

Operating Room Effectiveness: a Lean Healthcare Performance Indicator

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Operating Room Effectiveness: a Lean Healthcare Performance

Indicator

Purpose - Overall Equipment Effectiveness (OEE) is a performance indicator that is been used to measure manufacturing productivity. This paper proposes the Operating Room Effectiveness (ORE) for Hospital Operating Rooms, adapted from the OEE, to measure performance and identify losses based on Lean Healthcare principles.

Methodology - The present study is an exploratory, descriptive, and applied research work. Literature review, documents of the Hospital, observation and interviews with employees of a large university hospital in southern Brazil were analyzed to organize the proposed effectiveness indicator. After that, historical data of the Operating Rooms was collected and the usefulness of the indicator was analyzed. The indicator was applied for 10 months and validated with an expert committee from the hospital.

Findings - The present study describe an adaptation of a performance indicator to operating rooms of hospitals, allowing to classify its types of operational losses in a Lean Healthcare context. The application of this indicator and the development of improvement actions to an university hospital, resulted in operational efficiency gains of 12% and estimated annual savings of US\$400,000.

Practical implications - Operating rooms are a critical service for hospitals. This paper presents a new way to measure the performance of operating rooms and identify their main types of wastes. It also shows how to implement it and the potential gains of its application. The main research limitations are related to technical analysis of care data from doctors and nurses involved.

Originality - This paper fulfils the need to study how operating rooms performance can be measured and its operational wastes can be identified. In addition, this paper classifies the planning, performance and quality related losses, which can be used by researchers and practitioners to improve the performance of operation rooms.

Keywords: Hospitals Operations Management, Operating Rooms, Lean Healthcare, Key Performance Indicator, Overall Equipment Effectiveness.

1 INTRODUCTION

In the field of Operations Management, the analysis of production systems is based on assumptions about the relationship between the system's capacity and demand. The context of health services, especially in public systems, is typically characterized by significantly greater demand than supply (Graban, 2009). Furthermore, in many cases, demand has an upward trend, with no compatible increase in capacity. As a natural consequence, increasing the system's output requires effective and focused management processes to increase the system's efficiency and effectiveness (Hopp and Spearman, 2011). Given this context and given that overall healthcare costs, health systems are increasingly challenged to deliver better people care by using fewer resources, thus improving operational effectiveness and efficiency and reducing wastes.

In this context, a unit of particular interest in hospital management is the operating room (OR). Accounting for a substantial portion of the hospital's revenues and costs (Demeulemeester et al., 2013), the OR is a production structure that has a linear flow that typically consists of preparation, operation, and post-operation. Capacity is nominally limited to the number of available operating rooms, equipment, and personnel and to technical delays, administrative aspects, and other factors (Cima, 2011). An OR with underutilized capacity, in a context of increasing demand for surgery, will result in a scenario characterized by long lines and waits, in addition to patient dissatisfaction and the deterioration of the patient's condition. In some cases, clinical complications due to waiting for surgery can change the established demand for the OR by changing the procedures necessary to restore the patient's health.

The newly admitted patient in the OR represents an elective demand or an urgent demand. Urgencies can be further classified as critical (emergency) or non-critical (Cardoen et al., 2010). Managing the capacity of this type of demand requires careful study and the controlled maintenance of capacity, given the impossibility of controlling urgent demands and emergencies in particular. Therefore, the context of health and criticality imposes restrictions on maximizing the efficiency of this production system, unlike what is typically found in an industrial process. Nonetheless, the context is similar to the programmed inefficiency concept used in the Toyota Production System (Shingo, 1989). However, considering the importance of healthcare and the financial impact on the operation of a healthcare service provider, optimizing the outcome of this unit must be a priority of the health organization's management.

From the healthcare management perspective, there has been progress. In recent decades, technological developments have played an important role in the development of

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3 surgery and have caused substantial changes in the working conditions in the OR. The growing
4 number of complex devices leads to an increase in interactions between humans and technology
5 (Matern and Koneczny, 2007), requiring the adaptation of the layout of operating rooms, in
6 addition to investments in equipment that do not necessarily replace the existing equipment
7 (Graban, 2009). However, the lack of visibility of the most effective actions, from the
8 managerial perspective, can impede the possibility of increasing the OR's performance.
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13 In Brazil, the professionalization of health management processes has not followed the
14 trajectory of healthcare processes. The end goals of clinical protocols, high-tech equipment,
15 and costs and resources that represent annual investments of approximately 9% of the Brazilian
16 GDP (OECD, 2014) are limited or frustrated by the inadequacy or low efficiency of the
17 management processes associated with these issues. Studies that highlight this fact emphasize
18 the need for professional management based on advanced management techniques in a hospital
19 organization due to its complexity, management problems, financial constraints, and the need
20 for efficiency and quality in healthcare processes (Ribeiro, 1993). In response, management
21 methods emerge in Brazil and abroad that seek to reduce costs, increase efficiency, and solve
22 healthcare services through new structures and management processes (Spagnol and Ferraz,
23 2002; Graban, 2009).
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33 An alternative to addressing the managerial issues associated with production efficiency
34 is the Lean Healthcare approach (Young and McClean, 2008; Narayanamurthy *et al.*, 2018).
35 Derived from traditional lean thinking and adapted to the health management context (Raval,
36 Kant & Shankar, 2018), this approach aims to increase the productivity of the processes through
37 the elimination of waste, in addition to operations management techniques aimed at raising
38 efficiency rates (Womack and Jones, 2010). The term "lean" was originally coined to describe
39 a system that could achieve the same output by using lower number of resources – physical
40 space, work effort, capital investment, and inventory – and generating less defects and safety
41 incidents. Over time, the term has also come to mean a method for obtaining such results
42 (Graban, 2009). Bakar, Subari and Daril (2015) studied critical success factors for application
43 of improvement techniques such as Lean and Six Sigma, as well as their integration. The
44 authors demonstrate that Lean's primary goal in organizations is to improve the process flow,
45 reducing waste, non-value added work and cycle time.
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55 Despite its recentness, Lean Healthcare shows results. A multidisciplinary task force
56 conducted a study that applied lean thinking in an ear, nose, and throat (ENT) operating room
57 in the University of Michigan health system. After 18 months, the study reported improvements
58 in process efficiency and staff morale, which was supported by the education of residents, and
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3 financial gains of approximately \$330,000 were generated. The study projected an estimated
4 increase of 6,500 hours in service capacity per year based on the process's replication in other
5 operating rooms (Collar, 2012). In Brazil, a hospital in the interior of São Paulo applied
6 techniques from Lean Healthcare to study the flow of surgical patients, in turn applying Value
7 Stream Mapping for the process design. It was observed that the hospital in question was able
8 to increase surgical production by 34% through the greater use of rooms and reduced set-up for
9 cleaning and changing rooms (Morilhas *et al.*, 2013). However, efficiency or effectiveness
10 indicators in operating rooms are restricted to the analysis of only one variable at a time, such
11 as utilization, production, cancellations, or financial results, and they are not a global indicator
12 that signals the time used and respective losses in the process.
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20 A search applied in Scopus and in Web of Knowledge databases did not produce a
21 single result, in articles published in journals, about Overall Equipment Effectiveness (OEE)
22 applied in Lean Healthcare. The present study aims to fill this research gap, presenting an
23 adaptation of the Overall Equipment Effectiveness (OEE) indicator to operating rooms. This
24 research led to the proposal for a new nomenclature of the indicator focused on operating rooms,
25 Operating Room Effectiveness (ORE). The development of this indicator was based on a study
26 conducted in a large Brazilian university hospital responsible for performing approximately
27 7,000 operations per year. From the practice perspective, the incorporation of the proposed
28 effectiveness indicator in the OR create a measurement indicator focused on the productivity
29 and quality of the operating rooms, showing the types and dimension of operational wastes.
30 This approach also contributes to theory, to the extent that it encourages a more comprehensive
31 discussion of the performance indicators related to operating rooms, creating a systemic concept
32 of performance for ORs, including the identification of type of losses related to planning,
33 performance and quality. Thus, it opens a way to identify opportunities for improving
34 operational effectiveness in in the hospital and health environment. In summary, the adaptation
35 of OEE, an indicator commonly used in manufacturing systems to a hospital environment,
36 contributes for the reduction of a gap related to operational measurement in hospitals, more
37 precisely in the surgical services. The application of the proposed indicator in a specific OR
38 unit and the resulting actions geared toward process improvement, produced an operational gain
39 of 12% in the efficiency of the operating rooms studied. Waste has been lifted and a robust
40 action plan to mitigate them has been implemented by the hospital's management team resulting
41 in estimated savings of US\$388,000 per year.
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58 The paper is structured in six main parts. After this introduction (1), a review about
59 "Operating Rooms Performance Measurement" (2) is presented. After that, the paper presents
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3 the methodology (3) used in this work. Section 4 presents the “Operating Room Effectiveness
4 (ORE)” indicator. Section 5 describes an application of the indicator and the analysis of the
5 results. Finally, the paper ends with final considerations (6) to the work developed.
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10 **2 OPERATING ROOMS PERFORMANCE MEASUREMENT**

11 Operating Rooms are important contributors to patient turnover and the financial
12 sustainability of a hospital (Cima, 2011; Dexter *et al.*, 2003; Marjamaa *et al.*, 2008). However,
13 they also represent one of the costliest units. As the economic environment for healthcare
14 providers becomes increasingly challenging, increasing the productivity of the operating room
15 must be guided by the impact on the patient, the safety of personnel, and the results. Several
16 factors limit the productivity of operating rooms, such as infrastructure, human resource
17 management, scheduling dynamics, process flow, technology issues, and limitations in
18 information management. The following are factors that impede the achievement of high
19 performance in ORs: variability in patient problems; the variety of types of interventions;
20 unexpected events that occur in any surgical practice (Cima, 2011); and ineffective process
21 management that permeates the industry, such as the ineffective control of operating time, low
22 efficiency in room cleaning and preparation, weaknesses in inventory control and material
23 handling, and the ineffective management of queues. Continuously improving the efficiency
24 and effectiveness of ORs is manifested by the reduction in operating times; the training of
25 doctors, residents, and other employees; the choice of anesthesia; efficient scheduling; and
26 monitoring the overall performance of the operating rooms. The combination of actions such
27 as those listed above is important for continuous improvement and the achievement of the
28 objectives of a health system. When designing processes or changes, clear targets should be
29 established, and the results achieved must be monitored and communicated to everyone
30 involved (Marjamaa *et al.*, 2008).
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46 Various performance criteria can be used to assess the planning of operating rooms and
47 scheduling procedures. Eight performance measures can be analyzed in this context, namely,
48 waiting time, throughput, utilization, leveling, makespan, patient cancellations, financial
49 results, and preferences, as described in Table 1 (Demeulemeester *et al.*, 2013). These criteria
50 summarize the indicators used in operating room management, as shown in the literature, and
51 they quantitatively represent various stages of the surgical process, from the patient waiting
52 time to the time used for planning, cancellations of surgery, and even financial results, such as
53 the operating room’s income and expenses.
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Table 1 – Performance Measures. Adapted from Demeulemeester *et al.* (2013)

Performance Measures	Description
Waiting time	Represents the patient waiting time from the identification of surgical needs to completion.
Throughput	Measurement related to the patient and waiting time, such that the greater the yield of the operating rooms is, the shorter the patient waiting time.
Use	Indicator related to the time spent using the operating room compared to the scheduled time. The use does not take into account stops for preparation and cleaning the rooms or scheduled stops. It only accounts for the time used in relation to the time scheduled for production.
Leveling	Leveling concerns the development of operating room schedules that lead to the smooth occupation of resources, without peaks and minimizing the risk of capacity problems caused by unexpected events.
Makespan	Represents the time of completion of patient recovery. It generally can be defined as the time between the entry of the first patient and the completion of the last patient.
Cancellations	Number of canceled surgeries that result in idle capacity in the schedules, low productivity, and increased waiting time for patients.
Financial Results	Performance measures related to cost and financial gains that the OR refers to the hospital system.
Preferences	Analyzes the preferences of the different parties involved in the surgical process, such as preferences of surgeons, nursing staff, patients, etc.

In terms of measuring the performance of ORs, Mazzei (1994) provided the first published data for start-up times and set-up times for surgery in a teaching hospital. According to the author, patients for the first surgery of the day were generally taken to the operating room, the incision occurred between 21 and 49 minutes later, and the room set-up time took approximately one hour. It is observed that, 20 years ago, the author was studying opportunities to reduce start-up times and set-up times. According to the author, standardizations for these times should be agreed upon by the interdisciplinary areas, and constant measurements should be taken.

Dexter *et al.* (2003) considered the times of an OR of a tertiary hospital with four operating rooms. The study was conducted in 2001. The average set-up time for a room was estimated to be between 34 and 66 minutes. Reductions in the average set-up time of 3-9 minutes resulted in a reduction of between 0.8% and 1.8% of personnel costs, without affecting the level of service or production of surgeries. This reduction was estimated as savings of between US\$52,000 and US\$151,000, while considering only costs with staff and anesthesia in the four operating rooms studied. A projected reduction in the average set-up time of 10-19 minutes would lead to a reduction of 2.5% to 4.0% in personnel costs, representing an annual operating income of US\$151,000 to US\$243,000. Therefore, according to the study, even small improvements can represent substantial gains when placed in a sustainable and long-term perspective.

Based on the arguments presented, mainly regarding the performance measures set out in Table 1, we observe that the time dimension may be used as the primary metric for tracking and signaling OR efficiency because the use of the rooms is related to the time used and scheduled; surgical cancellations relate to operating room downtime after the cancellation; the yield or production of the rooms can be analyzed from the perspective of time, based on the available time for surgeries and use, such that the greater the use is, the higher the yield and the lower the waiting time for patients; makespan is also related to time, from the entry of the first patient to the exit of the last; and finally, the financial results can also be analyzed as the cost per hour of the operating room, causing non-working hours to be eliminated for better asset utilization. However, their use may be more effective if supported by specific assumptions, such as programming, use, preparation, and others studied in the surgical process, as shown in the next section. A vision guided by the surgical process is necessary to create a global indicator for operating room effectiveness.

3 METHODOLOGY

The present study has an exploratory, descriptive, and applied nature. It is exploratory because it approaches concepts regarding management in the healthcare operations environment, and it is descriptive because it narrates the application implemented in the specific context of the university hospital studied. The main steps for developing the study are presented in Table 2 and explained in the sequence.

Table 2 – Steps for the development of the approach

1. Bibliographical Reference
2. Direct Observation and Interviews
3. Analyses and Proposition of the Indicator
4. Application Study
5. Evaluation by Committee
6. Validation of Indicator
7. Creation of Hypothetical Scenarios

The study began with the construction of a bibliographical analysis about losses and performance in operating rooms. A search in the database SCOPUS about “operating rooms” and “performance indicator” and “Lean” resulted in only one study relating the subjects studied.

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3 Hassanain *et al.* (2017) evaluated the intervention on the performance of operating
4 rooms using the Lean methodology and performance measures different from the proposal
5 presented by this study.
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8 Given the lack of published evidence, a study was conducted in public and private
9 hospitals in southern Brazil, collecting information on the OR management process of these
10 hospitals through direct observation and interviews. The choice of hospitals was made based
11 on convenience, and not only geographically, given that a certain level of trust is required
12 between the researcher and the hospital to allow access to areas with high sanitary control.
13 Thirty nine employees from different areas of these hospitals were interviewed during four
14 months. All had at least 10 years of experience in the process or in fields directly related to the
15 OR. The structure of the interviews followed the protocol of open interviews, which were
16 conducted with exploratory purpose. The objective was to refine concepts (e.g. types of
17 operational wastes) related to the effectiveness of operating rooms, to support the adaptation of
18 the OEE indicator based on the qualitative information collected. The content of the interviews
19 was compiled to generate categories of losses. The results and the benchmarks were analyzed
20 to organize the proposed effectiveness indicator.
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23 After the indicator was proposed, an application study was conducted in the same
24 hospital and the application occurred during six months. Initially, the researchers collected 10
25 months of the OR's operation historical data from the organization's information system, in
26 order to analyze the effectiveness of the indicator. With the data compiled and adjusted, a
27 committee was formed with seven experts from the organization, including engineers, surgeons,
28 and members of senior management, to evaluate the results. The committee evaluated the
29 results, audited the calculation procedure used, and considered it valid. Then, the researchers
30 proceeded to implement the data collection processes and monitor the proposed indicator in the
31 organization, seeking a longitudinal analysis of the information produced by the indicator.
32 Finally, the indicator was presented and validated for use in the hospital organization studied.
33 Within this paper scope, researchers developed hypothetical scenarios with the data collected
34 to explore possible improvements and action plans for the study hospital or others to apply
35 using the proposed ORE indicator.
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54 **4 OPERATING ROOM EFFECTIVENESS (ORE)**

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58 OEE can be defined as an overall effectiveness indicator of a production facility or
59 equipment (Gibbons and Burgess, 2010). This indicator had its origin in Total Productive
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Maintenance (TPM), whose methodology aims to reach a compromise with all entities of an organization to integrate them, improve quality, and increase the productivity and effectiveness of the production system (Nakajima, 1998; Ivancic, 1998; Jain, Bhatti and Singh, 2014). TPM is regarded as one of the pillars of Lean Manufacturing due to the goal of eliminating waste by optimizing resource effectiveness (Sahoo and Yadav, 2018). It is also viewed as a method of measuring production performance that integrates data on equipment availability, performance indicator, and the quality rate achieved (Belohlavek, 2006).

OEE is calculated by identifying six basic types of losses grouped into three classes presented in Table 3.

Table 3 – Six basic losses by OEE (Nakajima, 1998; Ivancic, 1998; Busso and Miyake, 2013)

Classes	Losses
Availability Losses	downtime for lack of equipment
	downtime for setup or adjustments
Performance Losses	short breaks for poor equipment operation
	reduction in equipment speed
Quality Losses	defective production and rework
	losses incurred at the start of production due to adjustments for equipment stabilization

According to Nakajima (1998), these basic losses guide actions for improvement, given that the analysis of the component values allows us to identify where the weaknesses in the effectiveness of the production system are located. An interpretation of losses found in a healthcare system may be given by Vaccaro *et al.* (2015), reinforcing the importance of the classification above.

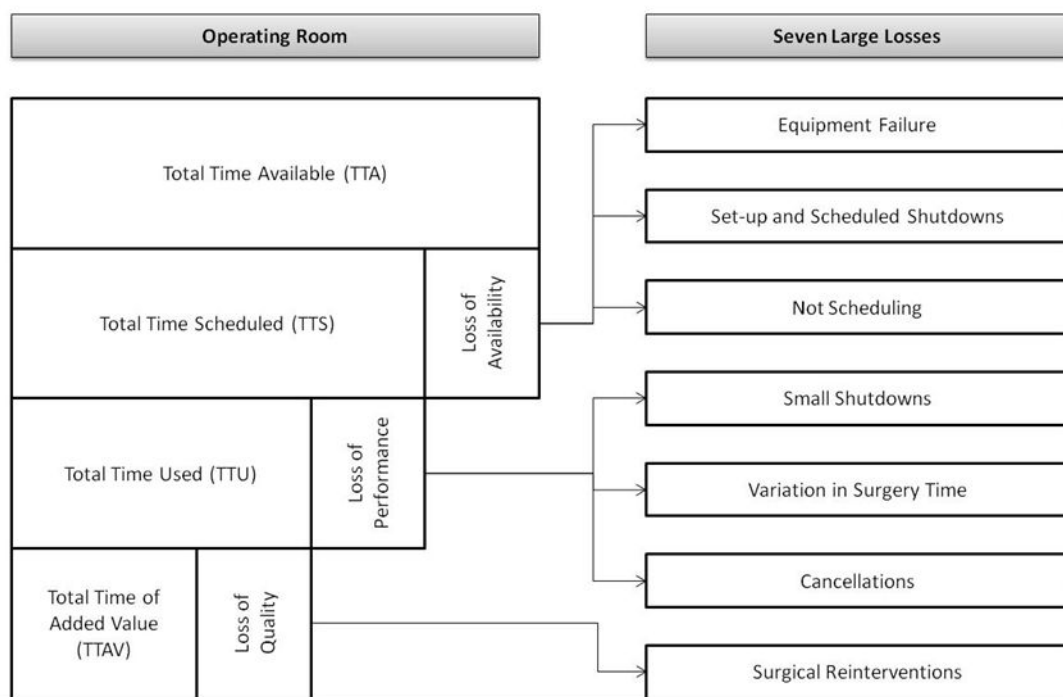
Using the OEE indicator and its consequences as a foundation, the present study makes an adaptation of the indicator to the Operating Rooms Effectiveness (ORE), for application in the OR in Lean Healthcare context. The main difference between OEE and ORE is the focus on the surgical flow and its specificities. Considering these specificities, the ORE presents seven types of losses. The proposed indicator maintains the classes proposed by Nakajima (1998) to maintain simplicity and compatibility with the existing interpretation of OEE. However, ORE presents a reinterpretation of the losses associated with each class that is consistent with the nature of operating room processes. The reference proposed by Nakajima (1998) of “heavy losses” is also maintained due to similarity in interpretation. Figure 1 presents the proposed calculation and perspectives of analysis for the proposed indicator.

Similar to the OEE, the ORE can be obtained by the product of the Availability, Performance, and Quality indicators or the ratio between the Total Time of Added Value

(TTAV) and Total Time Available (TTA) measures. Each indicator, shown at the right, is a fraction of time, and the numerators are smaller than or equal to the denominator because the times corresponding to losses are taken from here.

Availability is closely linked to the time available for the operating room's production and its operating time. It comes from Total Time Available, defined by managers and medical staff as the time destined for surgeries. It is typically associated with the time that teams of surgeons, nurses, and anesthetists are available.

Figure 1 - Operating Room Variables and Losses (inspired on Nakajima, 1998)



To calculate the room's availability index, we subtract from the Total Time Available (TTA), the time lost due to planned shutdowns for maintenance (equipment failure); set-ups (room preparation and cleaning); and idleness due to not scheduled surgeries. The latter loss is observed in university and public hospitals and can be due to schedule management: surgeons have pre-allocated time shifts to perform the procedures under their responsibility, regardless of whether these procedures occur. The incomplete use of these shifts may cause losses because the other team cannot use the reserved room. The net time is referred to as the Total Time Scheduled (TTS).

$$Availability = \frac{Total\ Time\ Scheduled\ (TTS)}{Total\ Time\ Available\ (TTA)}$$

The operating room's Performance is measured as the fraction of the TTS that is not lost with variations from the previously made schedule. These variations include short shutdowns (problems with equipment, surgical supplies, momentary power outages, etc.); complications related to the procedure or the patient's clinical situation that are only identified during surgery, exceeding the planned time; and cancellations of surgeries. The resulting time is referred to as the Total Time Used (TTU).

$$Performance = \frac{Total\ Time\ Used\ (TTU)}{Total\ Time\ Scheduled\ (TTS)}$$

Finally, the Quality Index is measured as the fraction of the TTU that is not lost on surgical interventions, error, or failure in the surgical procedure. The net time is called the Total Time of Added Value (TTAV).

$$Quality = \frac{Total\ Time\ of\ Added\ Value\ (TTAV)}{Total\ Time\ Used\ (TTU)}$$

When interpreting the nature of the losses that exist in the OR, this indicator approaches the operational reality of surgical service management. Cima (2011) states that the analysis of efficiency and effectiveness is essential for operating room management. Demeulemeester *et al.* (2013) proposes eight performance measures for the managerial analysis of the operating room process, but each indicator is analyzed separately in the system. Therefore, the present study proposes a combination of the performance measures related to the timing of operating rooms with an integrated analysis of efficiency, effectiveness and signaling the losses. The next section illustrates the application of the ORE in the hospital that participated in this study and presents the data for the tests.

5 APPLICATION, ANALYSIS, AND DISCUSSION

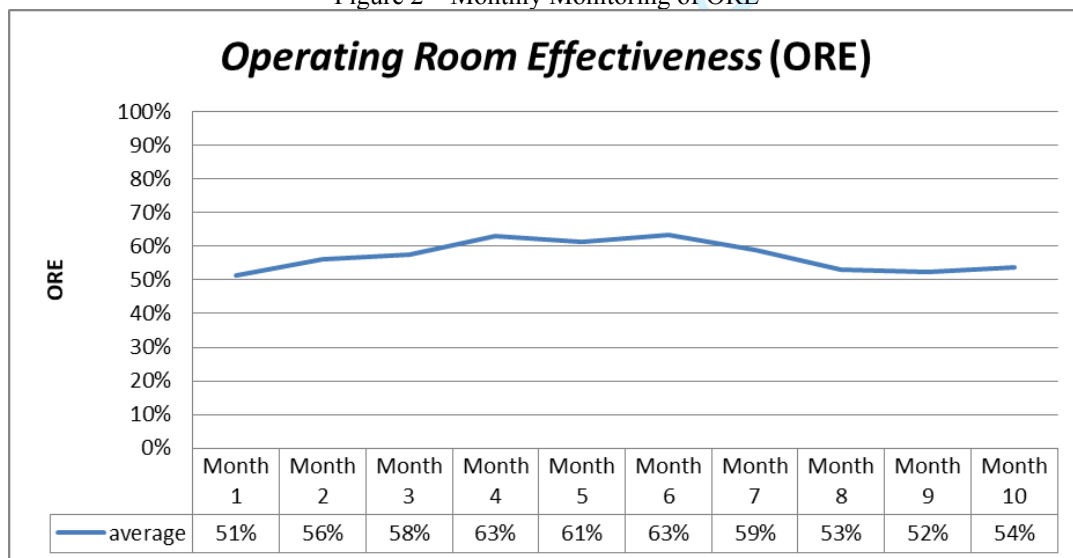
The hospital organization providing the data for the implementation of the proposed indicator is a large university hospital run by public-private management. It is located in

southern Brazil. It has 500 inpatient beds, an outpatient facility with approximately 11,000 consultations per month, 7,000 surgeries per year, and a Diagnostic Center and Laboratory for up to 72,000 tests per month.

The OR under study initially consisted of seven operating rooms divided to meet various specialties: Oral and Maxillofacial, Cardiovascular Surgery, Digestive Surgery, General Surgery, Pediatric Surgery, Plastic Surgery, Thoracic Surgery, Vascular Surgery, Coloproctology, Gastroenterology, Gynecology, Neurosurgery, Traumatology, Otolaryngology, and Urology. The scheduled availability of the operating rooms included the period from 07:30 to 19:00. In this period, elective and urgent surgeries were performed based on surgical scheduling, which was divided into two daily shifts.

The study analyzed 10 months the performance of the surgical center of the study hospital and the monthly values of ORE are presented in Figure 2, using the calculation of the indicator proposed in Figure 1. In aggregate, with an average effectiveness of 57% and seven operating rooms, the study unit conducted an average of 600 surgeries/month. There was an effectiveness gain between the months of December (51%) and May (63%), followed by a low after the month of July (53%). The drop was related to a lack of anesthetists caused by the reduction in government transfers, reducing the productive capacity of the system and thereby the effectiveness as a whole. As stated above, the operating room capacity is based on strong coupling between physical infrastructure, supplies, and personnel. Reducing the number of anesthesiologists had a strong impact on the cancellations of surgeries, and even with doctors, nurses, rooms, and demand for surgeries, the procedures could not be performed.

Figure 2 – Monthly Monitoring of ORE



An analysis of the impacts and causes of inefficiency was performed, and this article only presents the analysis based on the average value of the effectiveness identified (57.3%) in the collection period. An accurate month-to-month analysis was conducted but will not be shown to protect the organization's most specific data and characteristics.

Figure 3 illustrates the number of hours distributed for each monitored variable. On average, the hospital studied lost 346 hours of monthly availability. A more detailed analysis revealed that 269 hours were associated with set-up (room cleaning and preparation time, with a standard time of 30 minutes per procedure) and 77 hours due to no scheduled surgeries. As a result, the availability rate obtained was 72.6% (919 hours/1,265 hours). It is noteworthy that, on average, 6.08% of the available time was lost due to the management policy adopted by the hospital, with shifts for surgeons regardless of their actual demand and flawed control regarding the use of rooms for each surgeon. On average, the 77 hours lost were due to idleness resulting from the surgeons' shifts not having a full schedule, an exclusively managerial decision.

Figure 3 – Time Used to Calculate ORE

TTA	1.265 hours	
TTS	919 hours	346 hours
TTU	725 hours	194 hours
TTAV	725 hours	

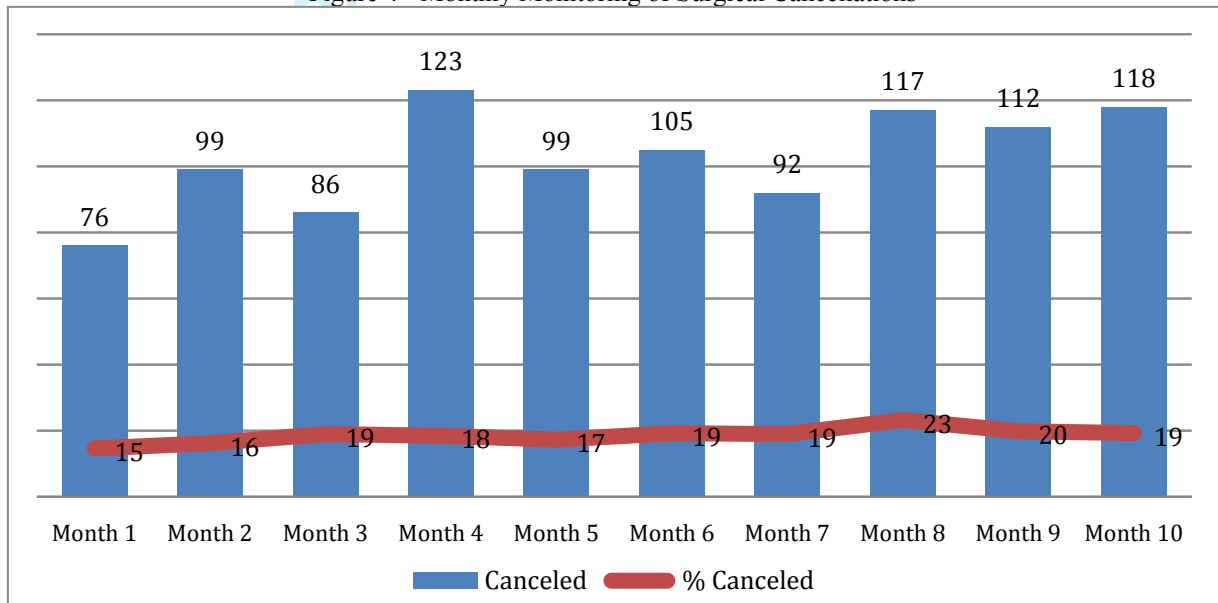
Total Time Available (TTA), Total Time Scheduled (TTS), Total Time Used (TTU), Total Time of Added Value (TTAV).

From the average of 725 hours spent, average performance losses of 194 hours were observed, resulting in a performance index of 78.9%. The details of these losses revealed 151 hours lost due to surgery cancellations and 43 hours due to the variability of surgical time, i.e., the time used was less than that scheduled. The analysis of these causes needs to be detailed, given that surgeries that take more time than expected may lead to subsequent cancellations. To show the impact of this interdependence, we sought data on cancellations. The average surgery cancellations during the listed months were 18% of the surgeries scheduled, i.e.,

approximately 100 canceled surgeries/month (Figure 4). The stratification of the reasons indicated the following: a lack of clinical condition of the patient (30%), patient absenteeism (20%), greater time spent on the previous surgery (14%), emergency fittings (7%), and several others with less frequency (29%).

It is noteworthy that 50% of cancellations occur due to the lack of medical condition or absenteeism of the patient. Based on an analysis of the literature, this fact can be a result of the flawed management of the preoperative patient flow, such as errors in scheduling, wrong information delivered to the patient, a lack of scheduling pre-operative tests, and pre-anesthetic ratings (Pires, 2010; Laganga, 2011; Lemos *et al.*, 2013).

Figure 4 - Monthly Monitoring of Surgical Cancellations



With respect to the TTAV, the present study considered that the time related to losses due to quality was 0 (zero). This decision was due to the lack of consistent data on surgical re-interventions or other technical data associated with surgical failure. Thus, the quality index was found to be 100%, a conservative estimate, yet knowingly overestimated according to the hospital collaborators.

Therefore, based on the collected data for time, the average effectiveness of the operating room evaluated by the proposed indicator in this situation is 57.3% ($= 72.6\% \times 78.9\% \times 100\%$ or 725 hours/1265 hours). In objective terms, this analysis indicates that over 40% of the nominal time provided by the OR is lost due to various reasons. Some of these reasons, such as the patient's clinical condition (Cima *et al.*, 2011), cannot be controlled, but most of the losses found can be managed and controlled through performance indicators and critical

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3 analyses, in addition to integrated scheduling sectors to improve the flow of patients and
4 information to the medical staff.
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6 It can be seen in the application of the indicator, according to Figure 1 where the ORE
7 calculation is presented, that there are losses in both Availability and Performance, since
8 Quality was maintained at 100%. Among the losses by Availability, it is synthetically visualized
9 Setup, Scheduled Shutdowns and Not Scheduling. Among performance losses, a high
10 percentage of Cancellations and Variation in Surgery Time can be verified.
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15 To illustrate the effects associated with ORE and its aim for improvements, some
16 scenarios are derived in Table 4. The scenarios presented are hypothetical and show the
17 usability of the ORE indicator, which is to guide actions with a focus on effectiveness. Seven
18 hypothetical scenarios are suggested to highlight possible improvements in the process and to
19 therefore increase the ORE of operating rooms. We also present a variation compared with the
20 times collected in the hospital under study and the gain in hours with such improvements.
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25 The focus of the scenarios is related to the losses found by the application of the ORE
26 indicator presented in the literature and pervades improvements in "No Scheduling",
27 "Reduction in Set-up", and "Reduction in Cancellations".
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30 The first scenario (A) proposes an optimization of scheduling operations in the surgeons'
31 shifts, and all scheduled surgeries should fit exactly in the total time available; therefore, no
32 scheduling is close to 0 (zero). Thus, ORE increases by 6.1%, although we know it is difficult
33 to fit surgeries exactly in shifts due to differences in the procedures in line and their different
34 completion times. However, further analysis and knowledge of these factors when scheduling
35 are suggested. The second scenario (B) is associated with reducing the set-up time or obtaining
36 optimized room set-up and cleaning. With this redesign, the ORE may have a 3.5% increase
37 and an additional 44.8 hours. There is a limitation in this item related to the number of
38 employees in the cleaning and preparation process, in addition to material handling. These
39 variables should be analyzed for application. The third scenario (C) aims to reduce non-
40 scheduling by half, given the complexity of the perfect fit of surgeries in shifts and the reduction
41 of five minutes in the set-up. With this scenario, ORE will increase by 6.6% or 83.3 hours.
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50 Another important factor to be considered is the cancellation of surgeries, which leaves
51 rooms idle. Scenario D indicates a 20% reduction in cancellations, mainly focusing on
52 absenteeism and variations in the time used and time planned. With the creation of control
53 mechanisms, this variable can achieve a gain of 2.4% in the ORE and an additional 30.2 hours.
54 Scenario E proposes a combination of scenarios A and D, but we already know the difficulties
55 with not-scheduling close to zero. Nevertheless, the analysis indicates a gain of 8.5% of ORE
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and 107.2 hours. Scenario F differs from the previous in the reduction of cancellations, and in this scenario, the proposal is to reach 50% of them. Thus, the impact would be a 12.1% gain in ORE and 152.5 additional hours.

Finally, the last scenario (G) for potential improvements in ORE presents a change in the management of the operation process and the highest gain, with a 31.6% increase in ORE and an additional 399.8 hours to perform surgeries. Although very difficult to achieve, this scenario should be analyzed and adapted, and it may be developed piecemeal over the long-term.

Noted that incremental improvements in the process, whether separate or integrated, directly impact the rates of Availability, Performance, and Quality, thus changing the overall indicator of ORE and adding hours to the operating room's production. It is noteworthy that the hypothetical improvements indicated are related to the problems found in the hospital under study and that equivalent simulations should analyze the situation in each operating room analyzed.

Table 4 – Impact of potential improvements on ORE

Scenario	TTA	TTS	TTU	TTAV	Availability	Performance	Quality	ORE	Variation from the Base	Additional Hours
Base	1265	919.0	725.0	725.0	72.6%	78.9%	100.0%	57.3%	0.0%	0.0
A * ¹	1265	996.0	802.0	802.0	78.7%	80.5%	100.0%	63.4%	6.1%	77.0
B * ²	1265	963.8	769.8	769.8	76.2%	79.9%	100.0%	60.9%	3.5%	44.8
C * ³	1265	1002.3	808.3	808.3	79.2%	80.6%	100.0%	63.9%	6.6%	83.3
D * ⁴	1265	919.0	755.2	755.2	72.6%	82.2%	100.0%	59.7%	2.4%	30.2
E * ⁵	1265	996.0	832.2	832.2	78.7%	83.6%	100.0%	65.8%	8.5%	107.2
F * ⁶	1265	996.0	877.5	877.5	78.7%	88.1%	100.0%	69.4%	12.1%	152.5
G * ⁷	1265	1243.3	1124.8	1124.8	98.3%	90.5%	100.0%	88.9%	31.6%	399.8

Improvements: *¹ No scheduling = 0. *² 5-minute reduction in set-up. *³ No scheduling reduced to half and 5-minute reduction in set-up. *⁴ 20% reduction in cancellations. *⁵ No scheduling = 0 and 20% reduction in cancellations. *⁶ No scheduling = 0 and 50% reduction in cancellations. *⁷ No scheduling = 0, 5-minute reduction in set-up, and 50% reduction in cancellations

6 FINAL CONSIDERATIONS

Much of the knowledge acquired in the field of operations management originated in manufacturing, and it can be applied to service operations (Johnston, 1994). Problems in operations management that arise in healthcare are often similar to traditional problems in operations management. Managers of healthcare systems must manage inventory, measure and manage performance and system quality, and evaluate the performance of critical processes

(Brandeau *et al.*, 2004). These issues are discussed in the application of Lean Management in hospitals, called Lean Healthcare. With focus on reducing wastes and improving flow, Lean Healthcare becomes necessary when discussing Operating Rooms. For, it is necessary to optimize the surgical flow increasing the effectiveness of the operating rooms and reducing the losses found.

The present article contributes to the field of health operations management in that it proposes a perspective for OR effectiveness that is guided by concepts recognized in the context of lean and operations management. Based on the appointment and analysis of process times and, above all, the typical losses of an OR, the study proposes an adaptation of the OEE indicator (Nakajima, 1998), called ORE (Operating Room Effectiveness), for the healthcare scenario. An application based on data from a Brazilian university hospital currently using this concept is presented, in addition to a set of scenarios for analysis created to illustrate how managers can use the indicator to determine action plans with an emphasis on increasing the ORE.

The application shows that, of the 1,265 monthly hours allocated for operations in the organization studied, only 725 are effectively converted into value for the patient. This figure is optimistic, considering that data on re-interventions do not exist and cannot be incorporated into the analysis. For the indicator, 27.4% (346 hours) were losses of availability related to the set-up time of the rooms and no scheduling (idleness), and 15.3% (194 hours) were identified as performance losses related to the time of canceled surgeries and less time scheduled than used. The use of the indicator by the organization showed the path to improvements in plans previously implemented by various measurements and without a focus on effectiveness.

The ORE indicator proposed by this study allow an integrated view of the performance of the OR, as opposed to the majority of other studies that present other performance indicators as Waiting time, Throughput, Utilization, Leveling, Makespan, Cancellations, Financial Results and Preferences presented by Demeulemeester *et al.* (2013). The analysis of OR losses supported by the OEE indicator allow a global view of the overall performance of the ORs rather than a partial view based on the analysis of each indicator referred by Demeulemeester *et al.* (2013). Therefore, with the application in a hospital OR, a validation of the ORE as an adaptation from OEE (Nakajima, 1998; Ivancic, 1998; Gibbons and Burgess, 2010; Busso and Miyake, 2013) was verified, contributing to the analysis of effectiveness in ORs in hospital environments.

This study is an exploratory study; it only proposes and applies an indicator for an OR. Although guided by theoretical and conceptual references, the definition of the types of losses

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3 and their association with the ORE indices is also based on the observation of real environments
4 limited to the south of Brazil. It is understood that mimetic isomorphism (Dimaggio and Powell,
5 2000) between hospital environments contributes to the applicability of the proposed indicator,
6 but further studies and applications must be performed.
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10 As reported by Kodali *et al.* (2014), there are obstacles in managing changes in health
11 organizations, such as the organizational culture of leaders, managers, and agents of change in
12 healthcare organizations. The awareness of the many variables that can support or hinder a
13 particular effort to change can inform implementation strategies for effective improvements
14 that are compatible with the DNA of the organization. In the present study, obstacles, such as
15 the fear of applying techniques from industry in the healthcare process, the acceptance of the
16 medical and nursing staff in measuring and scheduling time, and the implementation of
17 improvements that break the existing barriers in the organization, were encountered. However,
18 with the presentation of the collected data, the average ORE of the hospital under study, and
19 the impact of the scenarios on the overall indicator, some barriers were overcome with the
20 understanding of the scientific method.
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29 We suggest future research on the application of the proposed indicator in other health
30 institutions and a further discussion of the concepts of Quality and Added Value in operating
31 times, mainly with technical healthcare concepts due to the limitation in obtaining data on
32 surgical re-interventions in the organization, in addition to a technical discussion about how
33 many re-interventions are due to flaws and how many are not. Another research suggestion is
34 related to programming and leveling the productive capacity of an OR to analyze the overall
35 patient flow and the behavior of surgery waiting lines.
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Figure 1 - Operating Room Variables and Losses (inspired on Nakajima, 1998)

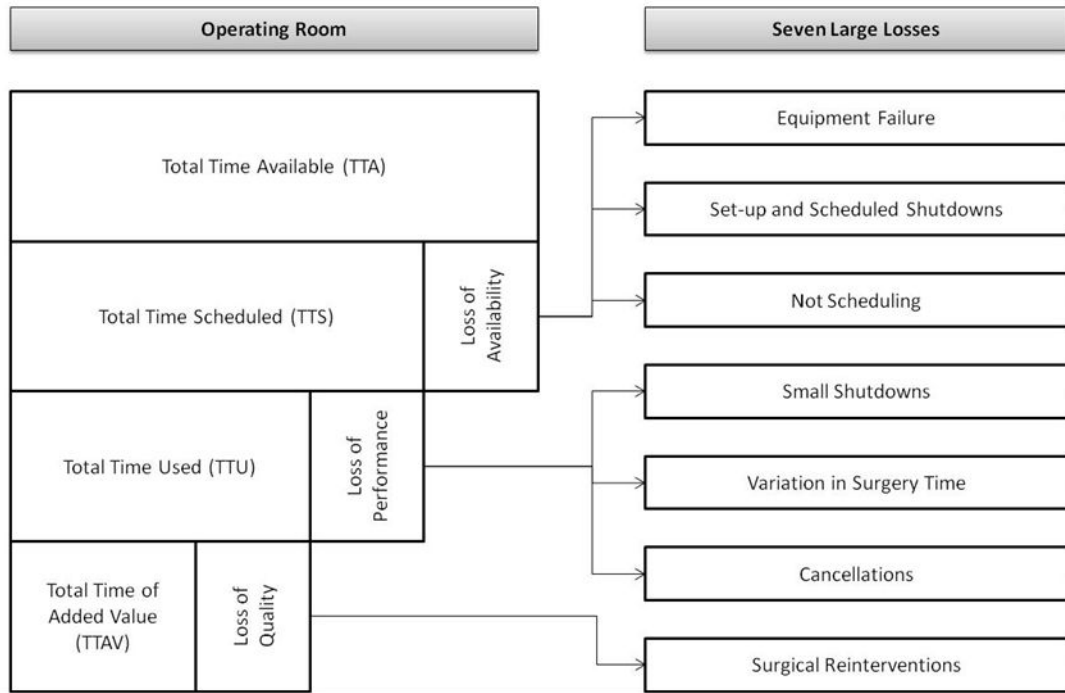


Figure 2 – Monthly Monitoring of ORE

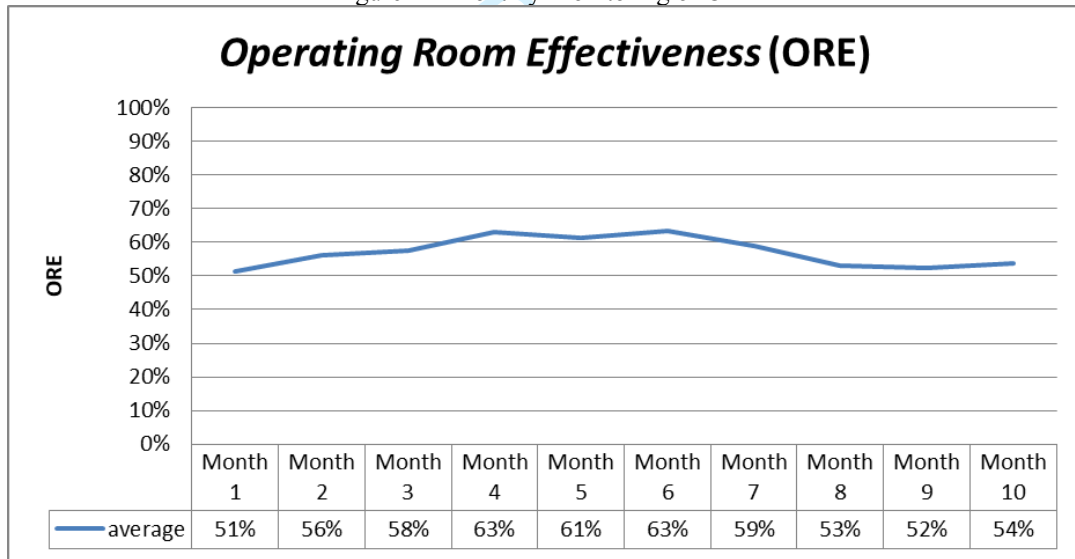


Figure 3 – Time Used to Calculate ORE

TTA	1.265 hours	
TTS	919 hours	346 hours
TTU	725 hours	194 hours
TTAV	725 hours	

Total Time Available (TTA), Total Time Scheduled (TTS), Total Time Used (TTU), Total Time of Added Value (TTAV).

Figure 4 - Monthly Monitoring of Surgical Cancellations

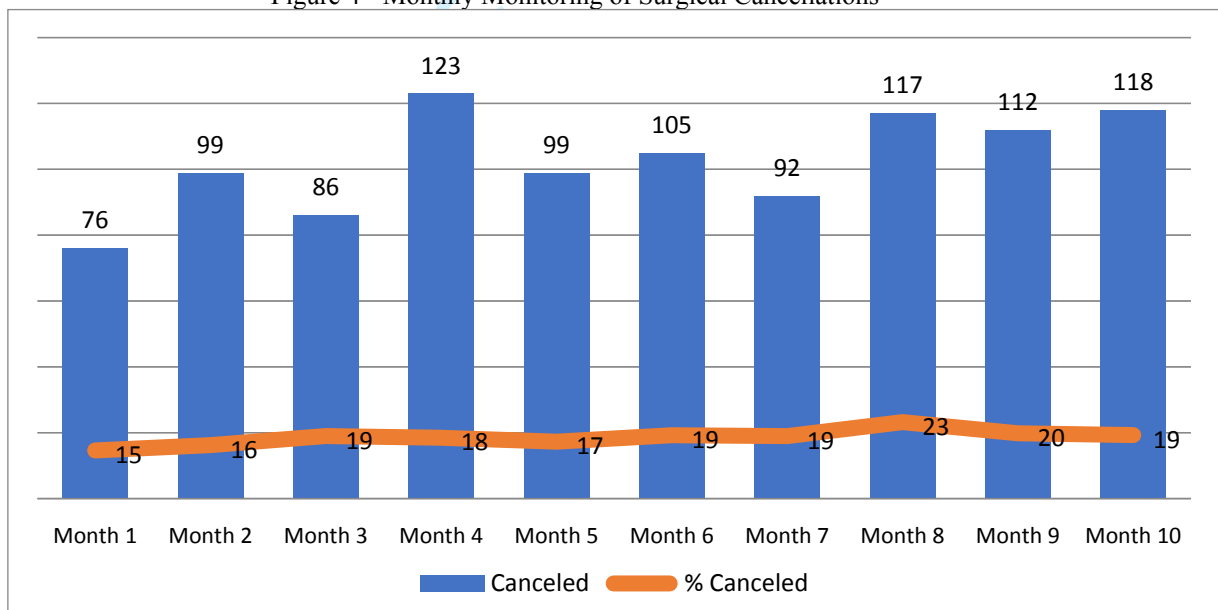


Table 1 – Performance Measures. Adapted from Demeulemeester *et al.* (2013)

Performance Measures	Description
Waiting time	Represents the patient waiting time from the identification of surgical needs to completion.
Throughput	Measurement related to the patient and waiting time, such that the greater the yield of the operating rooms is, the shorter the patient waiting time.
Use	Indicator related to the time spent using the operating room compared to the scheduled time. The use does not take into account stops for preparation and cleaning the rooms or scheduled stops. It only accounts for the time used in relation to the time scheduled for production.
Leveling	Leveling concerns the development of operating room schedules that lead to the smooth occupation of resources, without peaks and minimizing the risk of capacity problems caused by unexpected events.
Makespan	Represents the time of completion of patient recovery. It generally can be defined as the time between the entry of the first patient and the completion of the last patient.
Cancellations	Number of canceled surgeries that result in idle capacity in the schedules, low productivity, and increased waiting time for patients.
Financial Results	Performance measures related to cost and financial gains that the OR refers to the hospital system.
Preferences	Analyzes the preferences of the different parties involved in the surgical process, such as preferences of surgeons, nursing staff, patients, etc.

Table 2 – Steps for the development of the approach

1. Bibliographical Reference
2. Direct Observation and Interviews
3. Analyses and Proposition of the Indicator
4. Application Study
5. Evaluation by Committee
6. Validation of Indicator
7. Creation of Hypothetical Scenarios

Table 3 – Six basic losses by OEE (Nakajima, 1998; Ivancic, 1998; Busso and Miyake, 2013)

Classes	Losses
Availability Losses	downtime for lack of equipment
	downtime for setup or adjustments
Performance Losses	short breaks for poor equipment operation
	reduction in equipment speed
Quality Losses	defective production and rework
	losses incurred at the start of production due to adjustments for equipment stabilization

Table 4 – Impact of potential improvements on ORE

Scenario	TTA	TTS	TTU	TTAV	Availability	Performance	Quality	ORE	Variation from the Base	Additional Hours
Base	1265	919.0	725.0	725.0	72.6%	78.9%	100.0%	57.3%	0.0%	0.0
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G * ⁷	1265	1243.3	1124.8	1124.8	98.3%	90.5%	100.0%	88.9%	31.6%	399.8

Improvements: *¹ No scheduling = 0. *² 5-minute reduction in set-up. *³ No scheduling reduced to half and 5-minute reduction in set-up. *⁴ 20% reduction in cancellations. *⁵ No scheduling = 0 and 20% reduction in cancellations. *⁶ No scheduling = 0 and 50% reduction in cancellations. *⁷ No scheduling = 0, 5-minute reduction in set-up, and 50% reduction in cancellations