Framework for a retrospective analysis of operating room schedule execution

Leah Rifi, Franck Fontanili, Maria Di Mascolo, Clea Martinez

FRAMEWORK FOR A RETROSPECTIVE ANALYSIS OF OPERATING ROOM SCHEDULE EXECUTION

Leah RIFI[1], Franck FONTANILI[2], Maria DI MASCOLO[3], Cléa MARTINEZ[4]

[1] IMT Mines Albi, Allée des Sciences 81000 Albi, +33629693376, leah.rifi@mines-albi.fr
[2] IMT Mines Albi, Allée des Sciences 81000 Albi, +33620856033, franck.fontanili@mines-albi.fr
[3] Grenoble Institute of Technology, 46 Avenue Félix Viallet, 38031 Grenoble, +33671214714, maria.di-mascolo@mines-albi.fr
[4] IMT Mines Albi, Allée des Sciences 81000 Albi, +33679635720, clea.martinez@mines-albi.fr

RESEARCH WORK FUNDED BY OCCITANIE / PYRÉNÉES-MÉDITERRANÉES REGION (FRANCE)

BIOGRAPHICAL STATEMENTS

Leah RIFI (F) is a first year PHD student. She works under the supervision of both the Industrial Engineering Department of IMT Mines Albi and the G-SCOP (Grenoble-Sciences for Design, Optimization, and Production), a laboratory of the Grenoble Institute of Technology.

Franck FONTANILI (M) is an Associate Professor at the Industrial Engineering Department of IMT Mines Albi, France. His research activities focus on the use of discrete event simulation-based digital twin in healthcare operational process. He has achieved several industrial studies and research projects based on discrete event simulation and associated tools such as BPM, RTLS, Process and Data Mining. He is a laureate of the AP-HP Paris & CHU Nantes call for Expression of Interest on Digital Hospital of the Future in 2017, with a proposal on a Digital Twin of Patients Pathways.

Maria DI MASCOLO (F) is a Senior Researcher at the CNRS (French National Centre for Scientific Research), and a member of the G-SCOP (Grenoble-Sciences for Design, Optimization, and Production) laboratory. Her main scientific interests are related to the modelling, analysis, and optimisation of systems for the production of goods and services, and in particular healthcare production systems. She co-leads the GISEH (Hospital Systems Management and Engineering) working group of the SAGIP (French Society of Automatic Control, Industrial and Systems Engineering) https://www.sagip.org/fr/gt/giseh and is editor-in-chief of the ISTE OpenScience journal "Industrial and Systems Engineering", https://www.openscience.fr/Industrial-and-Systems-Engineering?lang=en

Cléa MARTINEZ (F) received the Ph.D degree in Industrial Engineering from Université Grenoble Alpes, France. She is currently working as an assistant professor at IMT Mines Albi, France. Her research interests lie in the areas of operations research, scheduling and optimization applied to healthcare systems.

ABSTRACT

The execution of an operating room schedule is constantly disrupted, which can decrease the initially targeted performance. Online operational management, which oversees daily activity, can reduce the deviations caused by disruptions between the initial schedule and the performed schedule. To support this process and encourage continuous improvement, we suggest a framework for *analysing schedule execution in retrospect*. The objectives are twofold: (1) to identify deviations and determine their root causes, and (2) to assess the relevance of the decisions made to reduce these deviations. This approach relies on a *logbook* to gather qualitative data on disruptions, and a *dashboard* to objectify the situation with computed indicators. We present an example of a schedule execution analysis in an anonymised French General Hospital.

Keywords: OR; operating room; surgical suite; inductive approach; retrospective analysis; online operational management; schedule disruptions; schedule deviations; uncertainties; continuous improvement.

1. INTRODUCTION

The surgical suite's performance impacts the hospital's performance. Indeed, service costs account for 10% of the hospital's budget (Macario et al., 1997) and surgical operations make up 60% of hospital admissions (Fügener et al., 2017). The operating room (OR) is gradually becoming the cornerstone of the care process. To perform well and deliver quality care while ensuring the safety of the patient, the surgical suite's relationship with external services as well as the coordination of its professionals are critical (Alameda et Macario 2017). Thus, to better organise this strategic resource, scientific research has increasingly focused on OR management over the last two decades. In this article, we suggest a framework for assessing the quality of the execution of the schedule the day of surgery.

The remainder of this article is organised as follows: Section 2 is our literature review. Section 3 presents our framework for a retrospective analysis. Section 4 describes an example of an application of the proposed approach. Finally, we present our limitations, our conclusion, and perspectives for further work.

2. LITERATURE REVIEW

Table 1 lists definitions and terminologies of the literature review needed to understand our article. Usually, the term "OR" can be used for both the surgical suite and the operating room. However, as this article requires a clear distinction between the two terms, we refer to a *surgical suite* as the surgical department in which operating rooms are clustered, and to an *operating room* (OR) as the surgical room in which cases are performed.

Figure 1 depicts a simplified timeline, based on our empirical observations, of the steps performed for each patient in an operating room. A *case* is the sum of a surgery and a room clean-up.

First, before beginning the surgical schedule, the staff must fill out an *OR opening checklist* to ensure that the room's equipment is in good condition (1st step). Then, for each case, the nursing staff carry the patient into the OR for the surgery (2nd step). Other professionals such as the anaesthesiologist and the surgeon participate during this phase too. Finally, the nurses and the patient leave the OR after the surgery while the OR assistants (ORA) enter to *clean-up* the room (3rd step). Once the ORA leave, the next case can start (4th step).

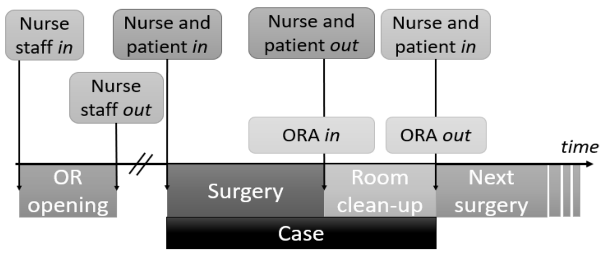

Figure 1: Simplified timeline of tasks performed for each patient in an OR

In this literature review, we first describe the core processes of the surgical suite. Second, we address the uncertainties related to its settings and processes. Third, we present solutions suggested by the scientific community. Finally, we synthesise the literature review and highlight the contributions of this article.

2.1. The surgical suite's core process: planning and scheduling

The patient's pathway in the surgical suite is characterised by the urgency of the surgery (elective or non-elective) and the admission type (inpatient or outpatient). *Elective patients* do not require immediate treatment. They are first put on a waiting list before being scheduled for a specific time. On the contrary, *non-elective* patients have an unknown arrival time and need to undergo surgery as soon as possible. Inpatients stay at least one night at the hospital whereas outpatients come and go during the same day. Further definitions can be found in (Zhu et al., 2019; Gupta 2007).

One of the main challenges in the surgical suite is to ensure safe and high-quality care to patients in a cost-effective way while preserving staff satisfaction. Consequently, hospitals must have a specific planning and scheduling process to design and deliver surgical care.

The decisions involved in this process are implemented across three hierarchical levels: strategic, tactical, and operational (which can be divided into online operational and offline operational).

In the long term (6-12-month horizon), the *strategic level* deals with capacity decisions that align available surgical suite resources with the forecasted medium- to long-term demand of care. In the medium term (1-2-month horizon), the *tactical level* addresses resource usage. This includes the Master Surgical Schedule, a cyclic schedule that describes OR time slots in terms of start and end times, surgical specialty, staff needed, etc. In the short term, the *operational level* is divided into *offline* and *online* management. *Offline operational* decisions (1-week horizon) are made during the construction of the schedule: each patient is assigned to a date, a starting time, and specific resources (Zhu et al., 2019). *Online operational* decisions (1-day horizon) are real-time decisions made during the execution of the schedule. They deal with disruptions that deviate the performed schedule from the initial schedule (Hulshof et al., 2012; Hans et Vanberkel 2012). Consequently, (Hulshof et al., 2012) defines online operational planning as "the control mechanisms that deal with monitoring the process and reacting to unplanned events".

Higher-level decisions constrain the flexibility of those at the lower level (Dexter et al., 2004). For instance, the OR staff decide on the scheduling strategy of the surgical suite (strategic level), build the corresponding surgical schedule for every workday (tactical and offline operational level), and finally execute the schedule (online operational level). In this article, we will focus on the latter part.

Table 1 - Definitions and terminologies relevant to our article

Term	*Definition*
Operating Room (OR)	A room where surgical cases are performed
Surgical Suite	A group of operating rooms where *surgical services* share *allocated OR time*. It is usually comprised of waiting rooms and recovery wards, storage rooms, staff changing rooms, and offices (Alameda et Macario 2017).
Surgical Service	A group of one or several surgeons (Dexter et al., 2004).
Allocated OR Time (AOT)	The hours during which it is possible to perform a surgery in the OR. An *OR time slot* is an allocated OR time with a fixed start time, end time, and day of the week assigned to a surgical service (Dexter et al., 2016).
Initial Schedule (IS)	The sequence of cases with their allocated resources, which is confirmed the day before (May et al., 2011).
Performed Schedule (PS)	The schedule effectively executed throughout the day. It is referred to as the realised schedule in (May et al., 2011).
Overutilised OR time	The positive difference between the duration of the performed cases and their turnover and the AOT for the same OR (Dexter et al., 2004; Strum et al., 1999).
Underutilised OR time	The positive difference between AOT and the duration of the performed cases as well as their turnover for the same OR (Dexter et al., 2004; Strum, et al., 1999).
Inefficiency of use of OR time	This is calculated by using the following formula: {nb of hours of underutilised OR time}*{cost per hour of underutilised OR times} + {nb of hours of overutilised OR time}*{cost per hour of overutilised OR times} (Dexter et al., 2004).
OR efficiency	This is the value that is maximised when the inefficiency of use of OR times has been minimised (Dexter et al., 2004).

In France, the responsibility for online operational management (OnOM) was historically scattered among OR professionals. It was then explicitly integrated into OR managers' duties. Recently, OnOM has increasingly been supervised by single individuals or teams of experienced nurses as well as by former paramedical or medical OR managers. These professionals are called *regulators* or *coordinators*.

They make real-time decisions on the day of the surgery to (1) execute, monitor, and control the OR schedule, and (2) react to unexpected events. In other words, the OnOM is responsible for reducing the gaps between the initial schedule (IS) and the performed schedule (PS) by limiting or even preventing the impact of uncertainties on the ongoing surgical schedule. (Hulshof et al., 2012; Hans et Vanberkel 2012).

As stated in (Dexter et al., 2004), disruptions are inherent in the functioning of the surgical suite and its ORs. In the following part of this literature review, we will try to describe how uncertainties can affect the surgical suite and thus make the execution of the surgical schedule more challenging.

2.2. Description of uncertainties in the surgical suite environment

The surgical suite is a complex environment: it includes all the conditions stated by (Ladyman et al., 2013). First, it is a service assembling multiple medical, paramedical and management professions that all aim to ensure the execution of the schedule (an ensemble of many elements). Second, all these individuals communicate and are dependent on one another (interaction). Finally, although the surgical suite is a place of uncertainty (disorder), standardised processes exist (robust order) and information is stored in both human memory and in OR software (memory).

In this article, we will focus on one of the major difficulties encountered in the surgical suite environment: uncertainties. Even though they are bound to happen, they are very hard to predict accurately. Thus, it is known from the start that the IS might deviate. Figure 2 shows the causality chain that leads to schedule deviations.

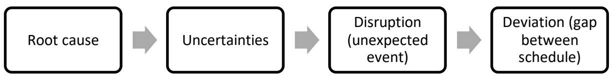

Figure 2 – Causality chain

(Zhu et al., 2019) lists four main uncertainties that are considered in the literature because of their negative impact on the schedule: (1) *surgery duration uncertainty* refers to potential deviations between the actual and the planned duration of perioperative tasks; (2) *patient arrival uncertainty* is defined by the unpredictable arrival time of patients (inpatients or outpatients); (3) r*esource uncertainty* is described as the availability and variability of human, material, and architectural resources; and (4) c*are requirement uncertainty* refers to the fact that professionals cannot always forecast what care the patients will need during their stay at the hospital.

Table 2 provides a synthesis issued from our literature review on the classification of uncertainties, with their causes and the disruptions they can bring (Cardoen, et al., 2010; May et al., 2011; Zhu et al., 2019).

Uncertainties can cause unexpected events called *disruptions*. Disruptions can result in gaps between the IS and the PS that are called *deviations.* Deviations can

Table 2 – Potential causes and consequences of uncertainties

Uncertainties	*Causes*	*Disruptions*
Surgery duration	surgical complication	early or late exit of the patient from the OR
Patient arrival	weather, traffic, or individuals' own situations for outpatients and non-elective surgeries, porters for inpatients	tardiness of patient, no show or non-elective patient arrival
Resource	arrival uncertainties, restrictions imposed to reduce OR costs, delays in support services, or breakdown of medical equipment	tardiness of surgeon or anaesthesiologist, insufficient nursing staff, unavailability of equipment or ready-to-receive patient OR.
Care requirement	patient situations evolve and are not always predictable	insufficient human, material, or architectural resources.

be linked to resources, to patients or to staff. For example, because of resource *uncertainty*, staff may lack the required material for the surgery (*disruption*). Consequently, the patient enters the OR 20' later than initially scheduled (*deviation*).

As already mentioned, online operational management takes place in a very complex environment. Thus, to ensure the proper execution of the schedule, the coordinator must handle each disruption while considering the specifications of the patient pathway, the internal situation of the surgical suite as well as the constraints brought by upstream and downstream services.

All these complexities make it difficult to follow the IS. Consequently, scientific research has been providing continuous efforts over the last decades to improve the fluidity of the surgical schedule.

2.3. Efforts made to ensure the proper execution of the surgical schedule.

There are different ways of improving OR operational performance.

First, certain steps of the patient pathway are particularly attractive to researchers because they are easier to standardise or are a major source of inefficiency.

(Panni et al., 2013; Cox Bauer et al., 2016) study *late start* delay, which is the duration between the real and the scheduled start times of a case. (Kodali et al., 2014; Gottschalk et al., 2016; Cerfolio et al., 2019) study OR *turnover time*, which is the time between the OR exit of a patient and the OR entry of the following one. More recently, (Fong et al., 2016; Athanasiadis et al., 2020a; Athanasiadis et al., 2020b) have also worked on perioperative time, which is the step during which the patient is in the OR. Except for (Fong et al., 2016), each of these studies starts with an audit. When possible, the authors suggest improvement methods and describe their obtained results.

Second, both hard and soft skills are required by the OR staff to take care of the patient efficiently and safely. Indeed, while technical skills are necessary, communication and teamwork are essential. (Russ et al., 2013a; Russ et al., 2013b; Müller et al., 2018) address tools that can be used to support and assess both types of skills.

Finally, it is also possible to adapt industrial approaches such as Lean Six Sigma to the surgical suite (Tagge et al., 2017; Cima et al., 2011).

No matter how competent surgical suites are, disruptions are unavoidable. Consequently, strong online operational management can help orchestrate the actions of all actors and make real-time decisions on the day of the surgery. (Dexter et al., 2004) review 10 years of decision-making processes on the day of surgery and suggest a decision framework for dealing with daily schedule disruptions. (Dexter et al., 2007a) show that only explicit recommendations improve the quality of decisions. Indeed, with only passive and active status displays, staff tend to make decisions that result in performance degradation. (Dexter et al., 2007b) point out that these decisions are not motivated by reducing patient and surgeon waiting times but rather by increasing the OR work pace. Finally, (Dexter and al., 2011) propose a decision support system that provides recommendations to increase OR efficiency for scenarios occurring before and during the day of surgery.

On a side note, we point out the fact that the scientific literature strongly emphasises how important it is to accurately plan AOT before the day of surgery. (Strum et al., 1999) define *overutilised* and *underutilised OR times.* They propose a minimal cost analysis model to estimate AOT durations that minimises the costs of underutilisation and overutilisation per subspecialty. (Dexter et al., 2004) defines (i) *inefficiency of OR time* as the sum of the costs generated by underutilised and overutilised hours combined for that hour, and (ii) *OR efficiency* as the value maximised when the inefficiency is minimised (see Table 1). They use OR efficiency as one of the four priorities to consider when making OR management decisions. Efficiency is thus recommended as a crucial indicator when constructing and executing the OR schedule. For instance, in (Shi et al., 2016;

Dexter, et al., 2012), the authors dimensioned the AOT to minimise the inefficiency of use of OR time.

2.4. Contributions of this article

The planning and scheduling process is the key to aligning patient demand with surgical suite resources and to providing quality care in an efficient manner. However, because of the uncertainties linked to surgical suite management, schedule execution can become problematic.

In this literature review, we have described the core processes and the uncertainties of the surgical suite. We have presented a state-of-the-art of efforts made to ensure proper schedule execution on the day of surgery.

First, we highlight the importance of a strong OnOM. Under these circumstances, it is particularly interesting to study how the OnOM handles schedule deviations. Thus, in this article, we address the following research question: **How can we assess the way online operational management deals with deviations between the initial and the performed schedules to reach the targeted OR performance?**

Second, as we have seen, an audit is the first required step for improving OR performance. The audits presented in this literature review focused on specific steps of the patient pathway as well as on the surgical team or the anaesthesiological team. In our article, we follow the professional in charge of online operational management throughout the entire surgical suite as they ensure the proper OR schedule execution.

Finally, thanks to (Dexter et al., 2004), OR managers have access to a framework for guiding online management decisions. However, even if they describe the general situation during which there is a need to make a decision, they do not describe how to retrospectively identify the moments where decisions should have been made during a specific day of surgery. Thus, we suggest a solution for identifying deviations and working back to the disruption that caused them so that we can point out all the times the online operating management should have made a decision.

In this article, we propose a framework for a retrospective analysis of the daily execution of the schedule. The final goal of the framework is to assess the quality of the schedule's execution and thus, the quality of the *online operational management* (OnOM). To do this, the framework aims to accurately describe the execution of the OR schedule, describing the deviations and their root causes, and assessing the relevance of the OnOM's decisions.

This framework is a method for assessing the quality of the schedule's execution and not a solution for reducing the gaps between the IS and the OS. It stems from a continuous improvement strategy of the OnOM.

3. PROPOSITION OF A FRAMEWORK FOR A RETROSPECTIVE ANALYSIS

This framework is the result of an inductive approach, based on empirical observations and analysis of our partner's surgical suite as well as on our literature review. In the following section we first present our general framework. Then we describe the three components of the framework: (1) a dashboard, (2) a logbook and (3) an analytic process. Finally, we explain how to adapt the general framework to a specific surgical suite.

3.1. General framework overview

Figure 3 describes our general framework. It guides the user to (1) gather the relevant data on the execution of the schedule for a specific day, (2) remove the deviations due to inconsistent scheduling, (3-4) study the schedule execution at the scale of the surgical suite and the OR, (5) identify the deviations, (6) link the deviations to their root causes, and (7) assess the quality of the execution of the schedule.

We recommend paying attention to the following facts. First, we recommend performing steps 2 to 7 shortly after the day of the observation (step 1) so that the feedback stays relevant. Indeed, OnOM days are filled with events and we noticed that after a lapse of time there is a tendency to forget what happened on a specific day and to focus on new specific dysfunctions.

Second, to collect the required data for the study, the user should have access to the Master Surgery Schedule and to both the initial IS and PS.

Third, the framework's application does not need a real-time display of timestamps. Information on the patient pathway can be collected at the end of the day via OR software data extraction. If timestamps are not available in the OR software, then one possibility would be to ask the staff to write the data in real time and then collect it at the end of the day. This would, however, make the study more onerous on the staff.

Finally, in this framework, we consider that the calculations of the Allocated OR Time have already been set. Optimal AOT is not necessary for the framework to be relevant; however, it would greatly facilitate the work of the regulator.

3.2. Description of the general framework

In this section, we will present in detail the three components of the framework: the dashboard, the logbook, and the analytic process of the framework.

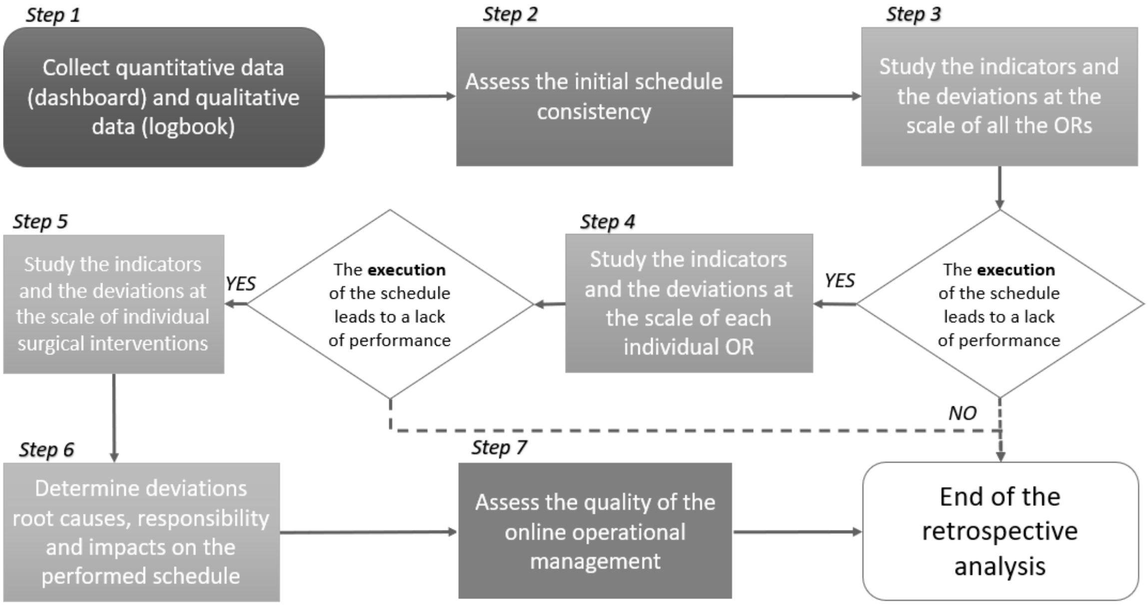

Figure 3 : A 7-step process to guide the retrospective analysis

3.2.1. Dashboard presentation

The dashboard computes Key Process Indicators (KPIs) for the IS and PS as well as the differences between them. It helps in studying the schedules and highlighting the deviations.

The scientific literature abounds with indicators set to manage surgical suite activity (Macario 2006). The multiplicity of stakeholders of the surgical suite makes it hard to find a unique set of KPI. Hospital administrators tend to be more interested in high utilisation and low costs, surgeons in high throughput, anaesthesiologist and paramedical staff in low overtime, and patients in short waiting times (Samudra et al., 2016).

We decided to use, among others, the KPIs and their targets recommended by the French national agency for the performance support of healthcare and medico-social facilities, also known as the ANAP (ANAP 2016). We describe these 5 indicators in the paragraph below.

The **utilisation** time is the sum of case durations (surgery plus clean-up) during allocated operating hours. The **late start** is the duration between the OR start time and the first patient entry. It includes the duration needed for the OR opening needed before the first patient. Consequently, it is expected to be between 10'-15'. The **early stop** (or underrun) is the duration between the moment the last clean-up finishes and the OR end time. The **overtime** (or late finish or overrun) is the sum of *surgery* durations outside of opening hours. It does not include clean-up. In this article, we focus on **restrained overtime**, which is the overtime taking place up to an hour after the end of the allocated OR time. The **idle time** is the operating time during which the OR is not utilised. It can be one of three possibilities: (1) **waiting for the clean-up**: the unclean OR is empty because ORA(s) have not started the clean-up, (2) **waiting for the patient:** the cleaned OR is empty because the patient has not entered it yet, (3) **early stop**: the OR is empty because there are no more scheduled surgeries. We will focus on **idle time between cases during allocated OR time**: waiting for both the clean-up and the patient. Table 3 concisely presents these indicators with their targets.

Table 3: Indicators used in this article, extracted from ANAP KPI recommendations.

Indicator	Definition	ANAP Target
Utilisation rate (UR)	[Utilisation time] / AOT	85%
Late start rate (LSR)	[Unused time at the start of the time AOT] / AOT	< 5%
Early stop rate (ESR)	[Unused time at the end of the AOT] / AOT	< 5%
Restrained overtime rate (ROR)	[Sum of the surgery duration outside of the AOT less than an hour after or before the AOT] / AOT	< 5%
Time between cases rate (BCR)	[Unused time between the cases during the AOT] / AOT	< 5%

Table 3 presents indicators that are ratios of specific durations over the AOT. Within our framework, we compute these KPIs at different spatial scales: the case, the OR, and the surgical suite.

Let's illustrate with an example of a surgical suite with two operating rooms: OR1 and OR2. OR1's utilisation rate is 85%. 2 cases are scheduled in OR2 with case times of 90' and 75'. The AOT of OR2 is 240'. The utilisation rates of the surgical suite and OR2 are:

UR_{OR2}= (90+75)/240=68.75%

UR_{suite} = (68.75+85)/2 = 76.87%

3.2.2. Logbook presentation

The logbook describes the schedule disruptions or deviations that the OnOM handled during the day as well as the actions it took to integrate them into the schedule or to anticipate them. Table 4 describes the information required for each disruption and deviation noticed by the OnOM.

Table 4: Description of the logbook

Fields	Data and information
Disruption or deviation	
ID	Unique disruption or deviation ID
Detection time	When did the OnOM notice the disruption?
Description	Possible to structure it with the five Ws: who, what, when, where, why
Impacts on the schedule	Impact on the PS in terms of unavoidable, potentially avoidable, or avoidable delay
Root causes	Possible to use the 5 Ws
Decision(s)	
Time	Decision time of the OnOM
Description	Considered and selected options. Justification of that choice.
Consequences	Decision's consequence on the schedule. Retrospective assessment of its relevance.

3.2.3. Analytic process presentation: a guide to using the dashboard and logbook

In this section we present in detail the steps of Figure 3. We refer to the agent(s) in charge of carrying out the analysis as "the user(s)", and to the agent(s) in charge of ensuring the execution of the schedule as the "regulator(s)" or "online operational management".

Step 1 – Collect quantitative data (dashboard) and qualitative data (logbook)

Since we are studying schedule supervision by the regulator, step 1 should occur during the regulator's shift. The objective of this step is to gather the qualitative and quantitative data relevant to the observation period we seek to analyse. To do this, the user needs to fill in the logbook throughout the observation period and feed the dashboard at the end of the day.

Step 2 – Assess initial schedule consistency

During the day of the surgery, the online operational management uses the IS as a guide. Infeasibilities and failure to respect basic scheduling rules in the IS can lead to deviations and prevent KPI targets from being reached. For instance, if a 15% late start rate is initially scheduled, the OnOM is not likely to reach the "<5%" performance target. Consequently, the IS must be as coherent and efficient as possible (May et al., 2011).

In step 2, we check the consistency of the IS by checking whether basic schedule construction rules have been applied and by studying the estimation of case durations. (Kroer et al., 2018) identifies the following infeasibilities: "*Big overlaps of operations (more than 5 min), operations planned outside the opening hours, operations performed by other specialities, and operations performed in ORs belonging to other specialities*". The user can adapt these to create their own IS construction rules to be respected.

This step should allow us to determine whether the schedule deviations are due to the construction of the schedule or to its execution. Consequently, the framework can continue to be useful even with an IS that cannot be truly used as a guide for the online operational management (for instance, if the capacity has not been planned appropriately).

Step 3 –Study the indicators and the deviations at the scale of all the ORs

During steps 3, 4 and 5, we study the indicators and their deviations at the scale of three successive levels: the surgical suite, the individual ORs, and the individual cases.

In step 3, we limit ourselves to the surgical suite perimeter as we try to determine if it is worth going on with our analysis, and, if so, how we could benefit from it. To do so, we compute the KPIs and their deviations at the surgical suite scale. Then, we check to see if they reached their target and we interpret the obtained results.

Step 4 – Study the indicators and the deviations at the scale of each individual OR

If the surgical suite indicators and deviations from step 3 identified a lack of performance, the user should move on to step 4 and study them at the scale of each OR (OR by OR).

Step 4 and 3 are similar, with the exception that in step 4, the indicators are calculated at the OR scale.

Step 5 – Study the indicators and the deviations at the scale of individual surgical cases

Step 5 is applied to each OR for which at least one indicator has not reached its target or for which the OnOM is potentially responsible for the deviations. In this framework we study the following deviations for each case: late start, early stop, restrained overtime, waiting for the clean-up and waiting for the patient.

For each of the deviations identified, we specify: its ID, nature, timestamps, and duration. If possible, we add under whose supervision it happened. Since we are focusing on the OnOM, as soon as the responsibility of a deviation can be linked to flawed Offline Operational Management (OffOM), it is removed from the study.

We find it important to point out here that even if the OnOM is found responsible, this does not imply that they are to blame. For instance, their inability to properly handle the deviation can stem from a lack of suitable tools or an unachievable IS.

We illustrate this step in Table 5 with a deviation called "waiting for the ORA". This refers to the delay during which the OR is empty, but the clean-up by the operating room assistant(s) has not yet started.

Table 5: Example of deviation identification: step 5

ID	2
Deviation nature	Waiting for the ORA
Timestamp	11h25-11h35
Duration	10’

Step 6 - Determine root causes of deviations, responsibility and impacts on the performed schedule

First, we cross-check data from both the dashboard and the logbook to identify the root causes and the responsibility for the deviation. Second, we label the impact on the schedule as avoidable *or unavoidable delay/advance*. For instance, if the first case in the IS begins at the same time as the OR start time, then a late start will be unavoidable since the nurses will not have time to set up the OR. However, unnecessary patient waiting time due to nurses being on a break is avoidable. We completed our illustrative example in Table 6.

Table 6 : Example of deviation identification: step 6

ID	2
Root cause	The ORA are taking a break
Responsibility	ORA and OnOM
Impact	Avoidable delay

Step 7 - Assess the quality of the online operational management

In this final step, we assess how the OnOM handled the schedule deviations it is potentially accountable for. Firstly, we check to see if the OnOM noticed the deviation and describe the actions taken in response. Secondly, we compare these actions to the root causes of the deviations. Third, we assess the quality of the OnOM according to the deviation’s impact on the PS and the surgical suite’s quality policy. It is possible to rely on (Dexter et al., 2004).

We conclude our example in Table 7.

Table 7 : Example of deviation identification: step 7

ID	2
Action	Inform the ORA that the patient is out of the OR.
Assessment	The action was relevant. However, earlier action could have prevented the delay.

Once the user finishes the data analysis, the results can be presented to the OnOM agent and other staff members with the objective of raising awareness of good practices, quantifying staff feelings/impressions, facilitating OR performance, etc.

This inductive approach-based framework that we have just described is a conceptual version that we extracted from our own surgical suite observations and from knowledge gleaned from the literature.

3.3. How to adapt the general framework to a specific surgical suite

In this last subsection, we describe, based on our own experience, the settings that can be adapted to a specific surgical suite.

Dashboard content. If the facility wants to add KPIs and targets to the dashboard, we recommend following these rules: (1) the KPI must be computed in the IS and PS, (2) the deviations between the schedules must be computed, (3) the KPI must allow the quality of schedule execution to be assessed. We encourage using the KPIs already proposed by the institution.

Dashboard format. The facility is free to choose the format of the dashboard. However, we recommend a format that allows the indicators and deviations to be computed shortly after the observation day.

Logbook format. The facility is free to choose the format of the logbook. However, we encourage a format that allows: (1) data to be gathered in almost real time, and (2) data to be structured shortly after the observation.

Analytic process settings. The IS construction rules are chosen in step 2. The management can add or remove rules based on the functioning of their own surgical suite.

4. ILLUSTRATION OF THE FRAMEWORK

In this last section, we will present a concrete application of the framework during a specific surgery day in an anonymised French General Hospital (AFGH).

First, we present the AFGH’s surgical suite. Second, we explain how we adapted the general framework. Third, we detail the steps of the analysis. This section only illustrates the framework; it does not to describe the results of a complete audit.

4.1. Context of the framework’s illustration

4.1.1. Brief presentation of the surgical suite

We have studied the 7-OR surgical suite of an Anonymised French General Hospital (AFGH).

The construction and execution of the OR schedule follows a three-step process based on a block scheduling policy. Firstly, at the *tactical level* and for the long-term horizon, the facility creates a Master Surgery Schedule. This cyclic schedule distributes the already agreed upon OR time slots among the different surgical services. The schedule is reviewed in case of a major resource change. Secondly, at the *offline operational level* and on the short-term horizon, the surgical suite and outpatient services representatives meet to validate a weekly schedule. They assign an OR, a date and a start time to each case meant to be performed during the upcoming week.

Thirdly, at the *online operational level* and on the short-term horizon, an experienced OR nurse executes,

supervises, and monitors the execution of the schedule. This person is called the “coordinator” or “regulator”. To our knowledge, no specific education was provided to the staff about online management decisions.
The AFGH’s surgical suite also receives emergencies. The OnOM only schedules non-elective surgeries when they (1) get the approval of the anaesthesiologist and the surgeon in charge, and (2) confirm the availability of an OR, a paramedical team, and the required medical equipment. In addition, each time slot is assigned to at least one surgeon. Thus, non-elective surgeries scheduled for the time slots already have an assigned surgeon; surgeries scheduled outside of the AOT are under the responsibility of on-call surgeons. Consequently, finding a surgeon for scheduling a non-elective case is generally not an issue (Stepaniak et Dexter 2016).

4.1.2. OR software functionalities

The AFGH has been using OR software for around a decade.
Duration computations. The OR software computes the surgery and the clean-up durations for each case. Each couple (surgery type x, surgeon y) is assigned to the moving average of surgery type x’s durations performed by surgeon y. Clean-up durations are manually set for each surgery type.
Surgical schedule displays. The ongoing surgical schedule is displayed on a screen accessible to the entire staff. It shows the surgery and clean-up duration for every case. First, the IS timestamps are shown, then, as the case goes on, the timestamps are updated with the PS information.
Computation of the remaining time. When a surgery is ongoing, the end time displayed is {real start time} + {initially estimated surgery duration} + {initially estimated clean-up duration}. The information concerning the remaining time of a case at an instant t could be improved since it depends on how long the surgery has already lasted (Tiwari et al., 2013). However, each estimation can be modified at any time by employees with the required access rights. Plus, the OR software’s displays are usually used as indicators as the staff rely heavily on their own experience.
Software recommendations. The OR software passively displays information and sends alert when cases are scheduled outside of the assigned time slots.

4.1.3. A performance audit

In 2019, a consultancy firm carried out a performance audit at the AFGH’s surgical suite. As we cannot display all the specific figures for confidentiality reasons, we will just share the conclusions of the study.
(1) Only 80% of the AOT is necessary and enough to absorb the global activity of the OR. Since the ANAP target for the utilisation rate is 85%, this means that the activity can still potentially increase by 5%.
(2) The utilisation rate of the OR is under 80%: not only is the AOT unfilled but surgeries are performed after the scheduled OR end time.
(3) In a word: the surgical suite is not maximising its potential for better performance and increased activity. Since a non-optimal execution of the schedule could explain this, it is relevant to apply our framework to the AFGH’s surgical suite.

4.2. Adapting our general framework to the AFGH’s specific surgical suite

As we were still in the validation process of the framework, we took the role of the user during the entire study and discussed the results with the OR staff.

Dashboard. The AFGH was already using the framework’s KPIs and targets. We wrote the KPI formulas in an Excel table and extracted the data from the OR software. In the long term, we would like to automate the extraction and treatment of the data.

Logbook. As the regulator moves around the surgical suite throughout the day, we decided to adopt a manuscript format for the logbook so that it could easily be carried. We transcribed our notes into an Excel file.

Analytic process. Not all of the infeasibilities from (Kroer et al., 2018) are relevant to this case. Consequently, we tracked the respect of the rules described in Table 8.

Table 8 : Construction hypothesis for IS construction

R1	The first surgery starts at least 15’ after the OR start so that the nursing staff has the time to prepare the OR
R2	There is a time slot dedicated to clean-up time after each surgery
R3	There is no surgery outside allocated OR time
R4	There is no time gap between two cases
R5	The case durations are accurately estimated

4.3. Applying the framework to a surgery day

In this last subsection we describe how we studied the schedule execution under OnOM supervision with an adapted framework.

4.3.1. Step 1 - Gather the data

We studied schedule execution during an 8am to 3:30pm OnOM shift. We computed the KPIs from Table 3, and we filled in the logbook as indicated in Table 4. We described in Table 9 the two entries used for this example. Disruptions that the OnOM prevented from having an impact on the schedule do not appear here.

Table 9: Logbook entries

Disruption		
ID	3	4
Detection time	10:37 AM	11:53 AM
Description	Patient 2 is waiting for loco-regional anaesthesia (LRA)	Case 2 did not start yet.
Impacts	Risk of delay if the LRA is not done in time	Risk of delaying case 2 start
Root causes	Anaesthetist not available	OR clean-up not done
Action		
Time	(1) 10:37AM (2) 10:43AM (3) 11:43AM	*No action taken*
Description	(1) Ask the recovery ward nurses for the location of the anaesthetist (2, 3) Check if patients received the LRA	*No action taken*
Consequences	(1) The anaesthetist was on their way (2) No (3) Yes	*No action taken*

4.3.2. Step 2 – Assess initial schedule consistency

We checked the IS construction rules of Table 8. R1 was not respected. Indeed, in the IS, the first surgeries and the OR opening were both scheduled at 8am. Consequently, the PS could not avoid the late start. R2, R3 and R4 were partially respected: 4 out of 31 cases did not have a scheduled clean-up, 2 ORs had scheduled overtimes of respectively 5' and 24', and 5 cases were followed by unused allocated OR time.
Finally, we assessed whether R5 was respected. This article provides an example for one OR only.
In Table 10, we computed the following ratio: (real_value – planned_value)/(real_value) for each for the surgery, clean-up and case durations (ranks 1 to 5). Then, based on these results we computed the mean absolute percentage error for each column.
On average, the estimations of durations on that day and for that OR are off by 6% for surgeries, 17% for clean-up and 14% for cases.

Table 10: The last line displays MAPE for surgery, clean-up, and case durations for one OR.

Rank	Percentage error		
	Surgery	Clean-up	Case
1	+14%	-43%	9%
2	+33%	+20%	+31%
3	-3%	+43%	+9%
4	+12%	+17%	+13%
5	-26%	+47%	+7%
MAPE	+6% (35')	+17% (99')	14% (81')

In Table 11, we provide for one OR: (1) the sum of initial and performed durations of surgeries and clean-up times, and (2) the deviation in minutes.

Table 11: Surgery durations and their deviations for one OR

KPI	IS	PS	Deviation
Surgery duration	7h20	8h	**+40'**
Clean-up duration	1h31	2h	**+29'**
Case duration	8h51	10h	**+69'**

From this assessment, we concluded that there was a risk of deviations in the PS.

4.3.3. Step 3 & 4 – Study the indicators and their deviations at the surgical suite and OR scales.

The KPIs at the scale of the surgical suite did not all reach their target (step 3). Thus, it was worth following up with step 4. We reduced the study perimeter to OR2, an OR whose performance indicators did not all reach their targets and for which only R1 was not respected. We computed the KPIs and their deviations in Table 12.

Table 12: KPIs and their deviations. The figures are in bold if they did not reach their target (IS and PS columns) or if there was a deteriorating deviation (deviation column)

KPI	Target	IS	PS	Deviation
Utilisation rate	85%	**91%**	88%	-3%
Late start rate	<5%	0%	2%	**+2%**
Early stop rate	<5%	**9%**	0%	**-9%**
Restrained overtime rate	<5%	0%	**5%**	**+5%**
Between case time rate	<5%	0%	**10%**	**+10%**

Below is a brief comment of the results. According to Table 12, we went from a 9% underrun at the end of the shift to a 5% overrun. In other words, the IS was supposed to end early while the PS finished late.
Would it have been doable to complete the cases before the end of the shift despite the imposed IS? Was it possible to obtain a performed Restrained Overtime Rate of 0%?
The 2% Late Start Rate was not avoidable as it was caused by an unfeasibility of the IS. The Between Case Time Rate reached 10% (with a deviation of +10%) and exceeded its target by at least 5%. This gap could have potentially absorbed the 5% overtime and thus allowed all the surgeries to be finished in time.
Therefore, the objective of this retrospective analysis was to (1) identify what caused at least 5% of the BCT

rate during the execution of the schedule and, (2) to determine if this could have been avoided.

4.3.4. Step 5 - Identify deviations at the case scale

We described the case deviations observed during the OnOM shift in Table 13. We set aside the restrained overtime deviation to simplify the study.

Table 13: Synthesis of step 5

ID	Deviation	Timestamps	Duration
1	Late start	8am-8:13am	13’
2	Waiting for clean-up	11:36am-11:54am	18’
3	Waiting for patient	12:15am-12:25am	10’
4	Waiting for patient	1:20pm-1:26pm	6’

4.3.5. Step 6 - Determine root causes, responsibility, and impact on the performed schedule

With the data contained in the dashboard, the logbook and the schedules, we identified the root causes and responsibility of each deviation, as well as their impact on the schedule.

Table 14: Synthesis of step 6. Resp. stands for responsibility.

ID	Root cause	Resp.	Impact
1	R1 is not respected so the IS is unfeasible.	OffOM	Unavoidable delay
2	Non-optimal clean-up sequencing	Still unknown	Potentially avoidable delay
3	Still unknown	Still unknown	Potentially avoidable delay
4	The deviation is inherent in OR functioning.	None	Unavoidable delay

ID1. The IS does not include the time needed to set up the OR before the first case. The deviation is an *unavoidable delay.*

ID2. The surgery in OR2 finished not long after OR5. OR2 had other incoming surgeries while OR5 did not. The ORA cleaned the first empty OR (OR5) and consequently, could not be there in time to clean OR2. Indeed, scheduling practices at the AFGH do not ensure that ORAs will be available on time for OR clean-up. This can lead to “waiting for clean-up” deviations. In some cases, however, choosing the right OR clean-up sequencing (in this specific case OR2 then OR5) or dividing up the ORA team could help reduce or avoid this deviation. Consequently, it is a *potentially avoidable delay*.

ID3. The OnOM did not notice the “waiting for patient” deviation. Since we do not know the details of the situation, we identify this deviation as a *potentially avoidable delay.*

ID4. The nursing staff needs a 10’ to 15’ turnover time between each patient. In this case, the clean-up was done after the preceding patient’s exit, from 1:10pm to 1:20pm (10’). Consequently, the entering of the patient at 1:26pm matches a 16’ turnover time, which is coherent. The deviations are an *unavoidable delay* inherent in the OR functioning. We present the results of step 6 in Table 14.

4.3.6. Step 7 - Assess the quality of the execution of the schedule

In this step, we kept the deviations for which the OnOM is responsible or potentially responsible. We cross-referenced the information on the deviations with the information on the disruptions from the logbook. Below is the analysis of these combined data.

ID2. The OnOM detected this at 11:53am, which is the same time that the ORAs finished cleaning OR5. It was too late to undertake any action. Had the OnOM anticipated the successive patients’ exits, several options could have been considered: (1) maintaining the OR cleaning sequencing but asking the ORA team to split up, (2) maintaining the OR cleaning sequencing and informing the nurses there would be a delay of around 15’ so that they could focus on other tasks or take a break, or (3) change the OR cleaning sequencing. Consequently, as this could have been detected earlier, *the 18’ delay was avoidable.*

ID3. This was not detected by the OnOM. Had the OnOM detected the deviation, they could have informed the nurses that it was possible to wheel in the next patient to the OR. *The delay was potentially avoidable.*

No action was undertaken for either of these deviations.

4.3.7. Synthesis

The objective of this analysis was to determine the root causes of at least 5% of the Between Case Rate and to assess whether this could have been decreased. The performed BCR value was 10%. It was caused by 5 case deviations that occurred during the AOT. Only 3 occurred during the OnOM shift (6% of the BSR): ID2 was avoidable (3%), ID3 was potentially avoidable (2%) and ID4 was unavoidable (1%). As shown in the previous steps, ID2 was detected too late to make a change and ID3 was not detected at all. We could have reduced the Between Case Rate at most by 5% and avoided any overtime with different schedule execution management. However, as certain deviations are *potentially* avoidable only, we cannot confirm this. On a side note, we showed that the IS was not optimal and that the scheduling process could be refined.

5. LIMITS

We encountered several limitations during our study. First, for the AFGH regulator, there is a thin line between the autonomy required by the staff and their supervisory role. Continuous improvement could be seriously hindered if neither the regulator nor the paramedical/medical staff feel responsible for reducing deviations. Second, we only included data from a specific centre. To ensure the generalisability of the framework, it would be interesting to have a multi-institutional approach. Finally, the fact that the user performs real-time observation might affect the behaviour of the online operational management agent.

6. CONCLUSION AND FURTHER WORK

Uncertainties and deviations are inherent in surgical suite activity, in which the human factor is predominant. In this article, we suggest a framework for a retrospective analysis of the execution of the schedule. It aims to (1) analyse deviations between the IS and the PS, and to (2) assess how online operational management dealt with them. In the example, we show how to carry out the framework on a restricted perimeter.

Our approach has shown that improvements can be made in both the construction and the execution of the program in the AFGH. Improvements could include more frequent checks of patient pathways and a decision support system for online operational management. The perspectives of this study are multiple: to present the results of a complete audit, to add indicators from the different stakeholders' perspective and to semi-automate the approach for the collection, processing, and analysis of data.

REFERENCES

Alameda, L. E. Muñoz, et A. Macario. 2017. « Advances in Operating Room Management. The Role of Operating Room Director ». *Revista Espanola de Anestesiologia y Reanimacion (English Edition)* 3 (64): 121-24. https://doi.org/10.1016/j.redare.2017.01.005.

ANAP. 2016. « Bloc opératoire - Liste des indicateurs fréquemment suivis dans les blocs ». bloc-operatoire.anap. 3 janvier 2016. http://bloc-operatoire.anap.fr/publication/1297.

Athanasiadis, Dimitrios I., Sara Monfared, Jake Whiteside, Ambar Banerjee, Donna Keller, Annabelle Butler, et Dimitrios Stefanidis. 2020. « What Delays Your Case Start? Exploring Operating Room Inefficiencies ». *Surgical Endoscopy*, juin. https://doi.org/10.1007/s00464-020-07701-6.

Athanasiadis, Dimitrios I., Sara Monfared, Jake Whiteside, Trisha Engle, Lava Timsina, Ambar Banerjee, Annabelle Butler, et Dimitrios Stefanidis. 2020. « Comparison of Operating Room Inefficiencies and Time Variability in Laparoscopic Gastric Bypass ». *Surgery for Obesity and Related Diseases* 16 (9): 1226-35. https://doi.org/10.1016/j.soard.2020.04.046.

Cardoen, Brecht, Erik Demeulemeester, et Jessie Van der Hoeven. 2010. « On the Use of Planning Models in the Operating Theatre: Results of a Survey in Flanders ». *The International Journal of Health Planning and Management* 25 (4): 400-414. https://doi.org/10.1002/hpm.1027.

Cerfolio, Robert J., Dana Ferrari-Light, Christine Ren-Fielding, George Fielding, Nissa Perry, Annette Rabinovich, Mark Saraceni, Maureen Fitzpatrick, Sudheer Jain, et H. Leon Pachter. 2019. « Improving Operating Room Turnover Time in a New York City Academic Hospital via Lean ». *The Annals of Thoracic Surgery* 107 (4): 1011-16. https://doi.org/10.1016/j.athoracsur.2018.11.071.

Cima, Robert R., Michael J. Brown, James R. Hebl, Robin Moore, James C. Rogers, Anantha Kollengode, Gwendolyn J. Amstutz, Cheryl A. Weisbrod, Bradly J. Narr, et Claude Deschamps. 2011. « Use of Lean and Six Sigma Methodology to Improve Operating Room Efficiency in a High-Volume Tertiary-Care Academic Medical Center ». *Journal of the American College of Surgeons* 213 (1): 83-92. https://doi.org/10.1016/j.jamcollsurg.2011.02.009.

Cox Bauer, Callie, Danielle Greer, Kiley Vander Wyst, et Scott Kamelle. 2016. « First-Case Operating Room Delays: Patterns Across Urban Hospitals of a Single Health Care System ». *Journal of Patient-Centered Research and Reviews* 3 (3): 125-35. https://doi.org/10.17294/2330-0698.1265.

Dexter, Franklin, Richard H. Epstein, Rodney D. Traub, Yan Xiao, et David C. Warltier. 2004. « Making Management Decisions on the Day of Surgery Based on Operating Room Efficiency and Patient Waiting Times ». *Anesthesiology* 101 (6): 1444-53. https://doi.org/10.1097/00000542-200412000-00027.

Dexter, Franklin, John D. Lee, Angella J. Dow, et David A. Lubarsky. 2007. « A Psychological Basis for Anesthesiologists' Operating Room Managerial Decision-Making on the Day of Surgery ». *Anesthesia & Analgesia* 105 (2): 430-34. https://doi.org/10.1213/01.ane.0000268540.85521.84.

Dexter, Franklin, Pengyi Shi, et Richard H. Epstein. 2012. « Descriptive Study of Case Scheduling and Cancellations within 1 Week of the Day of Surgery ». *Anesthesia and Analgesia* 115 (5): 1188-95. https://doi.org/10.1213/ANE.0b013e31826a5f9e.

Dexter, Franklin, Ruth E. Wachtel, et Richard H. Epstein. 2011. « Event-Based Knowledge Elicitation of Operating Room Management Decision-Making Using Scenarios Adapted from Information Systems Data ». *BMC Medical Informatics and Decision Making* 11 (1): 2. https://doi.org/10.1186/1472-6947-11-2.

———. 2016. « Decreasing the Hours That Anesthesiologists and Nurse Anesthetists Work Late by Making Decisions to Reduce the Hours of Over-Utilized Operating Room Time ». *Anesthesia & Analgesia* 122 (3): 831-42. https://doi.org/10.1213/ANE.0000000000001136.

Dexter, Franklin, Ann Willemsen-Dunlap, et John D. Lee. 2007. « Operating Room Managerial Decision-Making on the Day of Surgery With and Without Computer Recommendations and Status Displays ». *Anesthesia & Analgesia* 105 (2): 419-29. https://doi.org/10.1213/01.ane.0000268539.85847.c9.

Fong, Abigail J., Meghan Smith, et Alexander Langerman. 2016. « Efficiency Improvement in the Operating Room ». *Journal of Surgical Research* 204 (2): 371-83. https://doi.org/10.1016/j.jss.2016.04.054.

Fügener, Andreas, Sebastian Schiffels, et Rainer Kolisch. 2017. « Overutilization and Underutilization of Operating Rooms - Insights from Behavioral Health Care Operations Management ». *Health Care Management Science* 20 (1): 115-28. https://doi.org/10.1007/s10729-015-9343-1.

Gottschalk, Michael B., Richard M. Hinds, Raghuveer C. Muppavarapu, Kenneth Brock, Anthony Sapienza, Nader Paksima, John T. Capo, et S. Steven Yang. 2016. « Factors Affecting Hand

Surgeon Operating Room Turnover Time ». 2016. https://journals.sagepub.com/doi/abs/10.1177/1558944715620795.
Gupta, Diwakar. 2007. « Surgical Suites' Operations Management ». *Production and Operations Management* 16 (6): 689-700. https://doi.org/10.1111/j.1937-5956.2007.tb00289.x.
Hans, Erwin W., et Peter T. Vanberkel. 2012. « Operating Theatre Planning and Scheduling ». In *Handbook of Healthcare System Scheduling*, édité par Randolph Hall, 105-30. International Series in Operations Research & Management Science. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4614-1734-7_5.
Hulshof, Peter J H, Nikky Kortbeek, Richard J Boucherie, Erwin W Hans, et Piet J M Bakker. 2012. « Taxonomic Classification of Planning Decisions in Health Care: A Structured Review of the State of the Art in OR/MS ». *Health Systems* 1 (2): 129-75. https://doi.org/10.1057/hs.2012.18.
Kodali, Bhavani S., Dennie Kim, Ronald Bleday, Hugh Flanagan, et Richard D. Urman. 2014. « Successful Strategies for the Reduction of Operating Room Turnover Times in a Tertiary Care Academic Medical Center ». *Journal of Surgical Research* 187 (2): 403-11. https://doi.org/10.1016/j.jss.2013.11.1081.
Kroer, Line Ravnskjær, Karoline Foverskov, Charlotte Vilhelmsen, Aske Skouboe Hansen, et Jesper Larsen. 2018. « Planning and Scheduling Operating Rooms for Elective and Emergency Surgeries with Uncertain Duration ». *Operations Research for Health Care* 19 (décembre): 107-19. https://doi.org/10.1016/j.orhc.2018.03.006.
Ladyman, James, James Lambert, et Karoline Wiesner. 2013. « What is a complex system? » *European Journal for Philosophy of Science* 3 (juin). https://doi.org/10.1007/s13194-012-0056-8.
Macario, Alex. 2006. « Are Your Hospital Operating Rooms "Efficient"?A Scoring System with Eight Performance Indicators ». *Anesthesiology: The Journal of the American Society of Anesthesiologists* 105 (2): 237-40.
Macario, Alex, Terry S. Vitez, Brian Dunn, Tom McDonald, et Byron Brown. 1997. « Hospital Costs and Severity of Illness in Three Types of Elective Surgery ». *Anesthesiology: The Journal of the American Society of Anesthesiologists* 86 (1): 92-100.
May, Jerrold H., William E. Spangler, David P. Strum, et Luis G. Vargas. 2011. « The Surgical Scheduling Problem: Current Research and Future Opportunities ». *Production and Operations Management* 20 (3): 392-405. https://doi.org/10.1111/j.1937-5956.2011.01221.x.
Müller, Martin, Jonas Jürgens, Marcus Redaèlli, Karsten Klingberg, Wolf E. Hautz, et Stephanie Stock. 2018. « Impact of the Communication and Patient Hand-off Tool SBAR on Patient Safety: A Systematic Review ». *BMJ Open* 8 (8): e022202. https://doi.org/10.1136/bmjopen-2018-022202.
Panni, M. K., S. J. Shah, C. Chavarro, M. Rawl, P. K. Wojnarwsky, et J. K. Panni. 2013. « Improving Operating Room First Start Efficiency – Value of Both Checklist and a Pre-Operative Facilitator ». *Acta Anaesthesiologica Scandinavica* 57 (9): 1118-23. https://doi.org/10.1111/aas.12166.
Russ, Stephanie, Sonal Arora, Rupert Wharton, Ana Wheelock, Louise Hull, Eshaa Sharma, Ara Darzi, Charles Vincent, et Nick Sevdalis. 2013. « Measuring Safety and Efficiency in the Operating Room: Development and Validation of a Metric for Evaluating Task Execution in the Operating Room ». *Journal of the American College of Surgeons* 216 (3): 472-81. https://doi.org/10.1016/j.jamcollsurg.2012.12.013.
Russ, Stephanie, Shantanu Rout, Nick Sevdalis, Krishna Moorthy, Ara Darzi, et Charles Vincent. 2013. « Do Safety Checklists Improve Teamwork and Communication in the Operating Room? A Systematic Review ». *Annals of Surgery* 258 (6): 856-71. https://doi.org/10.1097/SLA.0000000000000206.
Samudra, Michael, Carla Van Riet, Erik Demeulemeester, Brecht Cardoen, Nancy Vansteenkiste, et Frank E. Rademakers. 2016. « Scheduling Operating Rooms: Achievements, Challenges and Pitfalls ». *Journal of Scheduling* 19 (5): 493-525. https://doi.org/10.1007/s10951-016-0489-6.
Shi, Pengyi, Franklin Dexter, et Richard H. Epstein. 2016. « Comparing Policies for Case Scheduling Within 1 Day of Surgery by Markov Chain Models ». *Anesthesia and Analgesia* 122 (2): 526-38. https://doi.org/10.1213/ANE.0000000000001074.
Stepaniak, Pieter S., et Franklin Dexter. 2016. « Constraints on the Scheduling of Urgent and Emergency Surgical Cases: Surgeon, Equipment, and Anesthesiologist Availability ». *Perioperative Care and Operating Room Management* 3 (juin): 6-11. https://doi.org/10.1016/j.pcorm.2016.02.001.
Strum, D. P., L. G. Vargas, et J. H. May. 1999. « Surgical Subspecialty Block Utilization and Capacity Planning: A Minimal Cost Analysis Model ». *Anesthesiology* 90 (4): 1176-85.

https://doi.org/10.1097/00000542-199904000-00034.

Tagge, Edward P., Arul S. Thirumoorthi, John Lenart, Carlos Garberoglio, et Kenneth W. Mitchell. 2017. « Improving Operating Room Efficiency in Academic Children's Hospital Using Lean Six Sigma Methodology ». *Journal of Pediatric Surgery* 52 (6): 1040-44. https://doi.org/10.1016/j.jpedsurg.2017.03.035.

Tiwari, Vikram, Franklin Dexter, Brian S. Rothman, Jesse M. Ehrenfeld, et Richard H. Epstein. 2013. « Explanation for the near-constant mean time remaining in surgical cases exceeding their estimated duration, necessary for appropriate display on electronic white boards ». *Anesthesia & Analgesia* 117 (2): 487-93.

Zhu, Shuwan, Wenjuan Fan, Shanlin Yang, Jun Pei, et Panos M. Pardalos. 2019. « Operating Room Planning and Surgical Case Scheduling: A Review of Literature ». *Journal of Combinatorial Optimization* 37 (3): 757-805. https://doi.org/10.1007/s10878-018-0322-6.