Multimethodology Applied to a Complex Health System

Simone Aldrey Angelo[1](✉) and Marcos Pereira Estellita Lins[1,2]

[1] COPPE/Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil
simonealdrey@gmail.com

[2] Federal University of State of Rio de Janeiro, Rio de Janeiro, RJ, Brazil

Abstract. This study aims to support a complex health problem, referring to a large public hospital, which works only with elective surgeries and stands out as a center of excellence in the treatment of orthopedic diseases and trauma. For this purpose, the CHAP^2 was used, which consists of a systemic methodology to structure and facilitate the integration between qualitative and quantitative aspects of complex social problems. This method provided a broad qualitative context for the problems, in particular the excessive size of patient in the admission queue and the huge number of exams with expired validity. The qualitative approach also supported the choice and application of quantitative simulation by mediating the selection of decision variables, their sensitivity analysis and the validation of results from simulation. The quantitative approach used scenarios and indicators in order to provide guidance for management to solve hospital management.

Keywords: Health · CHAP^2 · Simulation

1 Introduction

Papageorgiou (1978), Cardoen et al. (2010), Rais and Viana (2011) provide a vast survey of the applications and contributions of Operational Research (OR) to healthcare, which shows the considerable development of the use of OR in healthcare over the years. According to Brailsfordand and Vissers (2011), the application of OR in the health sector differs from the application in other areas, because of the special characteristics of healthcare, such as the lack of a direct command line, the fact that decision making is carried out by stakeholders with different interests, the difficult in standardizing products and process and the absence of a charge to the customer for the process as a whole.

According to Heyer (2004), Soft OR predominantly employs qualitative, rational, interpretive and structured techniques to deal, define and explore various perspectives of problems in detail. In a different way, Hard OR is characterized by the use of strict mathematical, quantitative and optimization techniques applied to a reduced scope a priori.

As OR aims to solve real and everyday organizational problems, one must consider human behavior with its impacts on the problem, since OR mathematical and technical

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optimization models alone do not take into account critical perspectives and missing qualitative factors, when solving the problem. In this sense, the Soft OR complements Hard OR (Reisman and Oral 2005; Kotiadis and Mingers 2006). And this complement occurs in multiple ways according to the problem posed, giving rise to a multimethodological view of OR.

The combination of Soft OR and Hard OR will be used through the multimethodology named Complex Holographic Assessment of Paradoxical Problems (CHAP^2), which, according to Lins (2018), consists of a systemic methodology to structure and facilitate the integration between qualitative and quantitative aspects of complex social problems. This methodology is based on metacognitive maps to assist in the resolution of poorly structured and overly complex problems, which involve interactions between human, technological, organizational and environmental components.

This research had formerly the original objective of finding a case study to which a preselected stochastic methodology could be applied. However, as we became aware later, the health sector problem in hands showed important non-stochastic events, which would make the initial approach unsuitable. It was necessary to carry out a comprehensive analysis of the various aspects related to the problem at hand in advance to understand the problem in its entirety and only then identify one or more methods that could contribute to the systematic treatment and the proposition of solutions.

This approach was then applied through the use of a multi methodology that performs a qualitative analysis to contextualize the entire process of patients in the queues, and through the understanding that some variables were neither independent nor stochastic, but deterministic. Therefore, it was decided to use Simulation to seek the most appropriate solution to the problem.

2 The Hospital

The hospital under study is large, works only with elective surgeries and stands out as a center of excellence in the treatment of orthopedic diseases and trauma, of medium and high complexity. It serves exclusively patients from the Unified Health System (UHS), which is one of the largest public health systems in the world.

High demands for surgery have incurred in a long waiting list, comprising 14 specialties that correspond to the following Specialized Care Centers (SCCs): Spine, Knee, Hip, Shoulder, Hand, Foot, Infant, Skull, Maxillofacial, Microsurgery, Tumor, Adult Trauma Center, Elderly Trauma Center, External Fixative, Sports Trauma.

2.1 Flow and Process

At the time of confirmation of surgery, indicated by the hospital's orthopedist, the patient is placed on the waiting list of one of the SCC, in a specific sub-queue. The orthopedist fills in the form "Surgical Planning" with the patient's data and the proposed procedure, detailing the sub-line in which he will be inserted. If the patient has two pathologies in different areas of the body, he needs to be inserted in two different sub-lines, in different centers and with different positions in the lists. This results in different waiting times as well.

Thus, after the patient is placed on the waiting list, the patient goes through several stages until he is operated on. In this study, such stages are called patient status. According to official hospital documents, there are nine status.

The map in Fig. 1 follows the methodology known as concept maps, where different kinds of relations between concepts are allowed and represented by arrows, using the CmapTools software, version 6.01, free license. It is based on patient status, as depicted and the arrows connect them to explanatory concepts. It is important to highlight that Inactive Status can occur at four different stages of the process, which follow different paths, so they were characterized by Inactive1, Inactive 2, Inactive 3, and Inactive 4 by facilitators and decision makers.

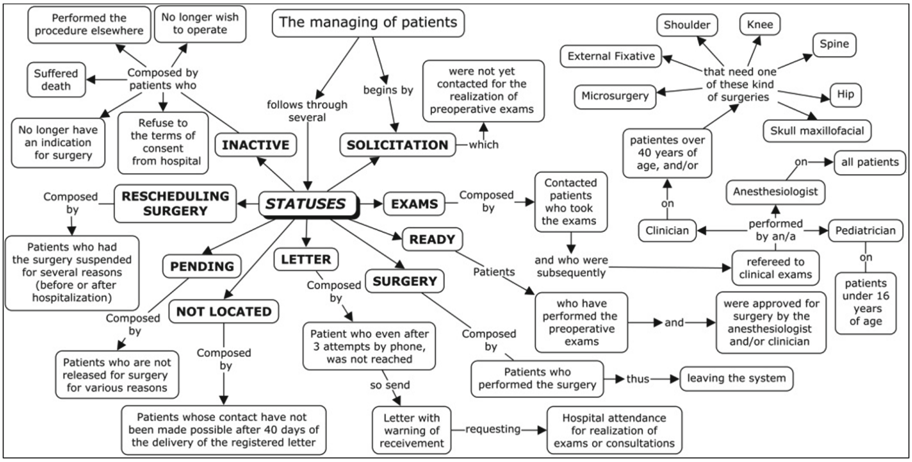

Fig. 1. Status description map

When there is no problem in the process, the patient follows the **ideal flow** through the several statuses, in the following order: **Solicitation, Exams, Ready, Surgery**. However, failing of requirements imply in a **deviation** from the ideal flow and the patient goes through some other statuses, such as: **Letter, Not Located, Inactive 1, Pending, Inactive 2, Inactive 3, Rescheduling surgery, Inactive 4.** Such deviations cause delays and disturbances in the flow, because when leaving the ideal flow, the patient will go through an additional status and then return to the ideal flow in the position following the one he left earlier.

The call for exams is made according to a First In First Out (FIFO) criterion based on the date of entry in the patient list. The calculation of the number of patients to be called for exams is based on the expectation of performing the surgeries due to historical productivity of the Centers. It is increased by a spare percentage on account of cancelled or delayed surgeries. The hospital currently applies a rule of thumb that specifies that the number of patients to be called for exams (Exam Call Rate – ECR) must be1.5 times the number of procedures performed.

2.2 Data

For data collection, 12071 medical records and 13054 reservation codes were analyzed, both referring to the period from 11/01/2016 to 11/01/2017. From these medical records, a spreadsheet was prepared with the following information: Reservation code, Number of the medical records, Date of arrival of patients, Age of the patient, Specialty, Date of change of status, Current status, Previous status, Motive for change of status and Date of surgery.

With the information in this spreadsheet it was extracted: the Matrix of transition probabilities of the states, the Times of each status, the percentage of patients who left the flow from the Inactive status 1,2, 3,4 and Not Located, the Rate of arrival of patients/day and the Rate of surgery/day.

Also, when considering only the patients who completed the complete flow (Solicitation until surgery), it is observed that they represent 64% of all cases, while the other 36% go through deviations.

After identifying the Times of each status, the Rates of patient arrival/day and the Rate of surgery/day, the distribution for such variables was adjusted using Stat Fit.

3 Methodology

Soft Operations Research methodology was proposed to help structuring issues, problems and situations before solving them properly. According to Rosenhead and Mingers (2001) there are many methods that help groups make progress with their problems, and some of them use formal models to deal with problematic situations. Amongst these, they present Soft Systems Methodology – SSM (Checkland 1972), Strategic Options Development and Analysis – SODA (Eden 1998), Strategic Choice (Friend and Hickling 2005) as well as Drama Theory (Bryant 1997), Robustness Analysis (Rosenhead and Mingers 2001) and Viable Systems Model (Beer 1981). These and many other methodologies present contrasting and converging characteristics regarding products, processes and complexity (Rosenhead and Mingers 2001).

The most widely used method for structuring problems is the SSM, developed by Peter Checkland (Checkland 1972, 1981; Checkland and Poulter 1994; Checkland and Scholes 1999). In short, the SSM is a general method for system redesign. Participants build ideal-type conceptual models (CMs), one for each relevant world view. They compare them with perceptions of the existing system in order to generate debate about what changes are culturally feasible and systemically desirable. SODA method was developed by Eden (1998), as a general problem identification method that uses cognitive mapping as a modelling device for eliciting and recording individuals' views of a problem situation. The merged individual cognitive maps (or a joint map developed within a workshop session) provide the framework for group discussions, and a facilitator guides participants towards commitment to a portfolio of actions. The SCA method was developed by Friend and Hickling (2005) and is an interactive planning approach centered on managing uncertainty in strategic situations through a process of communication and collaboration between people with different backgrounds and skills. SCA is carried out to support a group of decision-makers in through four modes: shaping, designing, comparing and choosing. Lins (2018) explains that, unlike the hard OR that starts modeling problems by exploring databases with different mathematical models, soft OR starts in a step backwards when characterizing the concrete problem to be studied. That's because the qualitative representation of the context allows to structure the problems, and only then to identify the necessary data and to adopt an integrated set of methodologies (multimethodologies) in order to support the decision in structured problems.

The methodology proposed here in, named Complex Holographic Assessment of Paradoxical Problems (CHAP^2) (Lins 2018) presents some striking differences in relation to the previous ones, mainly in terms of its cognitive foundations, which make explicit some aspects hitherto implicit. Firstly, it is characterized as a multimethodology, since it provides a mapping interface between Soft and Hard approaches, that accounts for both present and missing issues. This greatly enhances the metacognitive function of concept maps, and is supported by recent developments in the integration between individual and social groups concerning theory of mind (Malle and Hodges 2005), metacognition, organizational paradoxes and dialogical self (Hermans and Dimaggio 2004; Lins 2018). Both Habermas' emancipatory freedom (Midgley 2000) and cultural change as an invisible product (Rosenhead and Mingers 2001) require an improved understanding and awareness towards mental operations research, i.e. the applied management of our own minds. Another remarkable property of the proposed methodology is the emphasis on a double approach: one search for a consensus or accommodation of proposals and the other recognizes the need to preserve divergent and still irreconcilable aspects. These two approaches were called respectively conceptual and paradoxical models.

CHAP^2 comprises six phases, which are, in synthesis:

I. Facilitators prepare knowledge maps assumed as characterization of the real system, based on literature research and/or interviews with privileged specialists/generalists. An expanded group of agents is identified.
II. Training/guidance of agents is carried out through seminars to present the CHAP^2 methodology, evaluations and dynamics with techniques that facilitate the development of metacognition.
III. Characterization of agents' perspectives towards problematic situations are made through interviews, their transcription and representation in concept maps, where possible conflicting perspectives are preserved and even emphasized, under a metacognitive cultural setting.
IV. Workshop for discussing the thematic maps are organized, resulting in the conceptual (explaining convergences) and paradoxical (explaining divergences) models that represent the organizational context and priority problems.
V. Development of quantitative models and indicators to support decision making in the selected problems.
VI. Implementation of viable actions. Monitoring.

Therefore, the modeling of the problem was performed through the multimethodology CHAP^2, which comprises both qualitative (phases I to IV) and quantitative (phase V) approaches, with an explicit interface between them. We describe these phases as they are applied in this work. Notice that the application steps correspond to the phases of the methodology, as explained in Fig. 3.

Phase I - In this phase, we selected hospital's board of directors, as the privileged agent to start the problem identification. Meetings were held where they reported that the maximum period of validity of the exams is 6 months and that many of the patients, after undergoing the exams, are not submitted to surgery within their validity, causing the repetition of preoperative exams.

Afterwards, we organized information, raising the available documents concerning the queue, the history and the norms, and initiated the identification of the agents to be interviewed, who would be capable of contributing to the understanding and mapping of the flow and the process.

The selected interviewees were the ones in charge of:

a) Informatics to provide the indicative data of a previous context;
b) The Sector that manages the queue and deals directly with the flow of patients;
c) Diverse activities in the process (doctors, nurses, biochemists, etc.).

With the discussions and information from the meeting, the expert created a map that expresses his general view about the "real" problem, that is, a metacognitive map, since it represents the expert's perceptions about the problem situation.

Phase II - The available documents were analyzed to outline a draft for the flow of the process. Then, a previous contact with the interviewees was made to schedule the respective interviews. In this contact there was a brief explanation as to: the Method used, the Problem Situation, the Initial Flow of the process and the Metacognitive Map of the "real" problem. The latter two were subsequently made available to agents. In addition, we requested the information technology sector to provide the necessary data for the study. Thus, training, interaction, contribution of agents and their perspectives on the system, the problem and the process/flow were sought.

Phase III - The data made available by information technology were processed, interviews were conducted with the sector that manages the queues and agents in charge of each part of the process.

We asked the agents to elaborate on the assessment of the hospital, the understanding and contextualization of the process and to contribute to the modeling of flow based on the initial draft. They then acknowledged the inaccuracy of the ECR that causes several problems, including the increase in the cost of the surgical procedure and the social cost, and disruption to the flow of the hospital.

Thus, in this phase, the flow of the process previously built was discussed, changed and validated by the agents of the focus. In this way, after the first three phases, the problem situation was deeply explored, and it was possible to better understand the characteristics of the Hospital, map its process and consolidate the flow of patients according to the need of the model.

Phase IV - This phase is intended to provide a qualitative dialogue and integrate agents' perspectives, regarding the broader social context, the relevant process factors and the simulation modeling purposes, marked by the respective following 3 stages, described in chronological order of completion:

a) The first stage comprised the identification of issues that should be considered to perform desirable changes. Further interviews were carried out with the agents, aiming at making explicit cultural and behavioral factors that can contribute or hinder initiatives for improvement. In the latter case it is worth noticing that several barriers, disclosed in synthetic metacognitive map in Fig. 2, result from conflicts between cultural values or worldviews that cannot be resolved, but only managed, therefore composing a paradoxical model.

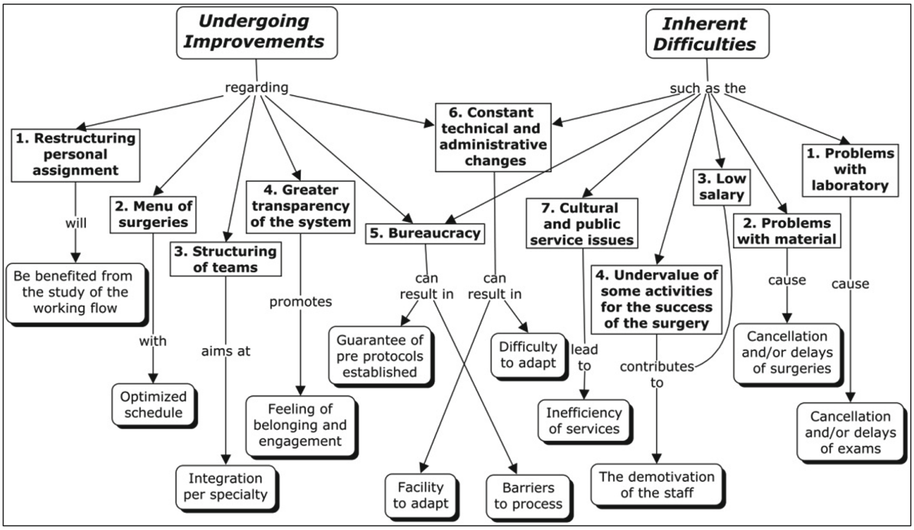

Fig. 2. Synthetic metacognitive map of the hospital

The synthetic metacognitive map in Fig. 2 represents some concepts related to improvements and difficulties in managing changes in the hospital. One can observe, for example, the importance of granting greater transparency to the system, thus promoting the feeling of integration between agents and groups. This proposition faces some difficulties, shown in this map, such as cultural and personal barriers. Among them, the undervalue some activities in the success of the surgery. The CHAP[2] method, due to its systemic nature, facilitates the emergence of attitudes favorable to integration between the parties, with the mutual perception of the agents' points of view and the relationships between their activities.

b) In the second stage a workshop was held, in which the data processing was presented and validated by the agents. This workshop presented and discussed:

– A General Spreadsheet of the data requested from information technology
– A matrix of states transition probabilities regarding the status of patients
– The Patient Arrival Rate, Examination Call Rate and Surgery Call Rate

– Average times of each status covered by the patients
– Percentage of patients leaving/returning to the flow

After presenting each item, the agents contrasted the collected data with the observed organizational knowledge. Afterwards, outliers and data were discussed and identified in order to obtain a sample as representative of the "real" observed system.

c) A third stage also consisted of a workshop, where we simulated the model and presented its results, which were discussed and validated by the agents. Faced with the simulated model, the agents highlighted the wealth of details of the flow and recommended that more information could be extracted, proposing to study the system from the perspectives of both reducing the number of Expired Exams and increasing the number of surgeries. Thus, we composed scenarios that could also account for uncertainties regarding both increase and decrease in the Capacity of Surgery, the first due to plans for expanding the hospital, the second due to the occurrence of problems that reduce the Capacity of Surgery, such as lack of surgical materials.

Phase V - Articulates with the quantitative method, which in this study is Discrete Events Simulation and will be presented in detail in Sect. 4.

Phase VI - Understanding and approval by the board of directors and technical personnel to enforce the recommendations obtained from this research.

In a general way, the application of the 6 phases of CHAP^2, as reported above, are presented in Fig. 3 below.

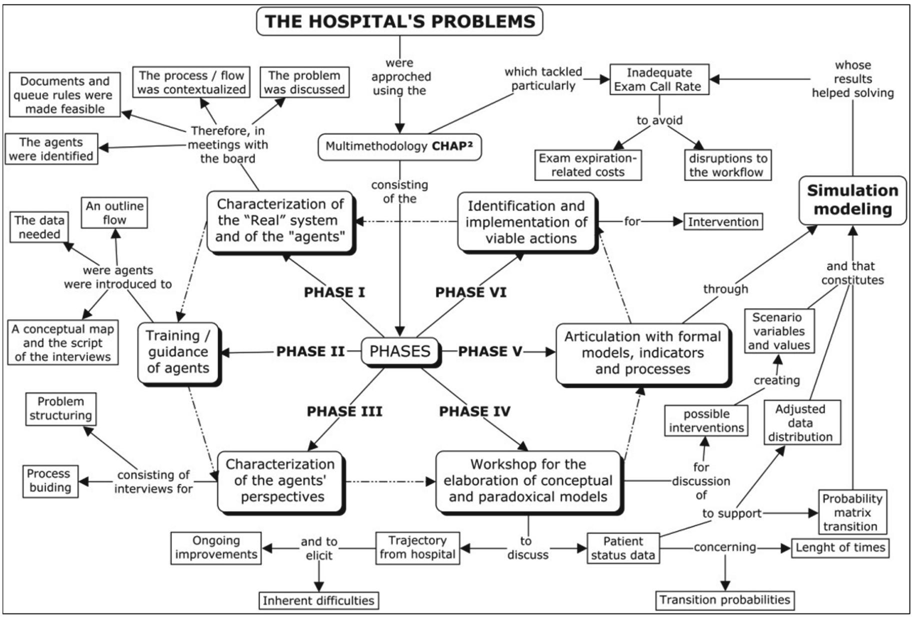

Fig. 3. Phases of CHAP^2

4 Simulation

"Simulation is the imitation of the operation of a real-world process or system over time. It involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented" (Banks et al. 2000).

Simulation is a powerful tool of traditional OR and has been successfully employed in several areas, mainly in the health sector, applied by Milne and Whitty (1995), Harper and Shahani (2002), Rhodes et al. (2012), Zhu et al. (2012), among others. Simulation has also been used in conjunction with soft OR. Kotiadis et al. (2014) describe the participation and integration of stakeholders during the structuring of conceptual modeling for a study of simulation of discrete events, which was tested in a real case related to obesity care. Pessôa et al. (2015) used Simulation together with concept maps to propose alternatives to increase the number of surgeries performed in a university hospital in Rio de Janeiro.

This study will also combine qualitative and quantitative methods, namely the Discrete Event Simulation as a phase in a multimethodological approach named CHAP^2.

4.1 The Simulation Model

We aim at simulating the status of the surgical hospital system based on estimative or assumed distributions for the patients' solicitation and the provision of resources for exams and surgery. These are characterized as the service rate, the status average times and the percentage of patients leaving/returning to the flow, as presented in Table 1. The Transition Probability Matrix that feeds the model with the probabilities of going from one status to another is shown in Table 2. The simulation model was built in the Simul8 software according to the flow in Fig. 4.

The relevant characteristics in the flow model in Fig. 4 are the large queue of 11000 patients at the beginning of the flow and the limiting validity of the exams, which is 180 days. Thus, in the model it was defined that from the exam status, the maximum period of time until performing the surgery will be 180 days, if this time expired, the patient would be directed to Expired Exams (EE) and then forwarded to Exams again. Thus, the number of patients with Expired Exams becomes an important measure to be controlled in the model is and the controlling variable is the Rate for Exams Calling (REC).

4.2 Model Settings

Warm-Up

To calculate the warm-up length, a model variable was selected, which in this case was the Solicitation queue time, successive simulations were performed with relatively short duration times compared to the original time. In each simulation, the times in the Solicitation queue were noted and, through a graph, it was possible to identify from which day, approximately, the rates showed stability.

Table 1. Service rate, average times, percentage patients leaving/returning to the flow

Service rate			**Status average times**			**Percentage of patients leaving/ returning to the flow**		
STATUS	AVERAGE patients/ day	DISTRIBUTION	STATUS	AVERAGE TIME IN STAGES (Days)	DISTRIBUTION	STATUS	LEAVE THE FLOW	RETURN TO FLOW
Solicitation	28	Pearson 6 (8.36, 1.59, 0.0025)	Exams	49	Pearson 5 (3.45, 159)	Not Located	43%	57%
Exams	40	Beta (1.59, 101, 0.0159, 0.667)	Inactive	51	Weibull (0.612, 36.5)	Inactive 1	32%	68%
Surgery	27	Beta (1.61, 101, 0.0238, 1)	Letter	34	Lognormal (28.8/21.7)	Inactive 2	99,9%	0,1%
			Not Located	30	Lognormal (37.3, 125)	Inactive 3	97%	3%
			Pending	66	Pearson 6 (1.65/4.12/129)	Inactive 4	100%	0%
			Rescheduling Surgery	26	Pearson 5 (1.11, 13.7)			

Table 2. Transition probability matrix

	Solicitation	Letter	Not Located	Inactive 1	Exams	Pending	Inactive 2	Ready	Inactive 3	Resch. surgery	Inactive 4	Surgery
Solicitation		14%		3%	83%							
Letter	8%		39%	5%	48%							
Not Located	21%			27%	52%							
Inactive 1					100%							
Exams		5%				5%	5%	85%				
Pending		18%			44%		29%	7%		1%		1%
Inactive 2						100%						
Ready		1%				5%			5%	12%		77%
Inactive 3										100%		
Resch. surgery					3%	8%					12%	77%
Inactive 4												
Surgery												

Thus, through the graph in Fig. 5, it is observed that around 350 days, Solicitation queue time started to stabilize, so the warm-up chosen for the simulations was 350 days.

Replications

Asimulated sample with 20 replications of the total number of expired exams resulted in a standard deviation (s) of 664. The minimum number of replications needed (n^*) can be estimated using the following formula $n^* = (\frac{zs}{h^*})^2$, where z is the level of significance corresponding to the desired confidence interval and h^* represents the desired accuracy. We assumed a confidence interval of 95%, corresponding to $z = 2.09$, a desired accuracy (h^*) of 200 and $s = 664$, which resulted in $n^* = 48{,}15$. Thus, the minimum number of replications adopted as a sample size was 49.

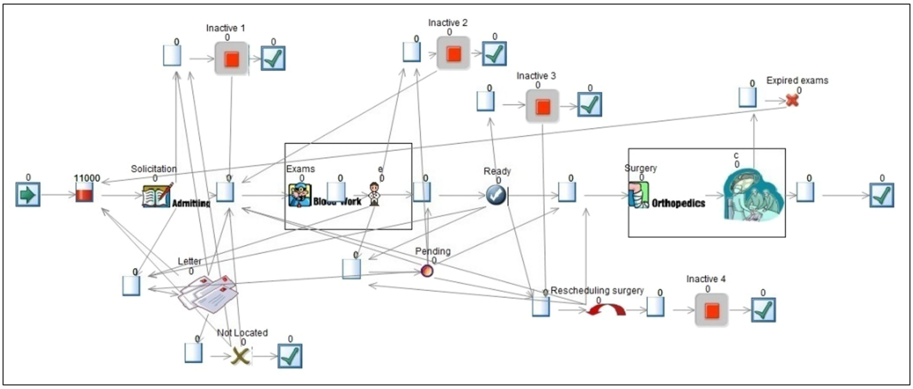

Fig. 4. Flow model

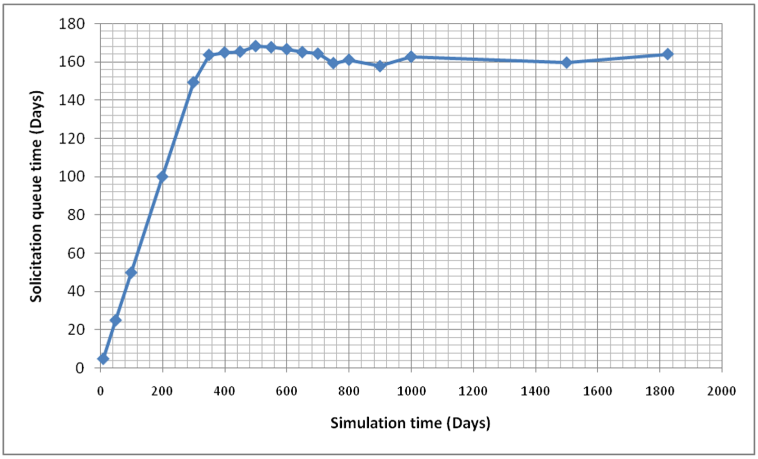

Fig. 5. Warm-up calculation

5 Resulting Simulated Scenarios

We used data from the period November 2016 to November 2017 to simulate a base current scenario and adopted the two varying scenario variables: the Exam Call Rate (ECR) and Surgery Capacity (SC), as recommended in the phase IV workshops of CHAP[2]. We created several scenarios and assumed that the Total Number of Arrival of Patients(AP) is constant in all of them.

5.1 Sensitivity of Performance to Variation in Exams Call Rate

The first proposed scenario variable in the workshop was the Exams Call Rate. ECR is the rate of patients called to exams as a percentage of the number of patients called for surgery. That is, currently the number of patients called for exams is 150% that of the available vacancies for surgery. We explored the feasible range using eight simulated scenarios together with the current, shown in Table 3.

Table 3. Sensitivity to alteration of exam call rate

	Rate	Total number	Average time of patients	Number of patients who left in					Average number of patients	Utilization rate	Total number		Ratio	
Scenarios	Exam call (ECR)	Arrival of patients (AP)	Solicitation queue (TSQ)	Not found	Inative 1	Inative 2	Inative 3	Inative 4	Surgery queue (NSQ)	Surgery (SUR)	Expired exams (EE)	Surgeries performed (SP)	Expired exams/ Performed exams (Ee/Pe)	Expired Exams simulated/ current (EEs/EEc)
1	1,00	31737	506	1031	494	2207	1197	379	1	78	875	21401	3,9%	-91%
2	1,20	31737	342	1211	570	2689	1422	442	6	93	1045	25599	3,9%	-90%
3	1,30	31737	268	1300	631	2936	1552	479	136	100	1213	27502	4,2%	-88%
4	1,35	31737	236	1354	640	3045	1597	496	650	100	1691	27543	5,8%	-83%
5	1,40	31737	203	1410	660	3146	1654	505	1315	100	2801	27539	9,2%	-72%
6	1,45	31737	177	1462	684	3268	1731	516	1997	100	5226	27536	16,0%	-48%
Current	1,50	31737	158	1527	709	3388	1805	531	2764	100	10138	27536	26,9%	0%
7	1,60	31737	142	1624	759	3608	1918	560	4114	100	15909	27537	36,6%	57%
8	2,00	31737	50	2033	929	4605	2368	688	10216	100	23891	27548	46,4%	136%

The results for the simulated and current scenarios shows that Expired Exams presents high sensitivity to the Exam Call Rate. That is, if the ECR, which is currently 1.50, is reduced to 1.00, the number of Expired Exams (EE) varies from 10138 to 875, equivalent to an approximate 91% reduction. It is also observed that its reduction is more expressive for the ECR from 1.50 to 1.30, from this point on, the reduction in the number of EE is less impactful.

However, another considerable and extremely important resulting variable is the Surgery Utilization Rate. Since all apparatus involved in the surgery must be optimized and not left idle, a high SUR ensures that when the apparatus is available, a patient is ready for surgery.

Considering the impact of ECR in both EE and SUR, we observe that, if the current Exam Call Rate is reduced from 1.50 to 1.30, the Surgery Utilization Rate is not impacted, as it remains at 100%. However, a reduction below 1.30 has a significant impact on the SUR, which is not desirable.

Regarding the Expired Simulated/Current Exams ratio, it is also possible to observe this expressive impact up to 1.30. For example, we observe if we reduce the Current ECR from 1.50 to 1.30, there is a 88% reduction in Expired Exams, in relation to the current value, but if it further reduces to 1.00 the additional impact on EE is much smaller, of 3%, with a total of 91%.

Therefore, the ideal operation point for the ECR is 1.30, since the Surgery Utilization Rate remains at 100%, the Expired Exams/Performed Exams Ratio goes from 26.9% to 4.2%, the Total Number of Expired Exams goes from 10138 to 1213.

Other performance results are:

- Average time of patients in the Solicitation queue (TSQ) - Increases as ECR decreases, that is, the fewer patients are called for exams, the longer the average time in the Solicitation queue, since this last status is anterior to the call for exams.
- Number of patients left in Not Located, Inactive 1, Inactive 2, Inactive 3 and Inactive 4 - increases as ECR increases, that is, if more patients enter, consequently more patients will leave, even though these exits are in the middle of the process.

– Average number of patients in the surgery queue (NSQ) - Increases as ECR increases, that is, if more patients enter, consequently there will be more patients for surgery queue.
– Total number of surgeries performed (SP) - When ECR goes from 1,00 to 1,30%, the total number of surgeries performed has a more significant increase, but after 1,30% the SP is practically constant. When SUR reaches the maximum limit of 100%, the number of surgeries performed tends to become almost constant.
– Ratio of Expired Exams/Performed Exams (Ee/Pe) - This ratio refers to the percentage of expired exams over those performed. It increases as the ECR increases and vice versa.

5.2 Sensitivity of Performance to Variation in Surgery Capacity

The second scenario variable proposed by the agents in the workshop was the Surgery Capacity. Thus, after definition the new Exam Call Rate to 1.30%, scenarios that alter the capacity of the surgery were simulated, exploring the range of possibilities, both for increasing and reducing the surgical capacity. And so, the results of the model were observed, especially the behavior of the Solicitation queue, which is of great concern to the hospital. These scenarios are shown in Table 4 below.

Table 4. Results of alteration of surgery capacity

	Alteration	Total number	Number of patients	Average number of patients	Average time of patients	Number of patients who left in					Average number of patients	Utilization rate	Total number		Ratio
Scenarios	Surgery capacity (SC)	Arrival of patients (AP)	Solicitation queue (after 3 years)	Solicitation queue (ASQ)	Solicitation queue (TSQ)	Not found	Inative 1	Inative 2	Inative 3	Inative 4	Surgery queue (NSQ)	Surgery (SUR)	Expired exams (EE)	Surgeries performed (SP)	Expired exams/ Performed exams (Ee/Pe)
1	-50%	31737	30589	21924	734	674	321	1429	758	275	74	100%	620	13859	4,3%
2	-20%	31737	16914	13542	458	1066	503	2294	1233	385	98	100%	967	22069	4,2%
3	-10%	31737	12278	10683	361	1185	556	2627	1395	431	136	100%	1110	24823	4,3%
4	-5%	31737	10118	9331	314	1243	598	2780	1468	457	142	100%	1162	26144	4,3%
5	Current	31737	7828	7581	268	1300	631	2936	1552	479	136	100%	1213	27502	4,2%
6	5%	31737	5601	6620	222	1366	644	3074	1611	496	107	100%	1254	28887	4,2%
7	10%	31737	3130	5111	171	1442	681	3226	1712	512	147	100%	1337	30296	4,2%
8	20%	31737	2	2716	97	1564	722	3487	1857	545	136	99%	1432	31834	4,3%
9	50%	31737	1	1479	57	1462	688	3390	1777	525	12	74%	1348	29835	4,3%

From Table 4, the following results were highlighted:

– When simulating the current model for a period of 3 years, a total of 7828 patients are observed in the Solicitation Queue, but if the SC is increased by 20% this queue practically disappears.
– The average number of patients in the Solicitation Queue (ASQ) decreases as the SC increases and vice versa. A small variation in the capacity of the surgery has a great impact on the average number of patients in the Solicitation queue, for example, the 20% increase in SC reduces the ASQ from 7581 to 2716 (reduction of approximately 64%).
– Like the ASQ, the average time of patients in the Solicitation queue (TSQ) increases as the capacity of the surgery increases. A small variation in the SC also has a great impact on the TSQ.

- As expected, the Ratio of Expired Exams/Performed Exams, hardly changed. This is due to the fact that the same RCT = 1.30% is used for all scenarios.
- When comparing the increase in SC from 20% to 50%, it is observed that, differently from what was expected, the number of surgeries performed decreased. This is because when calling more patients, bottlenecks are formed in stages prior to surgery, that is, some patients are stuck in previous stages and take longer to arrive at surgery. Consequently, the Surgery Utilization Rate reduces, considering that it went from 99% to 74%.

Thus, from the analysis of the Alteration of the Surgery Capacity together with the other performance measures, it is observed that a 20% increase in the SC is an optimal solution to the problems of the Solicitation queue, since after a period of 3 years the existing queue will practically disappear, the average number of patients in the Solicitation queue reduces approximately 64%, the Surgery Utilization Rate remains above 99% and the average number of people in the Solicitation queue reduces 64%.

It was also possible to analyze that any reduction in the Surgery Capacity has a negative impact on the Solicitation queue, since the reduction in SC reflects significantly in the increase in the number of patients and in their queue time.

6 Conclusion

The present study proposes the use of a multimethodology to improve the performance of a hospital that performs surgeries for orthopedic diseases and trauma. This approach provided a qualitative context for the problem and supported the identification of the quantitative model and its role to decision aiding. It also mediates the choosing of decision variables, their analysis of sensitivity validation of results from simulation.

The two decision variables: rate of calling to exams and hospital capacity, led to final recommendations that allowed a remarkable reduction of the mismatch between the call for exams and the call for surgery, with a corresponding decrease in expired exams. Changing the current exam call rate (RCT) to 1.30, the percentage of expired exams is reduced from 36,8% to 4,4%. Notice that its useless to further reducing RCT, since, even when RCT = 1.00, that is, Call Rate for Exams = Call Rate for Surgery, the percentage of expired exams is still 4.2%, due to time spent in previous status such as: Pending, Inactive, Rescheduling of Surgery, etc.

The results of the models that alter the Surgery Capacity were also useful for the Hospital, since there are plans to increase the Capacity of Surgery and with the changes in scenarios, it was possible to visualize its impact on various performance measures, especially in the Solicitation queue, which is considered a serious problem at the Hospital. In addition, this change in SC also made it possible to visualize the impact of a fact that occurred in the hospital. This fact refers to a significant increase in the Solicitation queue, which occurred after a period of shortage of some surgical materials and consequently a reduction in the Capacity of Surgery.

Moreover, it is emphasized that the results of this study allow us to go beyond the objective recommendations, as it has been shown to be an inclusive modeling process providing a wealth of information capable of supporting improvements in hospital management.

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