Emergency Operating Room or Not?

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Abstract Hospital operating theaters often face the problem of unscheduled emergency arrivals that should be treated as soon as possible. In practice different policies are used to allocate these emergency patients to the operating rooms. These policies are (1) keeping operating rooms empty and available for emergency arrivals; (2) treating emergency patients in elective operating rooms, postponing elective patients; and (3) a mix of these two policies. The use of a specific policy affects performance (e.g., utilization, waiting times, overtime). Currently, these effects are not clear, and there is no agreement on what works 'best' for a specific hospital.

Using discrete-event simulation, we evaluate the policies for many case characteristics such as hospital size, patient case mix, and fraction of (emergency) patients. We gathered the simulation results in a tool called OR analyzer. This tool is made available online and allows healthcare practitioners to gain insight into the effects of the scheduling policies in settings similar to their specific hospital setting. In addition, this tool allows others researching emergency scheduling policies to frame their hospital settings and compare results.

1 Introduction

Hospitals that perform surgeries on both elective and emergency patients are faced with the problem of how to deal with arriving emergency patients [15]. In this chapter we study three emergency surgery scheduling policies, commonly

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encountered both in practice and in literature. The policies differ in the way emergency patients are allocated to operating rooms (ORs):

1. Reserve ORs for emergency patients (dedicated policy).
2. Treat emergency patients in elective ORs (flexible policy).
3. A mix of the above (hybrid policy).

Policy 1 assigns all emergency patients to dedicated emergency operating rooms, thus preventing emergency patients from disrupting the elective program. If all emergency ORs are occupied, arriving emergency patients wait and are treated in the first dedicated emergency OR that becomes available. Policy 1 poses a trade-off between operating room utilization and emergency surgery waiting time: having more emergency ORs reduces waiting time but also reduces utilization. Policy 2 assigns all emergency patients to elective operating rooms. This is done by inserting emergency surgeries into the elective program without preempting elective surgeries. Consequently, an emergency surgery may start in any elective OR as soon as one becomes available, and elective surgeries must then be postponed or rescheduled. Furthermore, since preemption is not allowed, emergency patients may have to wait. Policy 3 combines advantages of both Policies 1 and 2; emergency patients may be treated in both elective and emergency ORs. If all emergency ORs are occupied and an elective OR is available, emergency patients are treated in this elective OR. In case all ORs are busy, emergency patients that arrive wait and are treated in the first OR that becomes available, regardless of OR type (i.e., elective or emergency OR). This policy aims to reduce the interruptions in the elective patient schedule caused by emergency arrivals while still allowing timely treatment of emergencies. Hospitals are thus faced with the question which policy to choose and, in case of Policies 1 and 3, how many ORs to dedicate to emergency patients (Fig. 1).

The use of a specific policy affects a hospital's performance (e.g., utilization, waiting times, overtime). However, these effects are not clear from literature, and there is no agreement on what works best and in which setting(s) to choose which

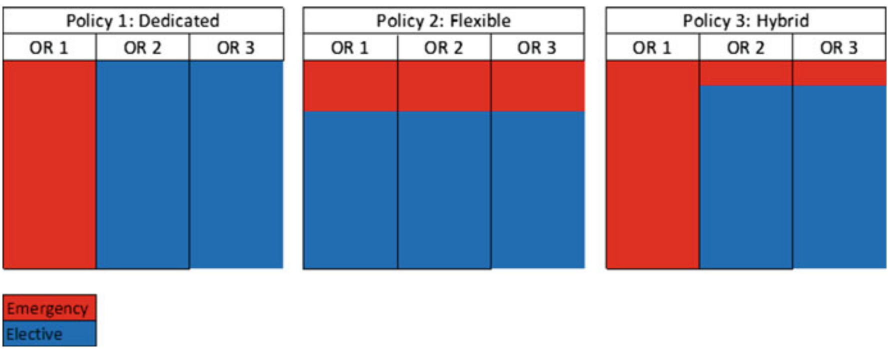


Fig. 1 Visualization of different emergency patient allocation policies

policy. For example, using a flexible policy (2) is stated to both decrease [23] and increase [4] overtime of ORs. Differences in hospital characteristics may account for the difference in results among papers. For example, using a flexible policy may only be possible if there are sufficient ORs to ensure a timely start of treatment for emergency patients. Further contradictory results on policies are reported in [15].

Please check sentence starting "Using computer simulation we evaluate the different policies under many hospital settings, allowing us to evaluate the trends and effects of different characteristics on the performance of policies, which has previously not been done in literature. In addition, we take into account many often encountered performance indicators. Previous studies often use performance indicators relevant for their specific case study which may differ considerably from other studies, making comparison difficult. The simulation results are gathered in a tool called OR analyzer which is made available online. The tool allows healthcare practitioners to gain insights into the effects of the scheduling policies in settings similar to their specific hospital setting. In Sect. 2 we review the literature, Sect. 3 details our approach, and Sect. 4 describes the simulation model and OR analyzer tool. Sect. 5 discusses results, and Sect. 6 provides a discussion and conclusion.

2 Literature

There is a considerable amount of literature on operating room (OR) planning and scheduling. As the ORs are often seen as the 'core' of hospitals, it is not surprising that this is a topic of much interest. Literature reviews on (among others) OR planning and scheduling are provided in [3, 7]and [10]. We consider the OR planning problem, where emergency surgery arrivals have to be taken into account. Work that specifically addresses non-elective surgeries and takes such surgeries into account on a tactical and/or operational level is less common. Two recent literature reviews that give an overview of OR planning and scheduling literature, taking into account non-electives and the trade-offs they pose, are [6, 15]. Van Riet et al. [15] note that it is still unclear what the effect is of different settings on the possible performance measures and that a key question is how to determine what level of demand and patient mix is required before a specific policy should be pursued.

Starting from the aforementioned literature reviews, we selected studies that evaluated the use of one or more policies to deal with unexpected emergency patient arrivals from an operational research perspective. In addition, we also include more recent studies not covered in the latest literature reviews. Wullink et al. [23] compare the use of dedicated emergency ORs and general ORs, for a case study with 12 ORs in total. Looking at waiting time for emergencies, overtime, and utilization, they conclude that general ORs perform better on all performance measures when using a flexible policy. Based on their work, the hospital decided to close dedicated ORs. Van Veen-Berkx et al. [21] compare the operating theater performance before and after the dedicated OR was closed in the same hospital and find contradicting results in practice, concluding that overtime increased. It is unclear, however, whether other changes took place in between measurements. In addition, overtime is defined differently between studies. Wullink et al. [23] define overtime as the time used for surgeries after regular OR time ends. Van Veen-Berkx et al. [21] define overtime as the difference (in minutes) between scheduled and actual surgery end time of the last patient of the day. Under a flexible policy, however, less elective patients are scheduled in ORs (to account for the emergency arrivals), and the end time of the last scheduled patient occurs before the regular closing time of the OR. This difference between scheduled end time and regular OR closing time may account for the conflicting overtime results.

Another work investigating a dedicated and flexible policy is by Ferrand et al. [4]. They consider a hospital with 20 operating rooms and, in case of the dedicated OR policy, vary the number of dedicated ORs. They also evaluate waiting time, utilization, and overtime. Contrary to the results of Wullink et al. [23], the average overtime per day increases under a flexible policy. Similarly, Persson and Persson [14] use simulation to model a Swedish orthopaedic department with two ORs and find a dedicated policy outperforms a flexible one. However, in their comparison, total available capacity also increased.

More recent work by Ferrand et al. [5] investigates the effect of utilizing some ORs by both elective and emergency patients. Their case study again has 20 ORs, and they vary the number of dedicated and flexible ORs. Also, they perform a sensitivity analysis to evaluate the effect of increased emergency arrivals, nonstationary (emergency) arrivals, and different procedure times for elective patients. Lans et al. [11] use computer simulation to look at both tactical and operational planning levels when evaluating different policies to anticipate emergency surgeries. On the tactical level, they evaluate: (1) dedicated ORs, (2) planned slack in some ORs, and (3) planned slack in all ORs. Performance measures used are utilization, overtime, and waiting time of emergency surgeries. Accounting for all measures, they find that using planned slack in all ORs performs best (i.e., a flexible policy).

A different policy is evaluated by Bowers and Mould [2] that investigate the effect of planning elective patients in an orthopaedic emergency OR session using simulation. These patients have a shorter access time; however there is a larger chance of cancellation. They find that throughput and utilization may increase, as long as elective patients are willing to accept a cancellation probability.

Bhattacharyya et al. [1] report a retrospective analysis where two 1-year periods were compared before and after the use of a dedicated emergency OR for orthopaedic surgeries. They measured the utilization, cases done during the night (overtime), and the delay frequency of elective surgeries caused by emergencies. They conclude that overtime was considerably reduced by using a dedicated OR. Similarly, Wixted et al. [22] perform a retrospective review after a dedicated trauma OR was opened. They compare performance for a specific surgery type (isolated femur fractures) and find that less overtime and disruptions have taken place since a dedicated OR is used. However, during the study several changes occurred such as an increase in surgeons, as well the number of surgeries performed. Sandbaek et al. [16] carry out a before and after analysis of implementing a dedicated policy (from a flexible policy), where three ORs are reserved for emergency patients. They report a reduction in overtime for both elective and emergency ORs, as well as an increase in utilization. However, during this redesign of the ORs, a new patient classification and booking policy was also introduced, which may have affected the results.

Under Policy 2 or 3, the way in which elective patients are scheduled may impact performance. Given that surgeries cannot be interrupted, emergency patients can only be treated if an OR is available and otherwise must 'break in' into the elective schedule when an elective surgery completes, before the next elective surgery starts. These completion times of surgeries are also called 'break-in-moments' (BIMs) [20]. As such, it may be beneficial for emergency patients to ensure that BIMs are spread evenly across the day. Van Essen et al. [20] take this into account and optimize surgery schedules such that the maximum time between BIMs is minimized.

Most research into OR planning reported in literature started from a single case study, with specific hospital characteristics. This may lead to conflicting results and be of limited value to healthcare providers with their own specific case characteristics. Our contribution is that we fill this gap by investigating the performance of the different policies, under many different case characteristics, and evaluate the circumstances under which specific policies may perform best. In addition we develop, and make available, a tool that allows readers and healthcare practitioners to further evaluate the policies under different hospital characteristics.

3 Approach

In this section we present the approach taken to investigate the different policies defined in Sect. 1. To compare policies not only among each other, but also under different case settings, we define broad hospital characteristics that make up a specific case setting. All possible case settings are then evaluated under all possible policies, including multiple settings per policy (e.g., Policy 1 having 1, 2, and so on emergency ORs) using computer simulation. Table 1 lists all the characteristics that make up a policy and scenario.

Note that the first two settings define the policy. For example, having 0 emergency ORs and allowing to treat emergencies in elective ORs defines the flexible policy. The third setting indicates the use of break-in-moment (BIM) optimization. Using this elective surgeries are scheduled during the day such that the start and end times of surgeries and thus the possible break-in possibilities for emergencies are spread out as evenly as possible. As such, this may further improve the performance of the flexible and hybrid policy where break-ins are allowed. For details on the BIM approach, we refer to [20].

Note that the number of ORs are based on the overall system load (i.e., total number of patients). This is done to reduce the number of infeasible or irrelevant scenarios which are likely not seen in practice. For example, scheduling 20000 patients in only 5 ORs may be impossible regardless of policy, as the required capacity exceeds the total OR time available. We only evaluate scenarios where the load is between 40% and 100% (i.e., $0.4 \leq \text{systemload} \leq 1$), where load is defined as

$$\text{System load} = \frac{\mathbb{E}[\text{surgery duration}] \cdot \text{Number of patients treated per year}}{\text{total yearly capacity}}. \quad (1)$$

To create the scenarios, for all combinations of settings 1, 3, 4, 5, and 7, all combinations of elective and emergency ORs are taken where the system load satisfies $0.4 \leq \text{systemload} \leq 1$. This results in 320.000 different policy and case characteristics combinations to evaluate. Please check if all occurrences of period used as thousand separator should be changed to comma. Section 3.1 gives more details on the case mix characteristics, and Sect. 3.2 describes the used performance indicators to evaluate the different policies and scenarios.

3.1 Case Mix

As observed in Sect. 2, most studies consider a specific hospital setting and case mix. The case mix describes the volume and properties of surgery types (i.e., sampled distributions and parameters) that a hospital performs. As the case mix may influence performance, we carry out an extensive scenario analysis, including different case mixes.

To create distinct case mixes, we use the classification put forward by Leeftink and Hans [12]. They classify surgery types using two parameters: mean surgery duration (relative to total OR capacity) and coefficient of variation (CV) of the surgery duration, which both indicate the level of complexity involved in scheduling surgeries. Case mixes that include surgeries with a higher duration are more difficult to schedule, as schedules are more likely to have gaps which could not be filled.

Table 1 Case settings used to define policies and scenarios

#	Description	Values
1	Treat emergency patients in elective ORs	{True, false}
2	Number of ORs reserved for emergency patients	{0, 1, 2,. . . , based on system load},
3	Use of break-in-moment (BIM) optimization	{True, false}
4	Case mix of surgery types	{case mix A; case mix B; case mix C; case mix D}
5	Number of patients treated per year	{1000, 2000,. . . , 20000}
6	Number of ORs that is available in total	{5, 6, 7,. . . , based on system load}
7	Percentage of total patients that is an emergency patient	{0, 5, 10,. . . , 40}

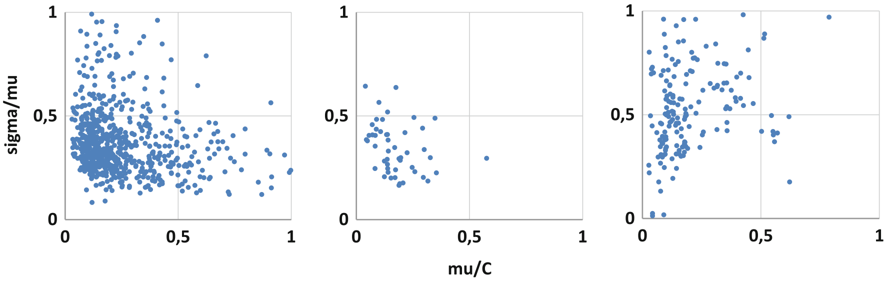


Fig. 2 Case mixes of three Dutch hospitals using classification by Leeftink and Hans [12]; sigma/mu denotes the CV, and mu/C denotes the mean surgery duration (relative to OR session size)

Conversely, low duration surgeries are easier to schedule, as gaps can be easily filled. The coefficient of variation indicates the variability of surgeries, which in turn leads to more uncertainty when carrying out planned schedules [19]. High variability may lead to overtime and cancellations. To account for the variability slack may be used when creating schedules [8].

Using these two parameters, it is possible to create different case mixes. To create multiple case mixes, we use a dataset that is based on historical data from both academic and nonacademic hospitals in the Netherlands over the past 10 years. In this dataset we categorize surgeries as high/low duration, as well as high/low coefficient of variation. Specifically, we denote a (relative) mean duration and coefficient of variation smaller than 0.5 as low and above as high. Figure 2 shows the case mix of three different hospitals that are included in the dataset. The figures show that case mixes can differ considerably between hospitals: hospital 1 (left) has surgery types with both high and low duration and CV, and hospital 2 (mid) almost exclusively has low duration and CV surgery types. Hospital 3 (right) has another case mix, where surgeries have both high and low CV, and only few high duration surgeries are carried out.

The surgery types underlying the dataset used to construct scenarios and evaluate policies are the same as used by Leeftink and Hans [12]. This dataset contains surgery types, defined as three-parameter lognormal distributions, which are shown to fit well to surgery duration distributions [13, 17], and denotes the (relative) frequency with which these surgeries take place.

To evaluate the influence surgery type case mixes have on the performance of the policies, we sample surgeries from different parts of the dataset. Figure 3 gives a visualization of the complete surgery type case mix and the different sample spaces to construct four theoretical case mixes. For example, by sampling surgeries from Fig. 3b, we have a case mix of surgeries with a low (average) duration and both high and low variability.

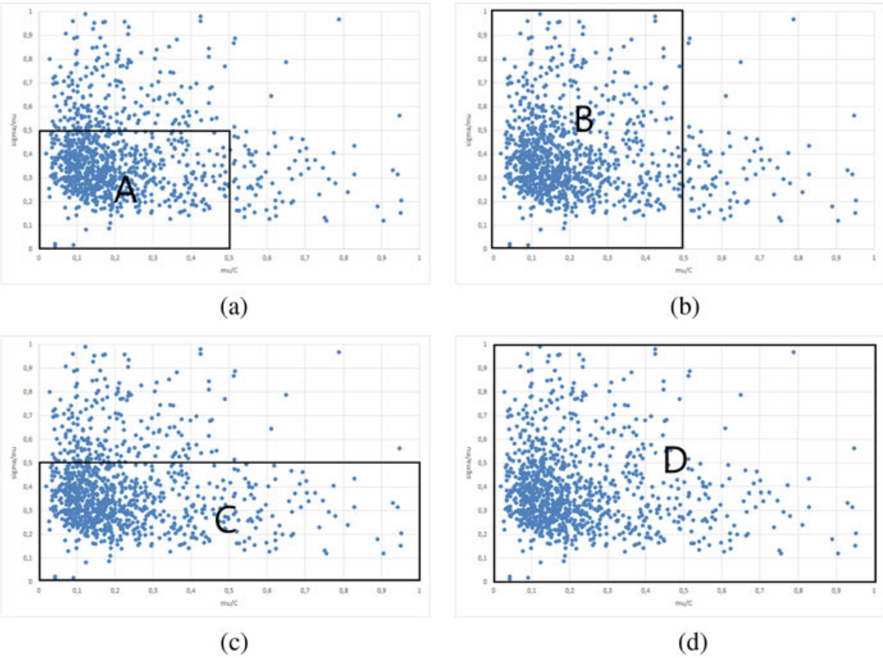


Fig. 3 Case mixes based on historical data of Dutch hospitals categorized by CV and duration. (**a**) Low duration; low CV (**b**) Low duration; high and low CV (**c**) High and low duration; low CV (**d**) High and low duration and CV

3.2 Performance Indicators

To evaluate the policies, we use performance measures most common from recent literature reviews [3, 7, 15], being utilization, overtime, and waiting time (for both elective and emergency patients). These represent the views of different stakeholders interacting with the operating theater, namely, patients, staff, and management. With respect to overtime, we evaluate both the average and the percentage of ORs that end in overtime, to evaluate the distribution of overtime over the OR days. In addition, we are interested in outliers with respect to emergency patients (e.g., patients that wait for longer than 30 min). While it may be acceptable for an emergency patient to wait for some time (e.g., some minutes), waiting a considerable amount of time may reduce health outcomes considerably. Finally, we also evaluate the number of cancelled surgeries (i.e., surgeries that could not start during regular hours). We use the performance indicators listed in Table 2.

Table 2 Used performance indicators

#	Description
1	Percentage of time ORs are in use during regular time
2	Percentage of ORs with work in overtime
3	Average overtime per OR day (in minutes)
4	Average waiting time of elective patients (in minutes)
5	Average waiting time of emergency patients (in minutes)
6	Percentage of emergency patients that wait longer than 30 minutes
7	Percentage of surgeries that are cancelled due to time constraints

4 Simulation Model and OR Analyzer Tool

In this section we first describe our simulation model, as well as settings used within the model in Sect. 4.1. Second, we present the OR analyzer tool that incorporates all results gained from the simulation model to quickly present and evaluate multiple policies and case settings in Sect. 4.2.

4.1 Simulation Model

All simulations are done using discrete-event simulation (DES) with the 'Operating Room Manager' software [8, 9]. This software is developed using the Delphi programming language from CodeGear and allows for the strategic, tactical, and operational evaluation of an operating theater. Within the program, detailed operating theater reconstructions are possible, taking into account additional resources (e.g., diagnostic equipment) and constraints (e.g., scheduled lunch breaks). Figure 4 shows a screenshot of the program.

In order to gain insights into the effects of the scheduling policies under different hospital characteristics, we do not model all complexities of a realistic operating theater. First, we assume the number of available (emergency) ORs is the only limiting resource. In practice, some resources besides the ORs may dictate when surgeries may start, such as available diagnostic equipment or surgical tools. Similarly, staff may not be available to immediately start a surgery. In the simulation model, these resources are not taken into account. Second, setup and changeover times are not considered. In practice, two surgical procedures may require changeover times between them, giving further importance to the elective patient schedule. We assume such changeover times are included in the surgery times. Also, we assume patient flow into and out of ORs may take place immediately (e.g., there are beds available at wards and pre-/post-anaesthesia care units) as we want to exclude effects other departments may have on the performance of the OR.

To evaluate a scenario and policy, we simulate an operating theater for 50 weeks (each week containing 5 working days), with daily capacity of an OR being 8

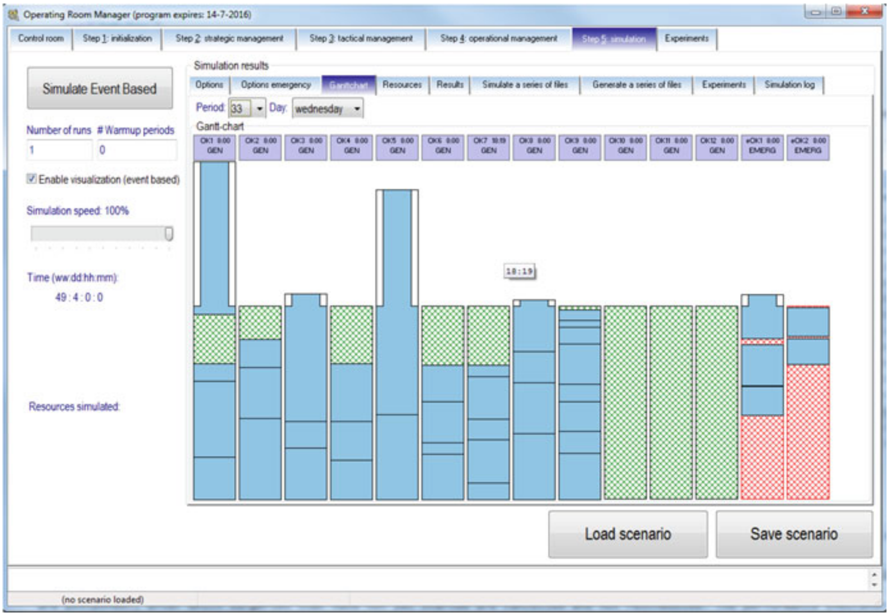


Fig. 4 Screenshot of the simulation model

hours. The elective surgeries that are sampled are spread evenly over the weeks (e.g., 5000 elective patients result in 100 patients to schedule per week). When creating the surgical schedules, surgeries are randomly selected and scheduled using a level fit policy, such that workload is spread over all available ORs. When using BIM optimization, surgeries are swapped (within their allocated ORs), such that the maximum break-in-interval is minimized over all ORs. ORs remain operational until 12 AM to complete an already started surgery (i.e., there is no cap on overtime, after which surgeries are postponed), but surgeries that have not started during regular hours are cancelled and not rescheduled.

Emergency patients that arrive must be treated as soon as possible and are prioritized by their waiting time. Based on the policy, these patients are treated in the first available (elective or emergency) OR and are always prioritized over elective patients. When allocating patients to ORs, we do not specifically plan slack time. Given the evaluated scenario, all elective patients are scheduled, and if any remaining available OR time is left, this is then spread evenly across ORs, as patients are scheduled using a level fit policy. In addition, we assume all elective surgeries are available at the beginning of the day (i.e., can start as soon as possible) and that there are no no-shows of patients.

Emergency patients are drawn from the same case mix underlying the elective surgeries (as noted in Sect. 3.1) and arrive at the ORs following a Poisson process. The (inter)arrival rates for each patient type are chosen such that the (expected) total number of arrivals corresponds to the number of patients arriving per year, as

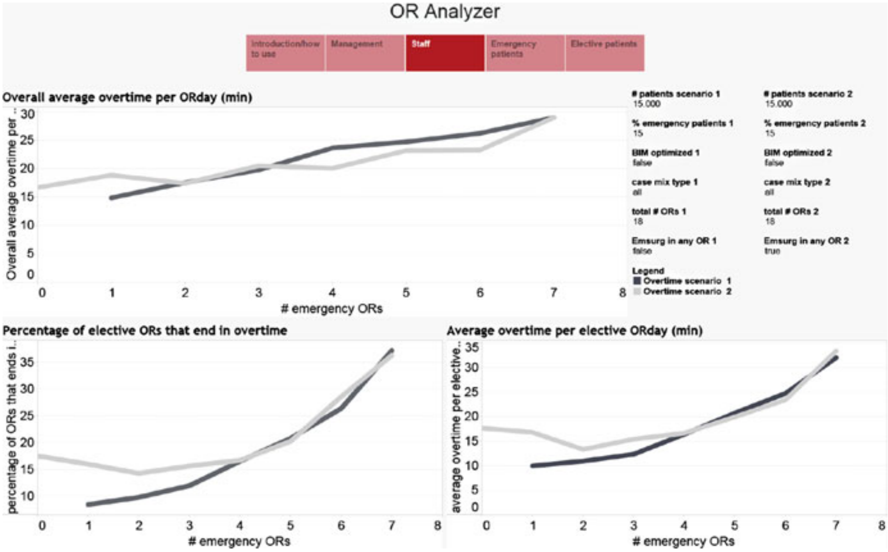


Fig. 5 Screenshot of the OR analyzer

detailed in Table 1. For example, with 10000 patients in total per year, of which 10% are emergency patients, there are 9000 elective patients to schedule, and (on average) 1000 emergency patients arrive during the year, with an overall rate parameter $\lambda = \frac{1000}{2080} \approx 0.48$ per hour (assuming 52 weeks with 5 working days of 8 h).

4.2 OR Analyzer Tool

The OR analyzer tool allows fast evaluation and comparison of two scenarios that were simulated using the simulation model and allows healthcare practitioners to gain insights into the effectiveness of the different policies for their specific hospital case. In addition, insights can be gained with respect to "what-if" analyses, such as the effectiveness of policies under expected future patient increases. The tool was developed using the Tableau visualization software package [18]. The tool contains all simulation results and can aggregate, display, and visualize the various performance indicators. Figure 5 shows a screenshot of the program. At the top a choice can be made between an introduction screen and screens for different stakeholders. In the stakeholder screens, their respective performance indicators are shown. The right columns can be used to set various scenarios and policy settings (e.g., number of patients, case mix, etc.). This may be done for at most two different scenarios (one column per scenario) simultaneously, which are both shown in the results graph.

Each performance indicator graph displays its respective performance on the vertical axis, for a different number of dedicated emergency ORs displayed on the horizontal axis. This allows the user to compare different policies in multiple scenarios. For example, the figure shows all three policies for a hospital case with 18 ORs in total, 15.000 patients, of which 15% are emergencies; surgeries are drawn from case mix D, and there is no BIM optimization carried out. The OR analyzer is available online (available at: http://tabsoft.co/29jrDwM).

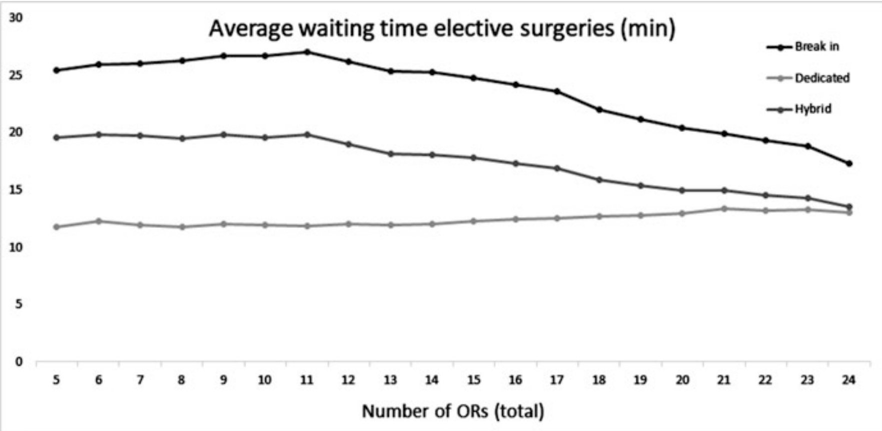
5 Results

In this section we discuss some general findings on the effectiveness of policies under different settings across multiple performance indicators.

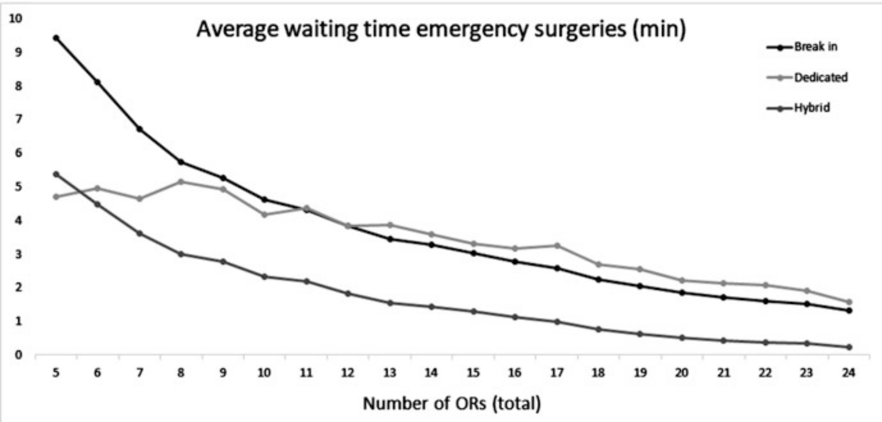
5.1 The Effect of Scale

In smaller settings (i.e., few operating rooms) we find that Policy 1 performs best, as emergency patients that have to break in most likely have to wait for one of the few surgeries to finish. For larger settings we find the opposite, and Policies 2 and 3 perform better as breaking in becomes easier. Figure 6 shows the waiting times for a given policy and total number of ORs averaged over all other settings (e.g., percentage of patients that are emergency arrivals, BIM optimization, etc.).

From Fig. 6 we see that there is always some waiting time for elective patients, regardless of emergencies, caused by the inherent stochasticity in surgery durations. Also, the elective waiting time under break-in and hybrid policies is considerably higher, as patients now may also wait for emergencies. In smaller settings (up to 8–9 ORs) there is no benefit in using a break-in over a dedicated policy, as waiting time for all patients is higher under the former policy. In addition, the average overtime and percentage of ORs with overtime is higher. The hybrid policy more quickly shows a trade-off, as waiting times for emergency patients are less in settings from 6 to 7 ORs at the cost of having longer elective waiting times. Nonetheless, in smaller settings there must be some dedicated OR capacity reserved for emergencies in order to ensure timely emergency care. While it seems that in larger settings there is little difference in emergency waiting time between a break-in and dedicated policy, Fig. 7 shows the average number of emergencies that wait longer than 30 min. Here we see that the waiting time is much less evenly distributed under a dedicated policy. This can be explained by the fact that the first few arrivals under a dedicated policy have zero waiting time as an emergency OR is ready for them, but subsequent arrivals wait much longer as they may have to wait for previous emergencies to finish. From this perspective it seems that both the break-in and hybrid policies outperform the dedicated setting for sufficiently large hospitals.



(a)



(b)

Fig. 6 Waiting times per policy and number of ORs averaged over all other case settings. (**a**) Average waiting time of elective patients (**b**) Average waiting time of emergency patients

For all sizes the hybrid policy seems to perform the best. This can be explained as it allows fine-tuning between the extremes of the other two policies and it ensures not too many break-ins into the elective program; however, if there are many emergency arrivals at once, there is the possibility of breaking in which gives more flexibility. This flexibility allows a better use of the ORs, as effectively a dedicated policy is used, until there are too many emergency arrivals, at which point a break-in policy is used.

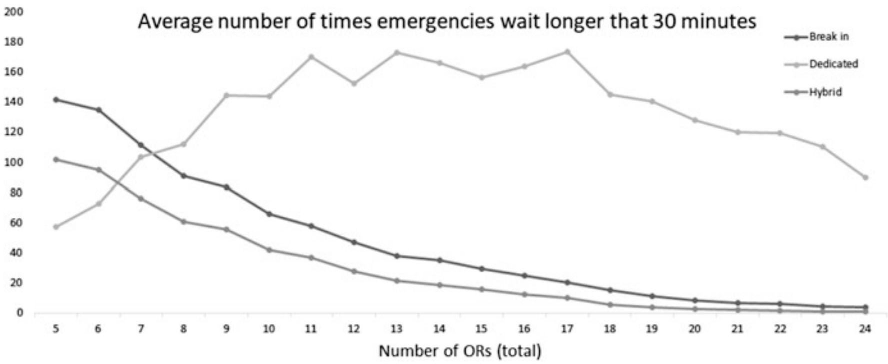


Fig. 7 Number of times emergencies wait >30 min per policy and number of ORs averaged over all other case settings

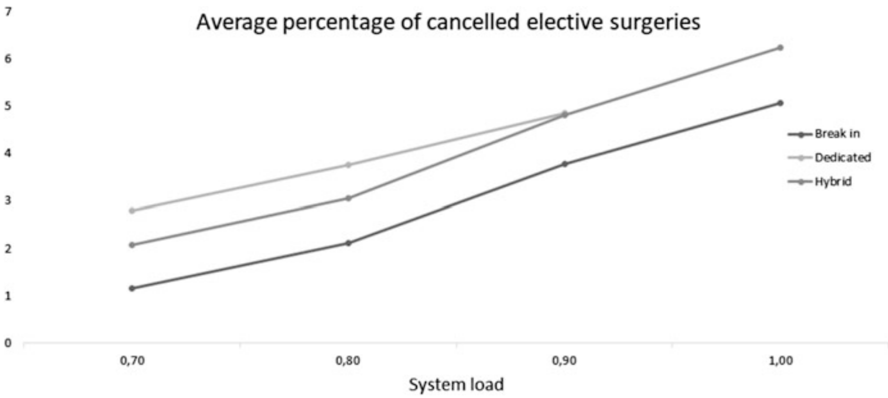


Fig. 8 Percentage of cancelled elective surgeries per policy and system load averaged over all other case settings

5.2 The Effect of Load and Case Mix Variability

Besides the effects of scale on policy effectiveness, we also evaluate the effect of overall system load (as denoted in Sect. 3) and case mix variability. Figures 8 and 9 show the average percentage of cancelled patients for different system loads. As the load increases, elective cancellations increase for all policies with larger percentages for the break-in and hybrid policies. This can be explained by the fact that under these policies, emergency patients are prioritized over electives, which decreases performance for elective patients.

For the emergency cancellations, we find the opposite result. As the load increases, the number of emergency cancellations rapidly increase under a dedicated policy while remaining low under the break-in and hybrid policies. When evaluating performances individually for case mixes with high and low variability, we see a

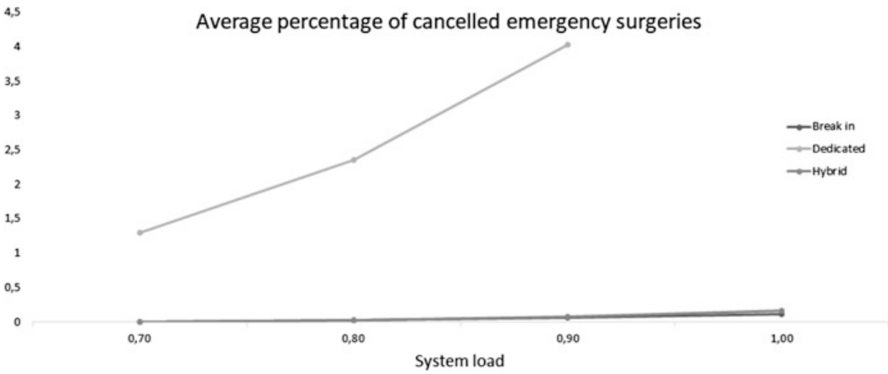


Fig. 9 Percentage of cancelled emergency surgeries per policy and system load averaged over all other case settings

similar pattern, only slightly more skewed towards lower loads. This makes sense as higher variability (and all else being equal) reduces system performance.

The ability of the break-in and hybrid policies to accommodate higher loads may be explained by the fact that there is a (one-way) pooling effect between emergency and elective patients. In contrast, the dedicated policy has two distinct OR settings that do not interact (electives and emergencies).

5.3 *The Effect of Break-in-Moment Optimization*

The use of break-in optimization may further improve the effectiveness of using a break-in or hybrid policy, as waiting times for emergency surgeries are minimized by reorganizing the elective program. More surprising is that the number of elective cancellations also decreases. Figure 10 shows the percentage of cancelled elective surgeries with and without BIM for the different policies and case mixes.

The decrease in elective cancellations can be explained by the fact that, when using BIM, the break-in-moments are not only spread more evenly over the day, they are also spread more evenly across ORs. This in turn more evenly distributes work across the ORs and reduces cancellations. In addition, we see that the improvements are (relatively) larger when the case mix has higher variability or longer surgery durations.

While the use of BIM improves Policies 2 and 3 and does not come at the expense of other performance measures, the increases in performance are not large enough to change the scale effect tipping points mentioned in Sect. 5.1. Even when using BIM, there needs to be a large enough number of total ORs for breaking in to be viable.

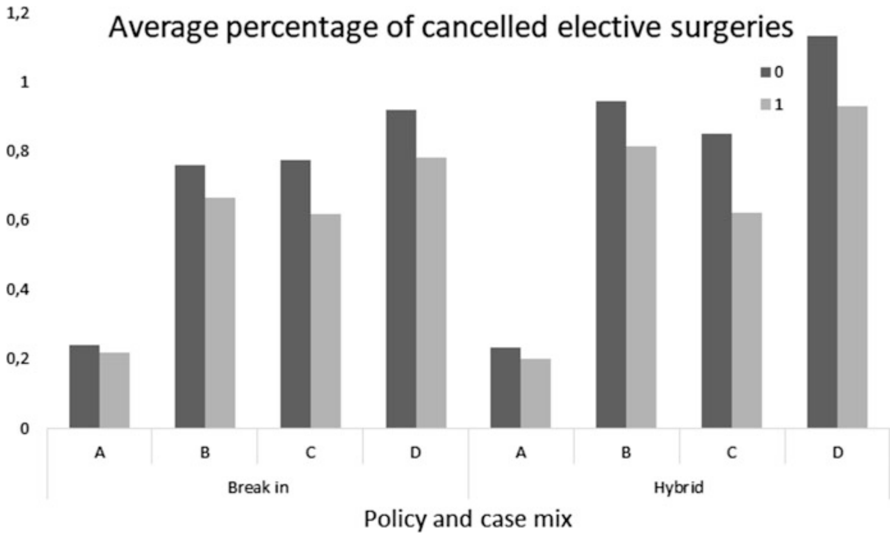


Fig. 10 Percentage of cancelled elective surgeries with BIM (1) and without (0) per policy and case mix averaged over all other case settings

6 Conclusions

In this chapter we have evaluated different policies that are used in practice to deal with emergency patients arriving at the operating theater. Three policies evaluated are the use of dedicated ORs for emergency patients (Policy 1), letting emergency patients break into the elective program (in regular ORs, Policy 2), and a combination of the two aforementioned policies (Policy 3). We evaluated the different policies using a discrete-event simulation model and incorporated the results in a tool to enable quick comparison of alternative policies and settings. This evaluation is carried out for an extensive set of scenario settings such as operating theater size and patient case mix, as well as multiple stakeholder performance indicators including utilization, elective and emergency waiting times, and overtime. In total, 320.000 scenario settings were simulated.

Generally, we find that, given a sufficient operating theater size, there is a trade-off in performance indicators between using a dedicated (1) or break-in (2) policy. Using dedicated emergency ORs leads to lower waiting times for elective patients, as there are no break-ins, but outliers in waiting times for emergency patients are more likely. The hybrid policy (3) outperforms the other policies as an intermediate solution that may be better tuned to the specific underlying hospital case.

The main characteristic influencing the effectiveness of the policies is the operating theater size. We find that for smaller operating theaters, it is more beneficial to use dedicated emergency capacity, as there are not enough ORs to allow for a timely break-in into the elective program. The minimum required number of

ORs lies around 8 to 9 ORs (in total) before a break-in policy becomes viable. Below this threshold, some dedicated emergency OR capacity is necessary regardless of all other characteristics.

The use of BIM shows that the scheduling of patients during the day influences OR performance. As such, other more dynamic allocation policies of patients into the ORs may be interesting to investigate in future work. For example, inserting breaks into the elective program may further reduce emergency patient waiting times when using a break-in or hybrid policy. Alternatively, taking into account expected surgery completion times before allocating emergency patients to an elective OR may further complement break-in policies. By only allocating emergency patients to elective ORs when emergency ORs are not expected to be available soon may reduce emergency waiting time outliers while reducing elective program disruptions.

To conclude, we have explored the relationship between policies to deal with arriving emergency patient arrivals at the OR and hospital characteristics such as case mix, hospital size, and fraction of emergency patients. To allow healthcare practitioners to evaluate policies and performance for their specific case setting, as well as perform what-if analyses, we made available the simulation results in the OR analyzer tool (available at: http://tabsoft.co/29jrDwM). We encourage readers to further explore and use the tool as they see fit.

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