A Simulation Based Model for Planning Operating Theater Activity in Complex Hospitals: Case Study in Orthopedics

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Abstract— **Operating theaters (OT) in hospitals represent some of the highest sources of economic expenditures since their high complexity in terms of technology equipment (integration of different complex devices and specific technical requirements), organization (multi-personnel area with complex patients flow) and usage (optimum planning between regular activity and emergency management). For the above reasons, it is essential to understand and plan the whole surgical path (patient and personnel) by avoiding foreseeable inefficiencies, delays and risks.**

Hence, the aim of this study is fully modeling a generic orthopedics OT in order to support hospital decision makers in OT design and activity planning for both regular and emergency scenarios.

In order to do that and due to the complexity of the OT system, a simulation approach is fundamental for properly understanding the whole process and for clearly controlling and analyzing all the factors involved (surgical durations, types, working times and rooms availability, etc..). Discrete event models have been found reliable and accurate to simulate complex health systems (e.g. emergency management, beds management, logistic and assets estimation, etc.).

Finally, after selecting the most appropriate type of model, and using past surgical data and experts' opinions from the hospital for its development and implementation, a more precise and reliable clinical validation of the model is currently in progress, by concluding a data verification that needs a period of on-site data collection.

Keywords— **Process simulation, Operating Theater Management, Surgical Activity Planning, Decision Support System.**

I. Introduction

Operating theaters (OT) in hospitals represent some of the highest sources of economic expenditures since their high complexity in terms of technology equipment (integration of different complex devices and specific technical requirements), organization (multi-personnel area with complex patients flow) and effective usage (optimum planning between regular activity and emergency management). An optimized OT usage, aiming to maximize the number of surgical interventions, would allow improving both the quality and economic sustainability of health services provided to the patients [1]. For this reason, it should be important to take immediately into consideration the surgical demand to be satisfied in terms of workload and type of interventions already at the OT designing phase in order to define the proper number of operating rooms, technology equipment, technical requirements and/or special structural constraints (size, location within the building, etc.).

Although a responsible use of OTs means an equilibrium amongst number of surgical rooms, available resources and local demand of surgical interventions, usually, due to the complexity of the system, it is not possible to predict the evolution of the whole process and, the use of models based on a simulation approach become necessary. For this kind of application, the discrete event systems have provided numerous examples of models capable of simulating complex systems, such as the healthcare processes, by showing high reliability and accuracy [2]. Mainly dealing with bottlenecks identification within the process, these models estimate specific key performance indicators according to the specific application (e.g. "waiting time to surgery", "maximum number of surgical treatments", "surgery duration"). The main advantage of such simulation models is the ability to compare different scenarios, quickly and reliable without interfering with the regular activity, simply by varying specific parameters. It's also important to model the specific system (OT activity) within a larger system (e.g. Hospital system) and simulate its behavior on the variation of other systems' parameters such as the availability of hospital beds. As reported in literature, the availability of beds is a critical factor since it impacts on staff, OT activity planning and performance of the emergency room [3]. The simulation thus plays a major role in complex systems management by providing realistic and reliable information on the future behavior of the system in specific scenarios, early at the design phase. This allows decision makers to correctly and economic sustainably plan the system before its final realization [4].

The aim of this study is, therefore, to provide a validated model capable of analyzing the general surgical pro-

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cesses and providing useful information for the management (design and monitoring) of an orthopedics surgery service for both regular and emergency scenario.

II. Methods

A. Key Performance Indicators

Discrete event models are able to reliably simulate processes, even complex, pending that the factors governing the process (defined as elements or entities) are mutually interdependent each other and achieve the common goal. Then, the simulation and characterization of the process allows carrying out a detailed analysis of the system performance, especially concerning efficacy and capability [5].

For the healthcare sector, the use of simulation models hospital processes allowed a more productive use of available resources and a reduction of waiting times to medical treatments (e.g. surgical intervention, medical check or diagnostic test), by reducing as far as possible, the length of queues. The main key performance indicators used for analyzing those processes include “waiting time to the medical treatment”, “number of patients treated within an acceptable waiting period” and “effective time of treatment (including all necessary side tests).” The main goal is to identify bottlenecks within the process and properly allocate resources in order to improve the whole process' standards[6].

Especially for OT activity, a further element affecting the reduction of the waiting time to the treatment is the prompt availability of free beds in the hospital wards [7]. Hence, the patient admission capacity often limited to the shortage of free hospital beds. For this reason is essential to correctly level the number of free hospital beds with the patients’ admittance and discharge ratios. Further complications are given by the availability of free intensive care units when necessary. All the above variables make it mandatory the adoption of specific models and tools for supporting decision makers on detailed analysis on specific patient flows and clearing all those hidden relations among more constraining factors [8].

B. Patients’ flow analysis

The final development of a reliable simulation model needs a correct identification of the main phases of the clinical process involving the patient, see figure 1. Then, through a specific process analysis is feasible to represent the organization/framework of a generic orthopedics department by defining the main functional flows constituting the surgical path.

Depending on the type of patient, the specific disease, illness severity and ward of belonging (emergency or regular), it is possible to establish a specific path characterizing the object "patient" within the model. The main difficulties in building such a model are given by the fact that it requires accurate values for both the precise steps within the hospital process (e.g. ward, intensive care, operating room, etc.) and the specific durations associated to them.

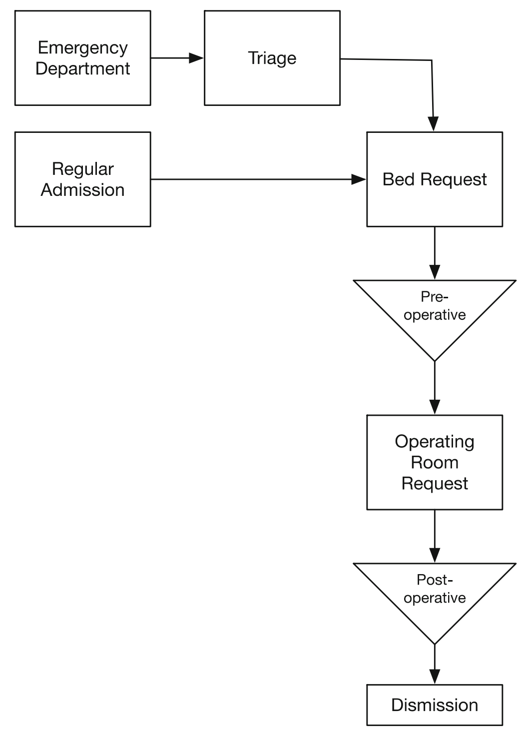

Figure 1. Patients’ flow analysis simulating the OT activity.

As reported in figure 1, each block represents a specific phase of the process and can be associated with an own processing time and a functional position within the whole process queue (i.e. entity number). Those data can be estimated by taking into account the available past data, and moreover to create a set of weights contextualizing the specific process or surgical discipline. Hence, the modeling of a complex department that performs both regular and emergency surgical interventions shall include two main inputs, one for regular admissions and the other for emergency ones.

III. RESULTS

A discrete event based model was developed in order to simulate OT activity in Orthopedics. The model inputs are the patients' admissions from both emergency department and hospital wards. Besides that, it needs further data regarding OT interventions (duration and type) to properly simulate the flow pattern of the patients, including estimations on queuing times to surgery, bed availability, expected occupancy ratio and average lengths of post-surgery hospital staying.

In the specific case study within the orthopedics emergency department, a total workload of 37.274 admissions/year has been considered, where in 2.755 cases subsequent hospitalization was necessary. Of these hospitalizations, unplanned surgical treatment was carried out in 2.210 events while the planned ones where 5.444. The resulting total workload for OT activity has been estimated in 7.654 surgeries/year.

The OT is composed by 9 operating rooms, where 3 rooms are mainly dedicated to urgency/emergency and 6 to regular/planned activity. The room distribution of past surgeries is shown in Figure 2.

Although rooms 6 and 7 have the highest number of emergencies, the other rooms have some cases as well with the only exception of room 9 that does not present any unplanned surgical treatment.

As one of the aims of the study is to evaluate specific organizational strategies that would allow improving OT activity performance, it should be able to estimate specific indicators such as the reduction of the "expected time to surgery," see figure 3. The simulation reported was obtained by taking as inputs the population shown in figure 2 and using as "surgery duration" values a Gamma distribution with the Alpha and Beta parameters calculated from the mean and variance of the above cited population.

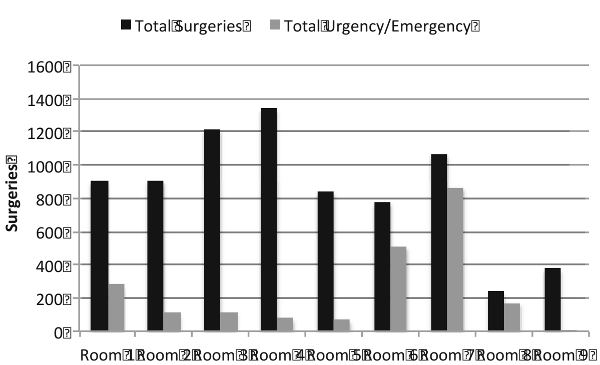

Figure 2. Number of annual surgeries per room at the Orthopedics OT.

The surgical rooms mainly characterized for planned activity (rooms 1-5) have an average waiting time to surgery of about 1 day, while the ones treating more emergency cases (rooms 6-7) show a waiting time of about 3/4 days. Those longer waiting times could depend on the fact that, comparing to planned surgeries, emergency cases often need extra exams or pre-surgery treatment that could delay the surgery itself. Room 8 has the lowest waiting time since it is reserved for life support activity while room 9 is not fully operational yet.

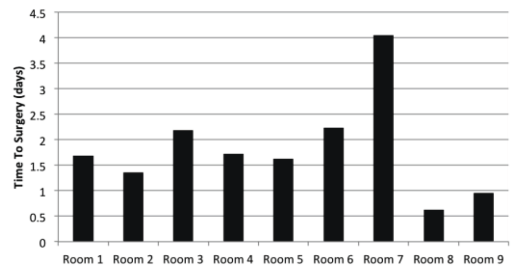

Figure 3. Simulation results: mean time to surgery per surgery room.

Unplanned events crashing on regular flow of OT activities are responsible for delays and inefficiencies [9,10] as shown by those operating rooms sharing both planned and emergency cases.

By the use of the model was possible to simulate a new organizational scenario where planned surgeries are carried out in different rooms than emergency ones. In the specific case, the operating rooms 6-8 where exclusively reserved to the emergency activity only. The planned surgeries were equally re-distributed to the other operating rooms.

The model showed how the new scenario is able to reduce the "time to surgery" for emergency treatments, but on the other hand, slightly increase the "time to surgery for regular interventions," see figure 4. This is mainly due to the increase of the number of surgical operations to be performed within the same number of operating rooms (1-5).

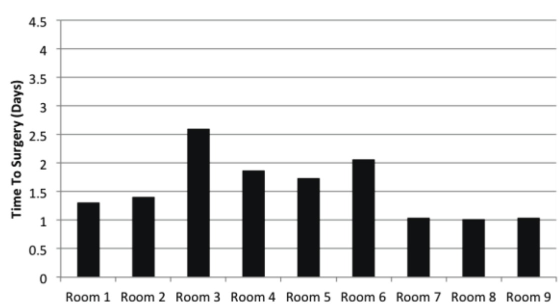

Figure 4. Simualtion results on new scenario: separation of planned and emergency paths.

In detail, the waiting time for unplanned treatments passes from 3.89 to 1.38 days and means 1 day less of mean post-surgery hospital staying (from 10 to 9 days). No changes were identified for the "OT occupancy ratio" (stable at 83%).

IV. CONCLUSIONS

The modeling approach supports decision makers in better evaluating, with more information and awareness, any possible changes on hospital systems, by estimating the most optimized solution and avoiding the waste of resources [11]. Among complex systems, efficiency of OT activity has been always a key goal for healthcare stakeholders since it would avoid unnecessary waste of resources, increase productivity, and reduce queuing times to surgery [12].

The developed model has shown its supportive role to hospital decision makers for proper organizational planning of orthopaedic OT by providing reliable and accurate results consistent with the real ones.

It was possible to simulate the whole surgical path of patients, from hospital admission to final discharge including the different queuing times, duration of each phases, OT occupancy ratio and post-operative length of staying. Two different organizational scenarios were simulated by the model, that identified the scenario resulting the most efficient and economically more sustainable.

A clinical validation of the model is currently in progress in order to verify the available past data (through on-site data collection) and better calibrate the model outputs to reality.

Finally, future developments regard the possibility to combine the use of OT monitoring dashboards to simulation models. Hence, although simulation models have the capacity to identify early design errors, it would be useful to monitor expected performance in order to keep the requested quality level or to evaluate needs of further organizational changes.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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