This issue our supplement focuses on one of the most expensive areas of the hospital: the Operating Room (OR). As usual, there is one copy for you and one to pass on to the relevant department. Van Essen et al. introduce a new decision support system to help OR managers successfully adjust their ever-changing OR schedules. The news section covers issues such as new technologies, teamwork and the effect of background noise on surgical team communication. The final article looks at the different ways to keep your OR sustainable in terms of costs and the environment.

RESCHEDULING IN THE OR

A Decision Support System Keeps Stakeholders and OR-Manager Happy

By J. Theresia van Essen, Johann L. Hurink, Woutske Hartholt, Bernd J. van den Akker

Managing the Operating Room (OR) department is difficult due to the conflicting priorities and preferences of stakeholders. Therefore, planning and scheduling methods are helpful to increase the efficiency in OR departments (see Cardoen et al. and Hulshof et al. for an overview on OR planning and scheduling). In this article, we focus on the rescheduling of surgeries, or more precisely, on the rescheduling of surgeries throughout the day.

On any given day, emergency patients who need surgery arrive in the OR department. In many hospitals, these surgeries are scheduled in one of the elective ORs, which disrupts the OR schedule. Changes in the duration of elective surgeries may also disrupt the OR schedule. Therefore, the initial OR schedule may have to be adjusted throughout the day to ensure that it is still possible to execute.

The new OR schedule must fulfill quite a number of restrictions, and in addition, there are several stakeholders whose preferences should be taken into account. Since it is hard for an OR-manager to consider all these restrictions and preferences simultaneously, we developed a decision support system (DSS), which supports the OR-manager. The proposed approach is general, but the realisation and used preferences are based on data from a specific hospital in the Netherlands.

In the next section, we discuss the various stakeholders involved and their restrictions and preferences, based on a survey performed at the Isala Clinics, which is the above mentioned hospital in the Netherlands. Although these restrictions and preferences may differ between hospitals, the ideas of the method developed in this paper should be applicable for other hospitals too. Based on the achieved insights, we have developed a mathematical model that incorporates these restrictions and preferences to analyse which changes are preferred. These changes are incorporated as decision rules in the DSS. The developed DSS is tested by means of a simulation study to determine what improvements can be made to the OR schedule when the developed DSS is used in practice.

Restrictions and Preferences

The initial OR schedule is given by the assignment of the elective surgeries to an OR and the initially planned start times of the elective surgeries. Each surgery has an expected duration, however, in practice, the actual duration of a surgery generally deviates from this duration. When a surgery takes less time than expected, the initial OR-schedule is not disrupted. However, it may be beneficial for the OR and other departments to schedule this next surgery earlier. When a surgery takes longer than expected, the next surgery may have to start later. This results in a shift of the not yet started surgeries in this OR. Because of this, some restrictions may be violated. In addition, emergency surgeries may arrive which also disrupt the initial OR-schedule. Therefore, throughout the day, a new OR schedule may have to be created for all elective and emergency surgeries that still have to be performed. In this section, we first consider the overall restrictions for rescheduling surgeries throughout the day. Then, we consider all stakeholders involved when changing the OR schedule and discuss their restrictions and preferences.

Overall restrictions

Rescheduling is done by assigning a new start time to each surgery. Note that we do not allow the elective surgeries to be assigned to another OR as this might lead to larger disruptions in the processes. Within the rescheduling, it may be necessary to cancel an elective surgery. Note that we do not consider the rescheduling of a cancelled surgery, because we only focus on rescheduling within the day and not from day to day.

The new start time of a surgery should fulfill a number of restrictions. It should be greater than or equal to (i) the ready time of the patient, (ii) the start time of the assigned surgeon , and (iii) the start time of the assigned OR. In addition, there may be some surgeries that should start before a certain time because of medical reasons, and therefore, cannot be cancelled.

The Patient
The key stakeholder is the patient. For patients it is important that the surgery takes place at the scheduled time. Penalty costs are incurred when the new start time deviates from this preference.

Ward
Prior to surgery, patients are admitted to a ward where they are prepared for surgery. The survey showed that when a surgery starts earlier or later than scheduled, the workload on the ward increases. Therefore, penalty costs are incurred when there is a change in the start time of a surgery.

Holding Department
After the preparation on the ward, the patient is transported to the holding department to be further prepared. A limit on the number of patients who can be treated simultaneously is determined by the number of available nurses and beds.

The survey at the Isala Clinics showed that the holding department prefers a levelled amount of patients that are present at each point of time. Therefore, penalty costs, specified by the manager of the holding department, are incurred when the number of patients exceeds a certain threshold.

Anaesthetist
The anaesthetist is responsible for administering and reversing anaesthesia on one or more ORs. However, during the surgical procedure, the anaesthetist does not have to be present in the OR, because the presence of an anaesthesia nurse is enough. Therefore, we do not allow that more than one anaesthesia is administered or reversed at a time in the ORs to which the anaesthetist is assigned.

However, there are a few exceptions. When a surgery is complex, for example when the patient is younger than six months, the anaesthetist must be present during the complete surgery, including the surgical procedure. This means that during this time no anaesthesia can be administered or reversed in one of the other assigned ORs.

Surgeon
The surgeon is assigned to one OR and only has to perform the surgical procedure. This means that he/she does not have to be present during administering and reversing anaesthesia. The surgeons indicated in the survey that they do not have any preferences concerning a change in the OR-schedule as they consider the patient to be the most important.

OR Assistants
The OR-assistants do not impose any restrictions on the OR-schedule. Their only preference is that overtime is minimised. Overtime can occur due to emergency surgeries and surgeries that take longer than expected. Therefore, penalty costs are incurred when there is overtime.

> The simulation study shows that by using this DSS, fewer surgeries are cancelled and patients and wards are more satisfied, but also that the workload of several departments increases to compensate for this

Recovery Department
After surgery, the patient is transported to the recovery department to be monitored while recovering from surgery. The limit on the number of patients who can be monitored simultaneously is determined by the number of available nurses and beds.

Like the holding department, the recovery department also prefers a levelled amount of patients that are present at each point of time. Therefore, penalty costs are incurred when the number of patients exceeds a certain threshold.

Radiology Department
For some surgeries, an X-ray machine is needed during surgery. For these surgeries a radiology technician should be present during administering anaesthesia and the surgical procedure. This means that he/she does not have to be present during reversing anaesthesia. We restrict the number of required radiology technicians to be smaller than or equal to the number of available radiology technicians.

The survey showed that it is important for the radiology department that their employees at the OR department finish as early as possible so that they can carry out other work in the radiology department. Therefore, penalty costs specified by the radiology department are incurred when a radiology technician finishes later than needed, i.e., when the time the radiology technicians are present is longer than the time the radiology technicians are needed.

Pathology Department
During some surgeries, tissue is removed from a patient that needs to be examined by a pathologist. After the surgical procedure, the tissue is transported from the OR to the pathology department. When tissue arrives after closing time and overtime is needed penalty costs are incurred.

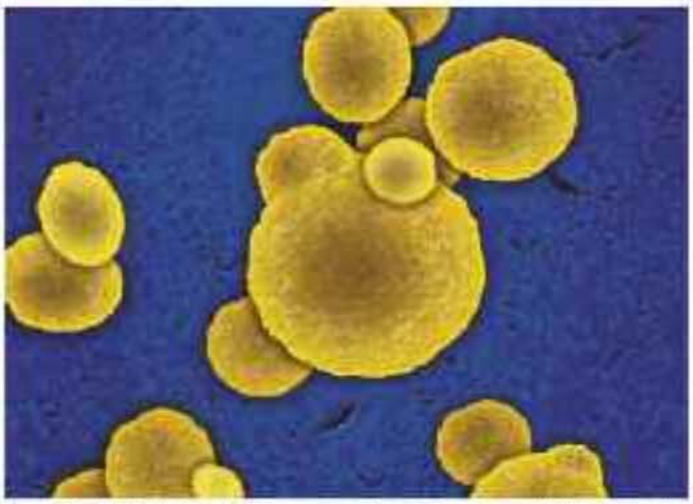
Logistic Department
The logistic department is responsible for preparing materials needed during surgery. The materials are laid out in the order in which the surgeries are scheduled. When two surgeries are interchanged, penalty costs specified by the logistic department are incurred, because they have to change the order in which the materials are laid out.

Decision Rules

All the restrictions and preferences described in the previous section are combined in a mathematical model (Van Essen et al. 2012). The model is used to determine optimal adjustments of the OR-schedule, however, the computation time of this model is too long to make the model applicable in practice. Therefore, the solutions obtained by this model are only used to determine which changes are preferred by the stakeholders in the solutions obtained by the mathematical model.

We tested the model on three scenarios for Isala Clinics. For each of the scenarios, we only considered surgeries that started or arrived after a certain point in time. Table 1 shows that for Isala Clinics, shifting a sur-

Pre-Surgical Screening of *Staphylococcus aureus* and Methicillin-Resistant *Staphylococcus aureus* Can Reduce Surgical Site Infection rates and Hospital Costs



The BD MAX StaphSR Assay can detect S.aureus and MRSA in under two hours, allowing healthcare facilities to begin treatment earlier

Surgical site infections (SSI) now affect approximately 5% of all surgical patients and are the second most frequent cause of health-care associated infections (HAI). They adversely impact mortality and patient quality of life and result in prolonged hospitalization. In the U.S., approximately 500,000 to 750,000 SSIs occur annually, resulting in an overall mortality rate of 3% and increasing to a rate of 20% or higher for cardiac patients. According to the CDC, on average each SSI increases a patient's hospital stay by more than a week and hospital charges by more than $3,000.

The National Healthcare Safety Network (NHSN) reports that *Staphylococcus aureus* (*S. aureus*) is the predominant organism of SSI (SA-SSI), accounting for about 30% of all infections. Approximately 25-30% of healthy people are colonized with *S. aureus*, while only about 5 to 8% of people carry methicillin-resistant *Staphylococcus aureus* (MRSA), which is more commonly associated with exposure to healthcare institutes. Most SA-SSI derive from a person's own flora and carriers of *S. aureus* have three to eight times the risk of acquiring an HAI with this organism. Studies have now shown that SSIs can be prevented by conducting preoperative screening to identify patients colonized with *S. aureus* or MRSA, followed by targeted decolonization and/or antibiotic prophylaxis. This strategy can also improve patient outcomes by positioning healthcare professionals to introduce interventional strategies for SSIs before the development of painful and potentially life-threatening complications.

A recent Dutch randomized controlled trial evaluated the benefits of screening surgical patients for *S. aureus* through a real-time polymerase chain reaction assay. In results published in the **New England Journal of Medicine**, the authors provided strong evidence indicating that rapid identification of patients carrying *S. aureus* combined with peri-operative decontamination using mupirocin nasal ointment and chlorhexidine gluconate soap can reduce the rate of SA-SSI development by nearly 60%, while causing very few side effects. The study also found that this method reduced the mean hospital stay for patients by almost two days.

A second study in the Netherlands found that a "screen-to-treat" strategy helped to reduce per patient hospital costs by €2,000 and showed an annual savings to the study hospital of $1.5M. Targeted decolonization and/or antibiotic prophylaxis for *S. aureus* and MRSA carriers can also help reduce the use of un necessary antibiotic therapy and preserve maximum efficacy in antimicrobial treatments.

A study published in **Infection Control and Hospital Epidemiology** found that while 60% of infectious disease physicians perform preoperative screening for *S. aureus*, only 13% screen for both *S. aureus* and MRSA. Although screening strategies vary among physicians and hospitals, a screen-to-treat is positioned to deliver optimal results with the use of rapid molecular tests able to detect deadly superbugs in pre-surgical patients. In recent years, researchers at BD introduced the BD GeneOhm™ StaphSR Assay, a test that detects *S. aureus* and MRSA in less than two hours. Traditional culture-based testing can take up to three days to confirm detection. More timely detection can position hospitals and other health facilities to initiate treatment earlier while quarantining colonized patients and introducing other forms of intervention that can both improve outcomes and reduce the risk of new infection among patients and healthcare workers.

Based on the most recent data, broader use of a screen-to-treat strategy targeting both *S. aureus* and MRSA can help reduce the risk of SSIs for surgical patients while reducing average length of hospital stay and overall hospital costs.

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gery is the most frequent adjustment used, and we also see that often a break is scheduled between two surgeries. The latter may not seem optimal with respect to OR utilisation, however, these breaks can improve the perceived workload of other departments or may be necessary to fulfill the restrictions. Therefore, we incorporate the following two decision rules into our DSS:

1. Shifting a surgery
2. Schedule break between two surgeries

Table 1: Results scenario 1, 2, and 3

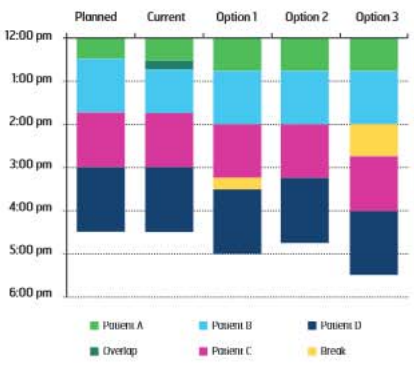
	10 a.m.	12 p.m.	2 p.m.
Number of surgeries	754	584	377
Rescheduled surgeries	566	416	213
Shifted surgeries	375	297	176
Exchanged surgeries	1	0	0
Cancelled surgeries	0	0	1
No break	264	183	71
Break 15 minutes	166	112	66
Break 30 minutes	62	33	21
Break 45 minutes	22	19	11
Break > 45 minutes	38	37	13

Decision Support System

To make our method applicable in practice, we have developed a DSS which can be used by the OR-manager. We incorporated the two decision rules that are derived in the previous section. The user can indicate for which OR the schedule should be adjusted. Then, the DSS presents the three best options to the user. A screenshot of the DSS is shown in Figure 1.

To determine the effect of using the DSS in practice, we tested the developed DSS on data of Isala Clinics by means of a simulation study. The results in Table 2 show that the DSS provides a much better solution than the original realised OR-schedule of the Isala Clinics as the total penalty costs are reduced by approximately 50%. In addition, the results show that the penalty costs for the patients and wards decrease, however, the penalty costs for the OR-assistants and the recovery, radiology and pathology departments increase. The penalty costs for the mentioned stakeholders increase because surgeries cannot be cancelled or exchanged and thus, more surgeries have to be done in overtime. Concluding, the use of the DSS provides a better trade-off between the preferences of the involved stakeholders and by this reduces the incurred penalty costs significantly.

Figure 1: Screenshot DSS



Conclusions

In this article, we treated the problem of rescheduling surgeries on the day of execution. We formulated a mathematical model that determines the best adjusted OR-schedule at a given point in time. The achieved results show that, with a few exceptions, the only used adjustments are (i) shifting surgeries, and (ii) scheduling breaks between two surgeries. These two decision rules are incorporated in a developed DSS. This system determines the best adjusted schedule for one OR with respect to the given restrictions. The simulation study shows that by using this DSS, fewer surgeries are cancelled and patients and wards are more satisfied, but also that the workload of several departments increases to compensate this.

Further research could focus on including the Central Sterile Supply Department (CSSD) into the model. This department prepares the instrument sets needed for a surgery. When a surgery is added to the OR-schedule during the day, this may influence the workload on the CSSD. In addition, the CSSD may impose some extra restrictions on the OR schedule.

There are several ways in which the developed DSS can be used, for example, to reschedule an OR immediately when it is disturbed or reschedule all ORs at some moments in time. The last example also raises the question in what order the ORs should be rescheduled. Therefore, it is interesting to investigate good ways to use the DSS.

Table 2: Results simulation study DSS

Total penalty costs	Realised OR-schedule	
	Original	DSS
Cancellation	66.67	0.00
Patient	40.91	29.50
Wards	34.40	21.44
Holding	0.00	0.00
OR-assistants	6.43	12.12
Recovery	8.85	14.70
Radiology	2.41	2.78
Pathology	0.70	1.14
Logistics	9.26	0.00
Total costs	87.03	45.13

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References:

Operating room planning and scheduling: a literature review. **B. Cardoen, E. Demeulemeester, J. Beliën.** 3, 2010, European Journal of Operational Research, Vol. 201, pp. 921-932.

ORchestra: an online reference database of OR/MS literature in health care. **P.J.H. Hulshof, R.J. Boucherie, J.T. van Essen, E.W. Hans, J.L. Hurink, N. Kortbeek, N. Litvak, P.T. Vanberkel, E. van der Veen, B. Veltman, I.M.H. Vliegen, M.E. Zonderland.** 4, 2011, Health Care Management Science, Vol. 14, pp. 383-384.

Decision support system for the operating room scheduling problem. **J.T. van Essen, J.L. Hurink, W. Hartholt, B.J. van den Akker.** 4, 2012, Health Care Management Science, Vol. 15, pp. 355-372.