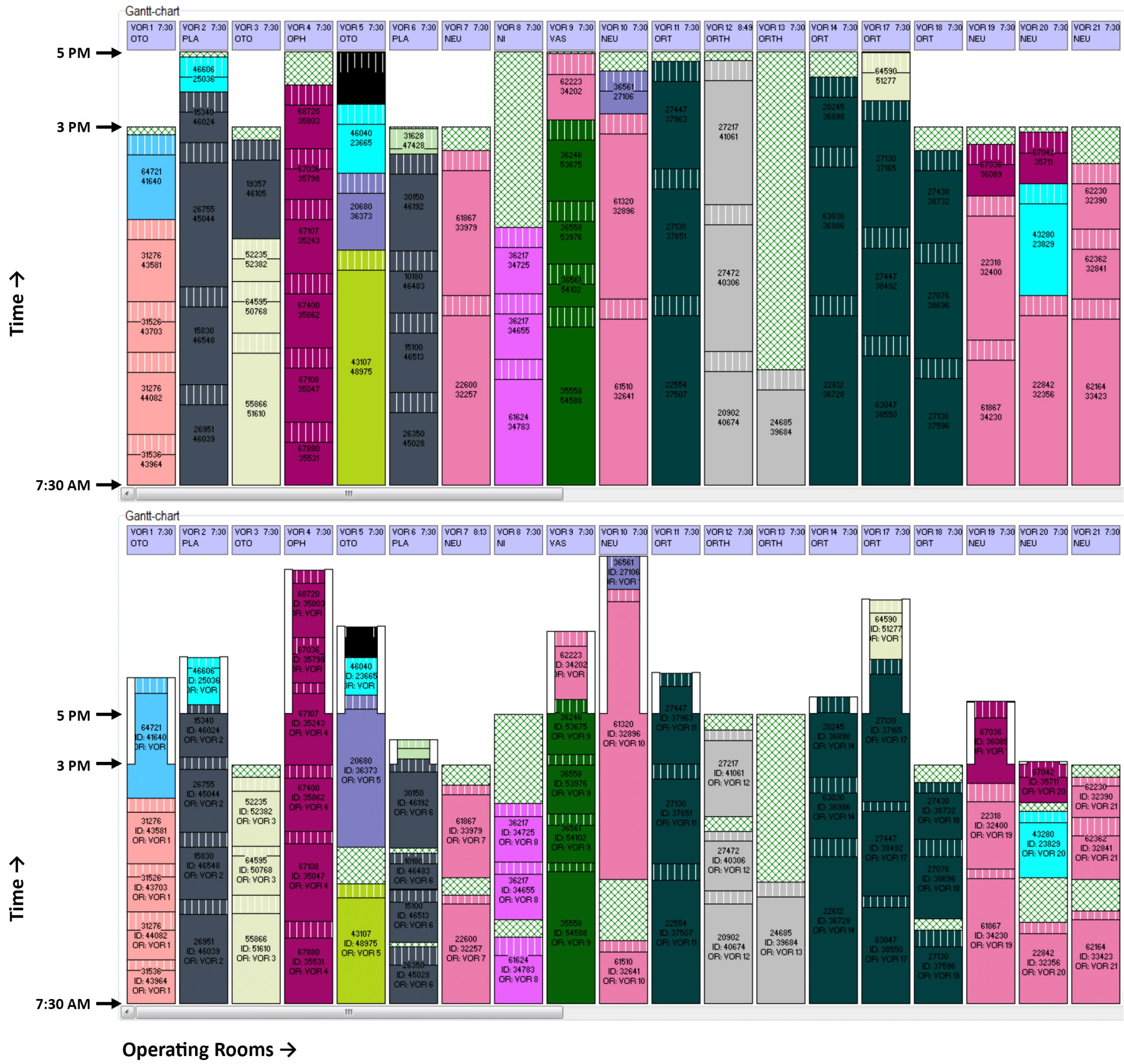

Figure 4: Simulated schedule

To represent the current situation in VUMC, we applied a 'first fit' rule for the regular elective cases that are scheduled in regular BT, this is in accordance with the 'Any Workday' scheduling (Dexter, Traub, and Macario 2003). The scheduling of regular cases happens directly into the BT schedule, as described in Section 2.

Staged cases have a request day. When a staged case appears, we first apply a 'first fit' rule to the rooms of the specialty on the requested day. When none of these rooms is available, then a 'worst fit' rule is applied to all of the released rooms. We schedule according to the 'worst fit' rule to reserve time for surgeries of the specialty that appear later. When a 'worst fit' was not possible on the request day, the case is placed on the unable to schedule list (one of the key performance indicators).

In our simulation, we consider alternative strategies for scheduling cases, which we evaluate under various scenarios. We evaluate the strategies under (i) varying volume, (ii) varying request day constraint, and (iii) varying scheduling policy. In Section 4.2 we discuss how we simulated the prospective solutions and present the results.

We implemented the generic model described in Section 3 and the OR scheduling policies in the 4GL programming language Embarcadero Delphi XE2. This implementation is used to simulate the case study of VUMC. The specific characteristics of this hospital are used in the generic framework, where we used the case specific information such as: number of ORs, number of non-released ORs, inpatient and outpatient ORs, surgery type statistical duration distributions, arrival distribution of the patients, and opening hours of the specific ORs. To determine the statistical distributions of the surgery type duration, we analyzed three years of historical information ($\pm$ 95,000 surgeries) over the full fiscal years: 2011, 2012 and 2013. The average computation time of one simulation run is approximately 17 seconds (MacBook Pro, 2.4 GHz Intel Core i7). One simulation runs consists of a year of schedule information and the effect when this schedule is executed, where we have approximately 32,750 surgeries per year.

To validate the simulation model, we used the verification and validation tools described by Law (2007). For example, we compared the historic data to the simulated results and the utilization rate was 2.1% lower in the simulation with the same number of surgeries performed on a yearly schedule. This was acceptable given the choice made in the fitting of the statistical distributions and level of detail that was put into the simulation model. The assignment of cases was also similar to the historic schedules, so VUMC trusts the model as a sufficiently accurate representation of the OR department.

4.2 Experimental Results

In this section, we present the experimental results of using a release policy under varying number of patients (Section 4.2.1), varying request day constraint (Section 4.2.2), and varying scheduling policy (Section 4.2.3).

4.2.1 Varying Number of Patients

Table 1 shows the results for varying number of patients per week, where VUMC currently has 630 patients per week. We conclude that with an increasing number of patients (i) the number of canceled cases increases more rapidly after 700 cases per week, (ii) overtime is relatively stable and bounded to the variance of the surgeries, but undertime decreases, and therefore the utilization rate increases, (iii) access time remains relatively stable, only for the elective patients it increases, (iv) the average duration of the unscheduled cases decreases when the number of unscheduled cases increase, and (v) the share of 7 day release patients in the number of unscheduled patients increases. The latter can be explained because the patients that are scheduled under the elective policy are scheduled first, since they arrive earlier in the system and are scheduled more in the future, at that time the availability of time in the OR is larger. The staged cases arrive later in the system, this means that availability and scheduling options also decrease accordingly, therefore the share of unscheduled 7-day release patients in larger, and increases when the total number patients per week increases.

4.2.2 Varying Request day Constraint

Currently, a case is labeled as unscheduled whenever it cannot be scheduled on the request day. We choose to modify the request day constraint by considering the following possibilities: extend the request day with the day after (+1Day), extend with one day before and one day after ($\pm$1Day), extend with 2 days after (+2Day), and an all day approach (AllDay). In each case, the request day extension is limited to the upcoming 7 days.

The results in Table 2 show that one day, one day before and after, and two days after have almost the same performance. The AllDay approach drastically reduces the number of unscheduled surgeries (only

Table 1: Results with varying number of patients

Volume (cases per week):	610	620	630	640	650	680	710	740
Utilization rate (%) without turnover	67%	68%	69%	70%	71%	74%	78%	80%
Utilization rate (%) with turnover	79%	81%	82%	84%	84%	88%	92%	95%
Overtime (% of available time)	10%	11%	11%	12%	11%	12%	14%	15%
Undertime (% of available time)	22%	21%	20%	19%	18%	16%	13%	11%
Access time (days) 7-day release patients	3.5	3.5	3.5	3.5	3.5	3.6	3.6	3.6
Access time (days) regular elective patients	7	7.1	7.1	7.2	7.5	7.4	7.3	7.9
Nr. of unscheduled cases	2.0	2.1	3.3	2.9	2.8	5.2	9.3	15.6
Nr. of unscheduled 7-day release cases	1.5	1.7	2.7	2.5	2.4	4.8	8.9	15.1
Avg. duration (hours) unscheduled cases	9.3	8.9	8.4	7.7	8.2	6.8	6	5.3

the cases that cannot be scheduled within 7 days are labeled as unscheduled). We also tested the scenarios in the case of 730 scheduled surgeries per week, and observe similar results (results not shown here). Scheduling the volume of 730 cases according to the current scheduling policy results in 12.6 unscheduled cases per week, where the all days approach results in 0.8 unscheduled cases.

Implication for the patients of changing the request day to multiple days is that they do not know up front on which of the coming 7 days their surgery is to be scheduled. This means that there is a trade-off between the number of cases that can be scheduled and uncertainty with respect to the surgery date. We advise only to put the AllDay approach into effect when the number of cases increases and there is a need to schedule more patients.

Table 2: Results with varying request day constraint

Variation from request day:	Current	+1Day	±1Day	+2Day	AllDay
Utilization rate (%) without turnover	69%	69%	70%	70%	69%
Utilization rate (%) with turnover	82%	82%	83%	83%	82%
Overtime (% of available time)	11%	11%	11%	11%	11%
Undertime (% of available time)	20%	20%	20%	20%	20%
Access time (days) 7-day release patients	3.5	3.5	3.5	3.5	3.6
Access time (days) regular elective patients	7.1	7.2	7.1	7.1	7.4
Nr. of unscheduled cases	3.3	1.8	1.8	1.8	0.7
Nr. of unscheduled 7-day release cases	2.7	1.5	1.4	1.4	0.3
Avg. duration (hours) unscheduled cases	8.4	8.7	8.4	8.2	11.6

4.2.3 Varying Scheduling Policy

To show the impact of the 7-day release policy for VUMC, we simulate the following policies: current number of patients without using a release policy (NoRelease), current situation with the 7-day release program (7Day), the current situation with the 7-day release program and a waiting list of one day (7DayList), situation with the 7-day release program with 730 cases (7Day730), and the situation with the 7-day release program and a waiting list of one day with 730 cases (7DayList730). For the policies that use a waiting list, we sort the cases on this waiting list on decreasing expected duration. We then apply 'first fit' for the specialty rooms and 'worst fit' when specialty rooms are not available (see Section 4.1).

Table 3 shows that the performance improves by using the 7 day release policy. The unscheduled cases reduce from 71.9 to 3.3. Also the other indicators show an increase in performance. The use of a waiting list of only one day (7DayList and 7DayList730) leads to an increased performance. For the patient, this waiting list has only a minor implication as the staged cases are already planned at the end of each day, as described in Section 4.1. The number of unscheduled cases drops from 3.3 to 1.5 and in the case of 730 scheduled cases a week, it drops from 12.3 to 8.6. We recommend VUMC to implement this approach.

Table 3: Results with varying scheduling policy

Scenario:	NoRelease	7Day	7DayList	7Day730	7DayList730
Utilization rate (%) without turnover	62%	69%	69%	79%	80%
Utilization rate (%) with turnover	74%	82%	82%	95%	95%
Overtime (% of available time)	12%	11%	12%	15%	15%
Undertime (% of available time)	23%	20%	20%	12%	11%
Access time (days) 7-day release patients	0.0	3.5	3.5	3.6	3.6
Access time (days) regular elective patients	8.4	7.1	7.2	7.9	8.0
Nr. of unscheduled cases	71.9	3.3	1.5	12.6	8.6
Nr. of unscheduled x-day release cases	0	2.7	1.1	12.3	8.3
Avg. duration (hours) unscheduled cases	2.9	8.4	9.5	5.4	5.2

5 DISCUSSION & CONCLUSION

In this paper, we presented a generic discrete event simulation framework. By the use of a case study, we showed that the simulation model is capable of evaluating the performance of the OR department on key performance indicators. We showed that different what-if approaches could be simulated. We illustrated our simulation model using a case study at VUMC. We showed that for VUMC it is beneficial to use the 7-day release policy, because of a reduction in access time, a reduction in the number of unscheduled surgeries, and increased flexibility for the surgeons. We therefore advise other hospitals to take a release policy into consideration. This article gives a guideline on how to simulate and evaluate such a policy.

The simulation model is also applicable to other hospitals, for which we expect different results. Small hospitals might achieve higher benefits of using a release policy compared to larger hospitals because it is harder to find a good fit between demand and need for the specialties in regular BT assignment. We displayed a simulation framework that is able to answer the question whether it is beneficial to implement a release policy for a hospital and a model that is able to simulate the best release policy.

One point of discussion is that we were not able to produce reliable results for other release days, i.e., for 5, 6, 8 and 9-day release policies. This was caused by the fact that our historical data, that we used as input for our simulation model, was taken from a period in which the 7-day release program was already in use. For a proper analysis, we would need data of another hospital that does not have a release policy yet.

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