# Patient flow simulation as a tool for estimating policy impact

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## Summary

**Patient safety in operative and postoperative structures is closely linked to adequate resource allocation and patient flow organisation. New policies concerning working hours or resource allocation are designed to improve patient safety. However, it is necessary to measure their impact before taking action. In this paper we describe a simulation tool which makes it possible to measure the impact of various organisational policies in a hospital operating theatre and postoperative structures. We illustrate its use by an example assessing the impact of a new training policy for operating room personnel upon recovery room utilisation and the attendant staffing requirements at the Geneva University Hospitals.**

## Introduction

The set of hospital operative and postoperative structures (hereafter denoted OPS) constitutes a complex system. Unorganised patient flows through these structures are a potential cause of inappropriate bed utilisation or room overcrowding and thus, occasionally, of adverse events. Patient mismanagement may be due to improper resource allocation or communication failures [1]. Improving the organisation of the OPS, the most costly hospital structure [2], can be achieved, for example, by better management of its resources [3]. Nevertheless, when considering OPS resource reallocation it is necessary to evaluate the impact of a policy of this kind beforehand. As on-field trials can rarely be carried out, computer simulation plays a key role in illustrating and quantifying these effects. OPS performance depends heavily on the list of patients and their scheduling [4]. Designing an efficient organisational structure constitutes a complex task due to the large number of individuals (e.g. patients, surgeons, anaesthetists, nurses), their often contradictory objectives, and clinical, technical and time constraints [5]. Additionally, many unpredictable events arise. They fall into two main categories: resource unavailability (e.g. unannounced staff absence), and variation of event duration (e.g. an intervention lasts longer than expected). Due to the already complex constraints imposed on weekly OPS organization, these unpredictable events are rarely taken into account. When considering a new policy it is nevertheless important to acknowledge their existence and evaluate their impact upon the OPS's overall performance. In this paper we describe a simulation tool which has been designed and developed by the Hôpitaux Universitaires de Genève (HUG; Geneva University Hospitals) and the Ecole Polytechnique Fédérale de Lausanne (EPFL) [6–8]. The overall design of the simulator is first of all presented, followed by an example illustrating the impact of a new training policy for operating room personnel on the utilisation of the recovery room and the attendant staffing requirements.

## Simulator design

Although the design is fairly general, the simulator has been tailored to the specific case of the HUG. The main OPS are shown in figure 1.
A set of events takes place in each of these structures, such as room/patient preparation, anaesthesia induction, patient emergence, admission, discharge and room closing. These events determine the functioning of the OPS. Each of these events involves a set of actors constituting the resources required for the event to take place, e.g. rooms, beds, surgeons, nurses, anaesthetists, patients.

The simulation of the OPS was initially designed using preexisting generic simulation software, which unfortunately did not allow integration of key OPS working rules. We decided to develop a new simulator which would fully acknowledge the complexity of the OPS system and adapt to the specific needs of the HUG. The simulator was developed in Java. It takes as input an XML file containing a set of actors (e.g. elective patients, surgeons, rooms, beds), the events they are involved in, and their working constraints (e.g. room opening hours, personnel availability). The simulator then reproduces a typical week including the occurrence of unexpected events such as surgical delay or actor/room unavailability. The output consists of a sample of how the set of patients have interacted with the available resources, e.g. which interventions

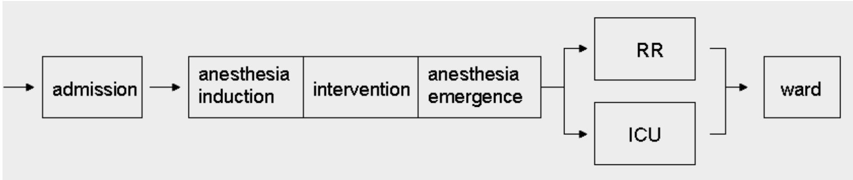


**Figure 1.** *Main operating and postoperative patient flows.*
*Upon admission to an operating theatre patients proceeed to an operating room where anesthesia induction, intervention and anesthesia emergence take place. They then proceed to their corresponding postoperative structure.*
*At the HUG there are two operating theaters. One is for elective cases, the other for emergency patients. There are two postoperative structures: the recovery room (RR) and the intensive care unit (ICU), these are shared by elective and emergency patients.*

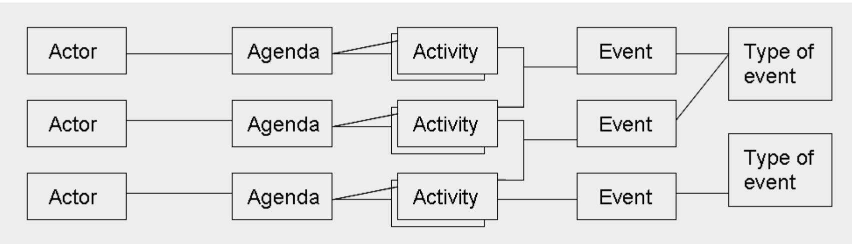


**Figure 2.** *Interaction between the main "objects".*

lasted longer than expected and thus delayed/cancelled other interventions. The information concerning changes in interventions is tabulated for further analysis. To make the interface more user-friendly a graphic output highlighting the unexpected events can also be obtained. By running numerous simulations with the same set of patients and resource constraints it is possible to estimate OPS performance, e.g. the average number of cancelled/delayed interventions, average resource utilisation/idle time. The simulator can thus be used to evaluate the impact of long term policy changes such as personnel and medical equipment allocation (e.g. working/opening hours) or new surgical policies (e.g. scheduling criteria). Its output can also be used to measure quantitatively the impact of uncertainty upon the current patient and resource configuration.

The simulator is based on an object-oriented design composed of the following "objects". The *events* describe the dynamic aspect of the OPS. Each event can be classified into a category denoted as *type of event*, e.g. closing a room, transferring a patient, surgical intervention. An event is fully determined by its type and expected starting time, while other details such as expected duration can also be set. Each event involves a set of physical resources denoted as *actors*. Only scarce or constrained resources that have an impact on the dynamic behaviour of the system are considered (e.g. patient, personnel, equipment). Certain events need to be carried out in a given order (e.g. patient is transferred to OPS *then* prepared for intervention). Such a set of events is denoted as an *activity.* Each actor has its own agenda, which consists of a set of activities. The interactions between the different objects are illustrated in figure 2. The events are organised in a priority queue andthe simulator processes them iteratively.

Each type of event is associated with a set of rules; each rule consists of a set of conditions and actions. As an example of the event type "surgical operation" (or intervention) a set of conditions could be: "if an actor is late" and "if the intervention can no longer be delayed", the corresponding action could be "cancel the intervention". The advantages of defining the logic of the simulator by subdividing the rules into conditions and actions allows incremental coding (rules are added progressively) and the combination of a large number of conditions and actions, thus rendering the creation of rules flexible. The *conditions* include the following: are all preceding events completed? Can the event be delayed? Can the event be cancelled? Is an actor available for the proposed time slot? Does the event interfere with a higher priority event? The actions include the following: start an event, defer an event. The rules are combined into a decision tree and tested accordingly.

To estimate the parameters of the simulator, a statistical analysis of HUG data was carried out. The dataset consisted of 40 weeks of OPS interventions. For each intervention we know the medical speciality, the type of anaesthesia required, the date, time and duration, and the waiting time, time of arrival and length of stay in RR/ICU. Distributions characterising both elective and emergency patient flows were fitted and appropriate statistical tests carried out to evaluate the convenience of this fitting. Empirical distributions were used for the parameters whose fitting was not satisfactory.

## Specific rules

### Presence of an actor

An event needs a pre-specified set of actors in order to take place. The presence of *all* actors may not be mandatory, e.g. the event "patient emergence" starts whether or not a bed is available in the RR, i.e. the patient may wake up while waiting in the operating room. To take this into account each actor contributes a certain amount to the achievement of a given event. An event can take place if the total contribution (the sum of contributions over all participating actors) exceeds a tolerance threshold. It is also possible to decide that an event requires only a partial contribution from an actor, thus allowing the actor to work simultaneously on several events. This allows, for example, the same anaesthetist to work on simultaneous interventions.

### Time constraints

A delicate and complex issue in the simulator is the rescheduling of events so that all resource and actor constraints remain satisfied. Delaying or cancelling events brings additional constraints. Events which cannot be arbitrarily delayed are associated with a latest feasible time. To account for the relative importance of the different events, a priority is assigned to each one. When several events are candidates for a time slot, the event with higher priority prevails. This allows, for example, an operating room to close later if an intervention lasts longer than expected, but does not allow an intervention to start if it is expected to end after closing hours. These event priorities also allow us to differentiate between events that can be delayed and cancelled (e.g. an intervention), and those that can be delayed but not cancelled (e.g. closing a room).

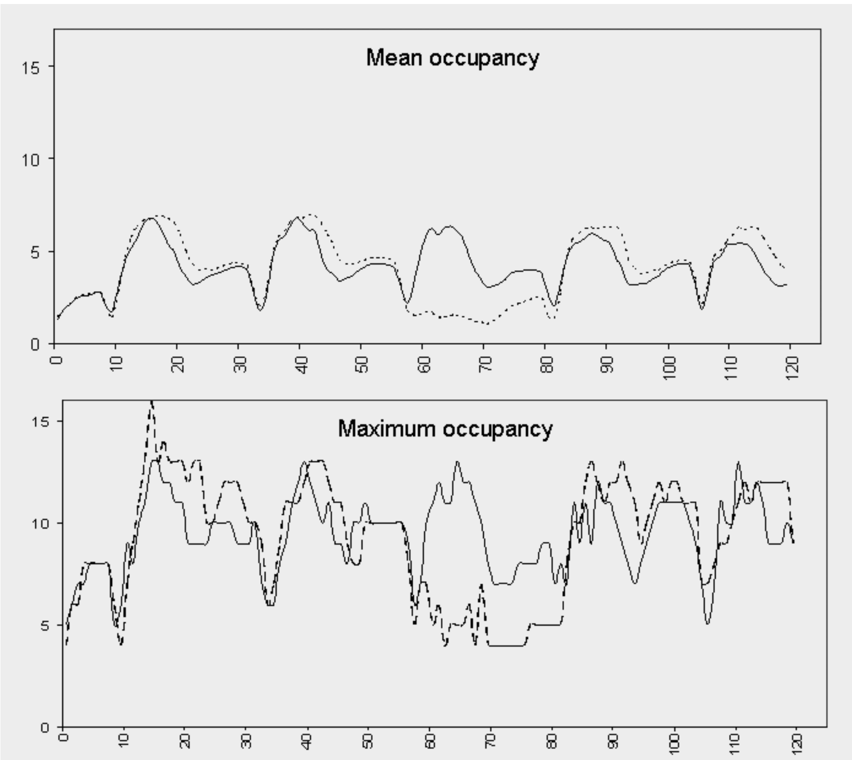


**Figure 3.** *Weekday recovery room occupancy.*
*The number of occupied beds is plotted versus the time in hours starting from Monday at midnight until Friday 11pm. The top figure displays the mean occupancy, the bottom shows the maximum occupancy. The solid line corresponds to the simulated occupancy given the current policy and the dashed line in the simulated occupancy under the new "Wednesdays off" policy.*

## Example

Keeping personnel training and qualifications uptodate plays a key role in patient safety. Courses are often scheduled according to personnel position (e.g. one course is scheduled for all anaesthetists), leading to events that cannot take place due to the absence of some actors: the surgeon cannot work without the collaboration of an anaesthetist or vice versa. It is therefore necessary to find a way to simultaneously schedule courses across all medical positions. An appealing idea is to completely suspend elective interventions once a week, thus allowing courses to be scheduled on the same day for all staff members.

We will now estimate the impact of suspending elective surgery on Wednesday and increasing surgery working time by 2 hours on the other weekdays.

In this simulation the structures of interest are the elective and emergency operating rooms, the RR and a virtual structure denoted as "other postoperative structure" representing both the ICU and wards. Data consist of patients that visited any of these four structures during 2004, i.e. approximately 4450 elective and 3850 emergency interventions. Seven different events were specified: four types of intervention (defined on the basis of the sequence of rooms visited by the patients), two events for stay in the RR, and one denoting room closing. Each event was assigned a starting time and duration.

One hundred simulations were carried out for each scenario (Wednesdays off or not). Figure 3 yields the utilisation of the RR under the two simulated scenarios. It was verified that the simulated utilisation within current opening hours is consistent with the observed utilisation. The top plot of Figure 3 shows that if elective operations were to be suspended on Wednesdays the RR would have on average a higher occupancy after 4pm and until 8am the following day. The bottom plot illustrates that in order to satisfy 100% of the demand, three extra beds (including corresponding staff) would be required. Such a policy change therefore has a strong impact upon RR occupancy. Anticipating this impact would benefit patient safety.

## Discussion

This tool allows staff at HUG to obtain performance measures of the service level of their OPS. The common resources used for a variety of events justify an object-oriented analysis. The input and output interfaces are user-friendly, thus allowing hospital staff to interact with the tool. Calibration of the model was feasible thanks to the extensive and detailed data provided by the HUG. The tool was adapted to the hospitals' needs by implementing their specific rules. The use of the simulator was illustrated by estimating the impact of a new personnel course-scheduling policy upon RR utilsation and its staffing requirements.

Accurate estimation of policy changes is data-expensive. In the case of the HUG their up-to-date data retrieval system yields detailed and extensive information. Unfortunately this is not the case of most healthcare institutions, which limits the use of such tools in other facilities. On the other hand simulation makes it possible to identify the main deficits of existing data, thus pushing the main IT systems to evolve.

This tool considers patient-, surgeon- and room-specific information, thus mimicking the behavior of the OPS and grasping its complexity. The performance measures obtained are realistic and rich in detail. Nevertheless, studying separate modules does not allow system-wide interactions to be evaluated. This motivates the need for modelling at a less detailed and more aggregate level, which yields less detailed performance measures but acknowledges the interactions between the different hospital structures. This is the aim of the current HUG – EPFL collaboration.

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