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Increase the Efficiency of the Surgical Center in a Brazilian Hospital using Computer Simulation

Roberto Max Protil
Pontifícia Universidade Católica do Paraná (PUCPR)
Programa de Pós-Graduação em Administração (PPAD)
Rua Imaculada Conceição, 1155 – 80215-901 Curitiba/PR - Brazil
e-mail: protil@ppgia.pucpr.br
phone: 00-55-41-32711634

Joelson Ricardo Stroparo
Pontifícia Universidade Católica do Paraná (PUCPR)
Programa de Pós-Graduação em Tecnologia em Saúde (PPGTS)
Rua Imaculada Conceição, 1155 – 80215-901 Curitiba/PR - Brazil
e-mail: joelson.s@pucpr.br
phone: 00-55-41-32711657

Gerson Linck Bichinho
Pontifícia Universidade Católica do Paraná (PUCPR)
Programa de Pós-Graduação em Tecnologia em Saúde (PPGTS)
Rua Imaculada Conceição, 1155 – 80215-901 Curitiba/PR - Brazil
e-mail: linck@ppgia.pucpr.br
phone: 00-55-41-32711657

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Abstract: Medical simulation is becoming common practice in multiple research fields. Research, evidence-based outcomes, medical education, performance assessment, ethics, business, all play an important role in acknowledging more about this new field and its potential impact on healthcare. The purpose of this document is debating the use of computer simulation for increasing surgical center occupation rate at University Hospital of Cajuru, located in the city of Curitiba (Brazil). The development stages of this study are: analysis of requirements, development of operational flow model, simulation, validation of developed model and analysis of results. For the attainment of this work three scenarios were created. The first scenario is one of the six existing surgical rooms. It was possible to improve the orthopedic surgical occupation rate specially through changing some input variables. The two following scenarios demonstrated the impact of amplification on existing rooms, as the second scenario acknowledges input data of the model as in the real system, making it possible to obtain a better occupation rate, and the third scenario showed an improved amount of occupancy using the input data. The result analysis provided subsidies for the reduction of idleness in this sector. This knowledge and the creation of a model can be used for research in the medical area, bringing a real benefit of information technology application for improving efficiency in hospital management.

Keywords: Computer simulation, surgical center, hospital management.

1 INTRODUCTION

Within hospital environment there is a complex surgery center system, which is an essential unit for performing surgical procedures with the support of a team of professionals in this area.

This area requires adequate support, so technical-administrative aspects regarding the layout, location, equipment, regiment, rules, routines and human resources are ensured as mechanisms that subsidize prevention and control of risks, supporting ethical-legal protection for the team of professionals and to the institution itself. Through these aspects it is possible to evaluate the vast complexity originated in the great number of external elements. Among them are (LANGE, 1999): frequent changes of patients and professionals involved in clinical procedures, various specializations and surgical procedures and the required integration with other hospital sectors, where patients, material, instruments and equipment, necessary for surgeries, originate.

Patients are submitted to some specific situations, in surgical environment, requiring the application of new techniques to make the execution of some tasks easier. Among these techniques are modeling and system simulation.

Simulation consists in describing a model through process or systems that feature parameters, allowing their configuration, enabling decision making regarding the real execution of a model (praxis) (CARSON, 2003). The simulation of a model is the representation that incorporates time and changes occurring within a pre-determined period of time.

Data pattern is capable of acknowledging reality based on known phenomena, enabling the execution of experiments that help us predict real behaviors. Certain factors that partially affect the system may be, during the system modeling process, simply ignored or treated as input and output of the referred system (ROSSETTI et al., 1999).

The simulation of patterns, as patterns represented by a mathematical and/or logical structure, tends to mimic the system behavior the most realistic way possible. By means of experiments, several observations are performed for subsidizing various conclusions about the system (LAW et al., 2000).

2 MATERIAL AND METHODS

After some meetings with hospital staff, focusing the monitoring and follow-up of current processes, as well as their improvement, it was possible to represent interaction between surgery center, other hospital sectors (intern unit and supply department), professionals and patient.

This stage, also known as data & requisites study, is characterized as *in loco* stage, where visits to the hospital surgery center frequently occurred, for it was necessary to make interviews, get to know and experience specific problems, obtaining conclusions from a critical point-of-view.

2.1 The study of surgery plan

The elaboration of the surgery plan enables activities to be performed within a specific period of time. Based on this plan we have: checking of room availability and respective booking, adequacy of surgery room, equipment and instrument reservation, acquisition or transportation of material to be used in surgeries, as well as patient preparation, take place.

For the plan it is necessary to fill out a surgery notice, informing the execution of surgeries performed by doctors. This can be done in two steps: when the patient has already entered the institution, or when the doctor checks the need for surgery intervention through consultation. In these notices, the main information is: patient’s personal data, surgeon and staff involved in the procedure, date and time of surgery, type of surgery, procedures to be performed, equipment, instruments and materials necessary for the execution.

Through the visualization of notices and availability of surgery rooms, equipment, instruments and other necessary material, an analysis of the number of surgeries programmed for each day, time and specialty is performed, enabling the confirmation and scheduling required through it, or the suggestion of new dates and times for surgeries.

2.2 Parameters and variables

Based on the surgery plan and sector characteristics, variables and parameters, necessary for simulation implementation, have been defined. Variables were divided in two groups. The first one was used for defining the work scope and the second for implementing the tool.

Parameters refer to model features that remain uncharged during the simulation, however, influencing in several stages of variables values, as the name itself defines, these are features that vary during their definition, and may present differentiated values according to their preliminary features. The parameters used in the simulation were: clinical specialty of procedure(s), procedure(s) to be executed, surgery room, days of the week and times when surgical procedures can take place, number of rooms per specialty available, surgery procedures start time limit during the morning hours, surgery procedures start time limit for afternoon hours, type and number of professionals involved during the surgery, type of occurrences (selective or emergency).

The list of variables used is formed by: time for cleaning the surgery room, post-anesthesia recovery time, surgery procedures time, anesthetic procedures time, time for material and anesthetist to get into surgery room, time for transporting the patient to the surgery room, existing cancelling, average delay time, total time of patient in the surgery room, availability of medical material in the referred sector and total number of occurrences scheduled and that were effectively executed.

2.3 Surgery room information system

With the system developed for the surgery room, surgery scheduling is made through surgery notices, filled out by the surgeon or person in charge of the surgery center. From this stage on, the surgery plan is elaborated. Before this work is performed, all the part referring scheduling is performed manually, using tools for processing text and electronic schedules. This system was implemented in the existing hospital information system.

2.4 System model

For the ideal development of a model through a simulation tool, it must feature the following components (LOWERY et al., 1999): delimitation of execution time interval, delimitation of model scope, procedure used for time scheduling and distribution and downtime definition.

2.4.1 Interval delimitation and execution time

The interval used for the execution of procedures followed the sector's real time, Monday through Friday, 7 AM through 12 AM and 1 PM through 6 PM, and on Saturdays, 7 AM through 12 AM. These time schedules correspond to the group of elective patients, and the last queue procedures of the period may exceed the time limit and, therefore, works only as a limit for execution start. The model processing time was 30 days, enabling comparison of these data with real ones.

2.4.2 Delimitation of model scope

This study was developed in only one of the surgery center rooms, considering it enabled a detailed vision of executed operational processes / flows. According to the specialty and surgical procedure to be executed, some details may be different. Therefore, only one of the various existing processes / flows existing in the surgery center became the work focus, considering the scope is not the entire sector, but only the surgeries and orthopedic group rooms. This choice was due to the fact the university hospital “University Hospital of Cajuru (HUC)” is specialized in body injury, within which it would be possible to opt for the type of service, which include: selective and emergency. For historical reasons of procedures executed, and also due to the fact the hospital presented a higher number of patients on government medical assistance (SUS), private plan patients were not taken into account.

Based on the orthopedic procedures group, a study was held on a time series started in 1998 until the end of 2001. Within this period, 10,036 procedures were executed in selective patients covered by SUS. From the total of procedures performed, only 6 corresponded to 31% (3,111 procedures) and other 253 corresponded to 69%. This way, detailing of processes was done based on those six ones.

2.4.3 Procedure used for time control and scheduling

For time control, several visits to the surgery center took place, during which the operational flow had been defined, containing modeling effective processes. Based on this flow, the variables involved were analyzed for defining their times from the evaluation of average timing between incoming and outgoing of each model entity.

2.4.4 Downtime definition

An important model component is maintenance time, also known as downtime, referring time intervals during which there is no activity (surgery, cleaning procedures or room preparation), usually due to delays (staff, patient or unavailable equipment) or discrepancies between scheduled surgery time and effective one. It is known that the great majority of surgery centers present occupancy rates varying between 80% and 85% (RINDE, 1976). In this work, the average time analysis of real timing of procedures is considered as downtime.

2.5 Model characteristics

Based on the study that defined the process, it was possible to perform relative timing readings related to it, which were used in the simulation elaboration. A flow containing significant processes regarding the simulation, and average timing, is shown in figure 1.

This flow does not refer to all model entities, considering that some of them are not significant to the simulation process, such as, for example, the process for filling out a form and leaving the room, executed by the attendant, not referring the patient. Other entities were included, such as checking of preparation needs and the respective execution of it.

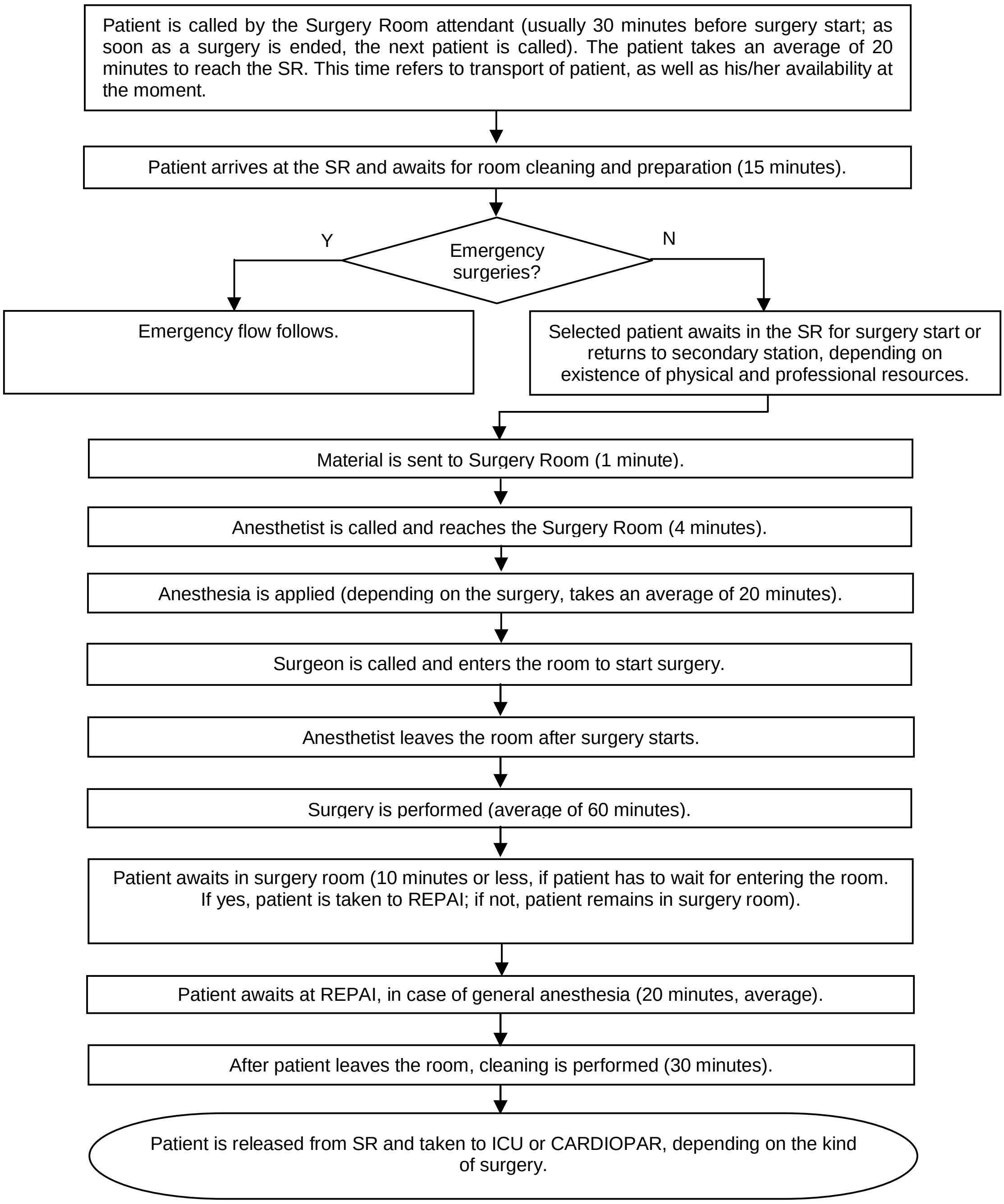

FIGURE 1: FLOWCHART WITH AVERAGE TIMING.

Other factors can interfere in the total duration of procedure; however, due to frequence, they are not taken into consideration. Among them is the fact of a professional, involved in the process, being absent in the surgery room at the moment he/she is required.

Analysis of time processing:

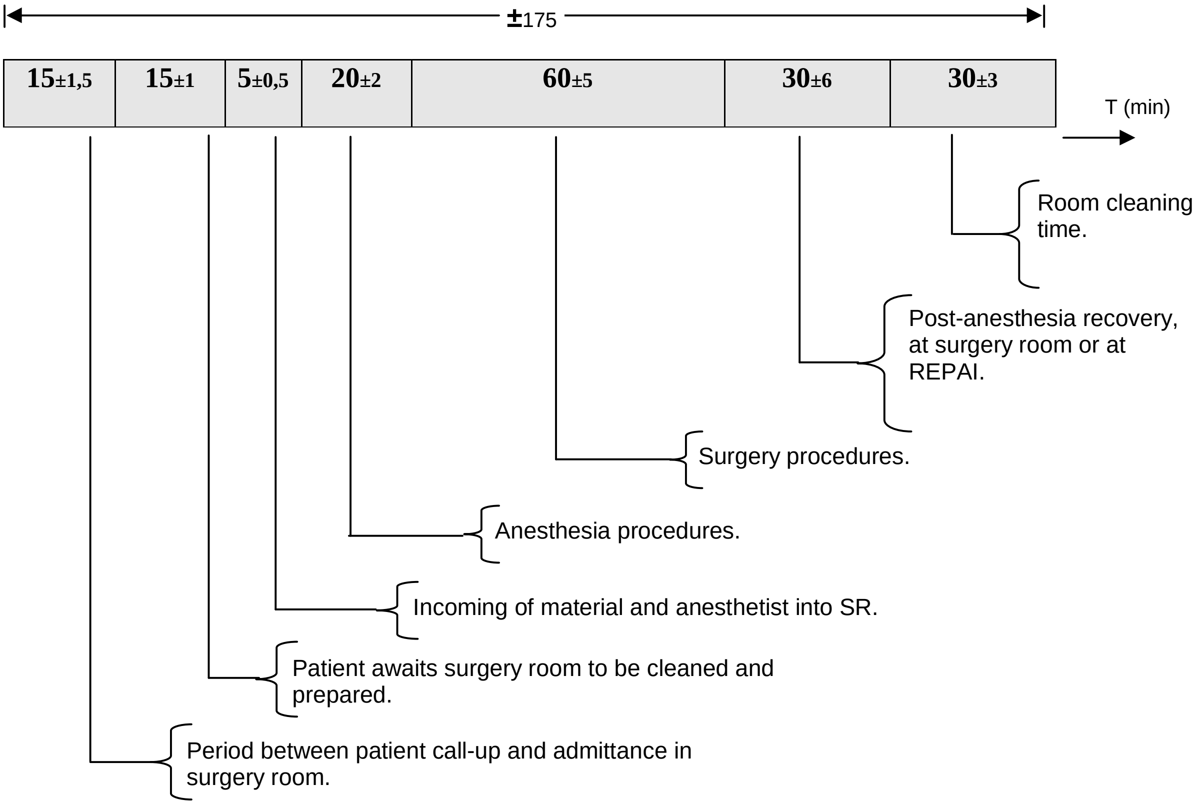

FIGURE 2: ON-TIME SURGERY EXECUTION.

After flow definition is simulated and variables are defined, the focus becomes the use of Promodel software. Among the existing libraries, MedModel is an important one, for it focuses health subject and related systems and was used for development and simulation of the model.

For the effective simulation of the model, two factors are fundamental: study of significance variables and interaction time registering among them. Variables were defined through analysis of operational flow containing processes that are significant to standardization (model), according to one previously shown and its respective timing originated, based on its average timing.

Using the surgery room layout plan and the MedModel graphic library, a computer model was created, representing the main physical components of the referred sector, as well as interaction among them.

3 DISCUSSION OF RESULTS

The validation of implemented model was performed by comparing real results collected in the surgery room during the month of March, 2004, obtained through SIH, with data provided in the same period by the simulator. After the execution, the variables compared were: the number of procedures executed, the number of cancelling registered and occupation rate in a single surgery room, considering that all orthopedic group procedures were executed only in this specific place. Table 3.1 shows these data.

TABLE 3.1: COMPARISON AMONG MEDMODEL RESULTS AND SIH*.

Results	**Procedures**			**Occupation rate**
	Executed	**Cancelled**	**Total**	
SIH	136	68	204	66,67 %
MedModel	145	~ 70	215	67,53%

*SOURCE: MedModel Output and Hospital Information System.

The difference can be explained, considering that some suppositions and situations which occurred in the real process, with the simulator, were not taken into account. Among the suppositions that can be used for the development of a simulation model, some are used in the current one:

- Possible occupation of a specific room for specialty procedures not previously programmed;
- As an emergency hospital, the number of surgeries of this type may be significant;
- If booking of new surgeries is not possible for some specific specializations, a scale re-distribution takes place, creating homogeneity in the number of surgeries in the rooms;
- For enabling the simulation of the model, some variables of the real process are dealt randomly or are simply ignored, for it was not possible to define values for them.

Therefore, above characterized items not dealt in the simulation, but occurring in the real process, are the origins of 0.86% of existing ones in the difference between occupation rates, checked in table 3.1.

According to several reasons leading to surgery cancelling, it is necessary to deal with them, using the model, as a random variable, with frequency pattern of 32.47%. This value originated based on data analysis provided by the simulator, according to what shown in table 3.2. At room 1, focus of this study, it is possible to identify the cancelling rate in the idle column (% *idle)*, for it represents the period during which the room was in use.

TABLE 3.2: ANALYSIS OF OCCUPATION RATES*.

Scenario : Normal Run
Replication : Average
Period : Final Report (0 sec to 9 hr Elapsed: 9 hr)
Simulation Time : 9 hr

LOCATIONS

Location Name	Scheduled Hours	Capacity	Total Entries	Average Minutes Per Entry	Average Contents	Maximum Contents	Current Contents	% Util
Recepcao	9	999999	344	16.126919	10.2734	18	10	0.00
Sala1	9	1	145	69.515034	0.675333	1	1	67.53
Sala2	9	1	72	139.970833	0.529444	1	1	52.94
.								
.								
.								

LOCATION STATES BY PERCENTAGE (Single Capacity/Tanks)

Location Name	Scheduled Hours	% Operation	% Setup	% Idle	% Waiting	% Blocked	% Down
Sala1	9	53.74	0.00	32.47	13.79	0.00	0.00
Sala2	9	46.14	0.00	47.06	6.80	0.00	0.00
.							
.							
.							

*SOURCE: MedModel Output.

It can also be observed that the simulator deals the occupation rate as being the period when some entity remains in the sector (operation*)*, plus the time during which the sector awaits the coming of entities (waiting*)*.

For analysis of surgery execution time it is necessary to evaluate the time during which the patient remained in the specific place (location), object of the study, more specifically, the surgery room #1. This information is checked in table 3.3. The simulator presents an operation rate: the patient was subjected to a surgical procedure, equivalent to 38.94%. In the real process, the procedure execution time is equivalent to 31.57% of the total, noticed through the figure with previously shown average timing. This difference can also be assigned to the same previously mentioned suppositions.

TABLE 3.3: MODEL ENTITIES SERVICE TIME ANALYSIS*.

```
--------------------------------------------------------------------------------
Scenario        : Normal Run
Replication     : Average
Period          : Final Report (0 sec to 9 hr Elapsed: 9 hr)
Simulation Time : 9 hr
--------------------------------------------------------------------------------
```

ENTITY STATES BY PERCENTAGE

Entity Name	% In Move Logic	% Wait For Res, etc.	% In Operation	% Blocked
Paciente	4.97	5.07	38.94	51.02
Zelador	1.69	0.00	1.25	97.07
Medico	0.93	0.00	0.10	98.97

*SOURCE: MedModel Output.

After performing current process simulation, several actions can take place in the surgery plan elaboration process, which need to have their values adjusted, making it possible to provide a new reality in the surgery center. For ensuring idleness decrease in surgery rooms, caused by previously mentioned factors, two actions may take place.

The first action refers to surgery scheduling which was not scheduled for a specific day. For the execution of this procedure it is necessary to analyze the surgery data bank. This analysis refers to surgery time (duration) compatibility checking, necessary equipment and material and, most of all, surgery team and patient availability (in many cases the patient has not been admitted in the hospital). Therefore, this procedure does not fit in the scope of this work due to the following reasons: first because, further than being necessary for the integration of the data bank simulation, it would be necessary for the implementation of automated management techniques for enabling the fitting in of surgeries, for this procedure is done manually at the present time; second, as previously mentioned, most of cancelling occur hours before scheduled time, leaving no time for rearrangements in the surgery execution schedule.

The other possible action is the rearrangement of surgical plan. In this case, the idea is enabling surgery room agenda scheduling at the end of the period or day. This action would result in the enabling a greater period of time for analysis of the surgery plan within the period / following day and, consequently, creating new time schedules available within the subsequent periods / days. The surgery center occupation rate would be upgraded if the study period is analyzed and not only the rearrangement day. Besides this upgrade, as the hospital under study also presents emergency service, this new available time could be used for a procedure of this group.

Due to the mentioned features and the fact that the surgery plan of a specific day is available, the rearrangement artifice was selected for implementation. Based on this definition, two scenarios within the simulation tool were created and executed with the purpose of reducing idleness in surgery rooms.

The first scenario refers to executing analysis in the surgery queue. The idea is detecting, at the end of it, a procedure with the same characteristics of the one being cancelled. These characteristics included analysis of the clinical team, if it is the same procedure, and patient physical and pre-operation availability. If positive, the exchange takes place and, consequently, there is no idleness in the room during this period. The result of this scenario was the existence of four procedures that satisfy the criteria for exchange.

The second scenario was created in advance with all procedures subsequent to the cancelled one. In this case, no situations or difficulties were created in the simulator to make it impossible of being performed; however, in the real model, what may occur is lack of effectiveness, with the execution of procedure on time, as initially proposed.

According to table 3.4, in advanced situations, it was not possible, during the simulation, to define the number of procedures that can be effectively executed due to randomness with which delays of the next procedure may occur.

The concentration of these delays may turn it impossible to start the procedure execution at the simulation tool before the end of the period (6 PM). This actually does not occur, for they may be started even after the mentioned time.

TABLE 3.4: COMPARISON BETWEEN RESULTS OBTAINED THROUGH EXCHANGE OF PROCEDURES AND ADVANCING IN THE PROCEDURES EXECUTION QUEUE WITHIN A PERIOD OF 30 DAYS*.

Simulation	Free periods	Procedures able to be executed
Procedures exchange	4	4
Advance	70	Not defined yet

*SOURCE: MedModel Output.

The total number of free periods presented corresponds to the total number of cancelling. As already mentioned, independently of any analysis, there is, within the simulator, the task of advancing the next procedures in relation to the cancelled one. This advance is not necessarily effective, although it may occur. In case it really does, the filling of time occurs and as in the first scenario, idle time is placed in the end of the period, or if another cancelling should occur, is placed after the first one.

With the intention of taking advantage of all created structure, a third scenario has been simulated. In this new scenario, a simulation environment was created, with the purpose of demonstrating, further than the 6 rooms currently in use within the HUC, adding other 4 surgery rooms which, despite already physically existing, are not being used. The intention was to demonstrate the performance of the system as a whole, which may be possible in the future.

In this new scenario there was no concern regarding room scheduling, but only analysis of the additional rooms' impact on the whole set, i.e., what is the new occupation rate, considering the same number of attendances and also which is the new number of possible attendances performed with the new physical structure, considering the simulator occupation rate of 67.53%. As the work is centered only in the orthopedic surgery group, the results refer only to this group.

The variable that identifies the number of attendances was dealt in two different ways. The first refers to analysis of the occupation rate, using the same number of attendances, which may occur in case the search for surgeries is not increased, according to what verified in table 3.5.

TABLE 3.5: ANALYSIS OF OCCUPATION RATES IN ROOMS DESTINED FOR ORTHOPEDIC GROUP IN THE SCENARIO PROPOSED WITH TEN ROOMS*.

```
Scenario        : Normal Run
Replication     : Average
Period          : Final Report (0 sec to 9 hr Elapsed: 9 hr)
Simulation Time : 9 hr
--------------------------------------------------------------------------------
```

LOCATIONS

Location Name	Scheduled Hours	Capacity	Total Entries	Average Minutes Per Entry	Average Contents	Maximum Contents	Current Contents	% Util
Sala1	9	1	95	68.415034	0.665333	1	1	44.19
sala7	9	1	75	69.487500	0.657443	1	1	34.88

LOCATION STATES BY PERCENTAGE (Single Capacity/Tanks)

Location Name	Scheduled Hours	% Operation	% Setup	% Idle	% Waiting	% Blocked	% Down
Sala1	9	36.86	0.00	55.81	7.33	0.00	0.00
sala7	9	28.06	0.00	59.47	12.47	0.00	0.00

*SOURCE: MedModel Output.

One of the observed characteristics refers to the number of cancelling. The simulator does not display, in none of the scenarios, the number of cancelling, but the room idleness, as previously mentioned. As the analysis refers to the situation in which the number of services has not been increased, the number of executed procedures also remains the same. Thus, room 1 idleness increases, for procedures in this room are being re-scheduled to room 7 (room assigned to the orthopedic group in the new scenario) resulting in a number of cancelling that is superior to total number of services provided.

Table 3.6 was developed through comparison of current scenario with table 3.1 data. In this table it is checked that, dealing rooms 1 and 7 independently, their occupation rates are smaller, as well as the number of procedures is going to be bigger when compared with original scenario. This occurs due to rearrangement performed by the tool.

However, in case a comparison of original scenario and new one is performed, but instead of analyzing the rooms independently, the number of procedures is added, it is possible to check that the number of cancelling decreases, which implies in more procedures in the surgery center being performed and, therefore, showing the occupation rate has increased in the sector.

TABLE 3.6: COMPARISON BETWEEN THE LAST TWO SIMULATED RESULTS (ONE AND TWO ROOMS OF THE ORTHOPEDIC GROUP) AND SIH*.

Results		**Procedures**			**Occupation rate**
		Executed	**Cancelled**	**Total**	
SIH		136	68	204	66.67%
Original scenario		145	~ 70	215	67.53%
10-room scenario	Room 1	95	~ 45	215	44.19%
	Room 7	75			34.88%

*SOURCE: MedModel Output and Hospital Information System (Sistema de Informação Hospitalar).

The occurred redistribution enabled variables within the simulator, which in the first scenario caused a negative impact on the number of cancelling, which reflected in the second scenario, increasing the number of surgery executions. The fact the occupation rate has decreased is a reality, for there was no offering for more vacancies. This characteristic of occupation rate decrease in a real model would be easily resolved by offering new vacancies for patients.

The second treatment performed in the new scenario refers to the analysis of the number of surgery notices that can be scheduled, in case it equals the occupation rate of the new scenario with original scenario, i.e., considering the same results obtained in table 3.1 for the simulation to be able to define which is the new number of surgery procedures to be performed and cancelled.

At this moment, the variable identifying the number of attendances is no longer analyzed, based on real data and a new variable, identified as rate X occupation, is added to the model. With this new variable and its value defined as 67.53, which for the tool means total number of attendances, 67.53% should really be applied. The data in table 3.7 were obtained after the simulator execution.

TABLE 3.7: ANALYSIS OF NUMBER OF ATTENDANCES OCCURRED IN ALL TEN ROOMS, CONSIDERING OCCUPATION RATE OF 67.53%*.

```
Scenario        : Normal Run
Replication     : Average
Period          : Final Report (0 sec to 9 hr Elapsed: 9 hr)
Simulation Time : 9 hr
```

LOCATIONS

Location Name	Scheduled Hours	Capacity	Total Entries	Average Minutes Per Entry	Average Contents	Maximum Contents	Current Contents	% Util
Sala1	9	1	140	71.424038	0.747443	1	1	67.53
sala7	9	1	138	74.576812	0.713333	1	1	67.53

LOCATION STATES BY PERCENTAGE (Single Capacity/Tanks)

Location Name	Scheduled Hours	% Operation	% Setup	% Idle	% Waiting	% Blocked	% Down
Sala1	9	59.08	0.00	32.47	8.45	0.00	0.00
sala7	9	54.31	0.00	32.47	13.22	0.00	0.00

*SOURCE: MedModel *Output*.

Data resulting from this new proposal show the possible number of attendances with orthopedic group patients. The difference between the two rooms refer to problems related to equipment availability, instruments and team of doctors, for in many situations the same variables must be in use at the same time interval, resulting in the fact that one of the rooms may not be available, which results in cancelling. In short, the three scenarios are shown in table 3.8.

TABLE 3.8: COMPARISON OF RESULTS CONSIDERING THE OCCUPATION RATE OF 67.53%*.

Scenarios	**Procedures**		
	Executed	**Cancelled**	**Total**
Original simulation with a single room.	145	~70	215
Simulation equaling 67.53% rate in room 1.	140	67	207
Simulation equaling 67.53% rate in room 7.	138	66	204

*SOURCE: MedModel *Output*.

The variables generating the decrease were defined in this new scenario based on values of the first scenario, which means they were proportionally increased to the desired occupation rate. However, in case they are re-defined, the occupation rate tends to be increased.

4 Conclusion

After definition, flow pattern, creation of graphic representation through simulation tool and result analysis are the main focus, independent of technical or clinical factors, demonstrating the actions to be taken in the sector. With results provided by MedModel, the model validation was executed, comparing these data with data provided by the information system from surgery center.

With validation executed, alternatives were analyzed, allowing rearrangement of the surgery plan. This study enabled problem identification referring increase in the number of executed procedures, allowing schedule improvement and, clinically, continues to promote a quality service. Thus, the main idleness generating factors were detected, providing subsidies for service and clinical team to make improvements in managing resources. Among these are: canceling of surgeries and delays in the execution of procedures.

The work conclusion made the extraction of satisfactory results a plausible action, such as analysis of the number of attendances due to physical expansion of surgery center. These results make the execution of an expansion project possible, considering physical and human resources; in a way that errors and dimensioning problems may be decreased rather than the project is executed without analysis of presented results.

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