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MODELLING AND SIMULATION OF AN OUTPATIENT SURGERY UNIT

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ABSTRACT

In this paper we propose a new approach to design and control an ambulatory surgery unit through formal modelling and discrete-event simulation. Taking into account the demand increase for ambulatory care in the hospital, we propose a comprehensive methodology to adjust the required resources (beds and stretchers) to optimize patient pathway through the ambulatory surgery unit. Several performance indicators are considered such as patient length of stay (late discharge evaluation) and patient waiting time to determine the optimal number of patients and types of surgeries to be performed each day. Resource sizing is also proposed to optimize patient rotation between the ambulatory unit and the operating theater. Along with quantitative results, a risk analysis is also proposed to help decision makers with the implementation of the new organization.

1 INTRODUCTION

The field of operational research applied to health care systems evolved a lot during the last decade. Modern health care systems can be viewed as a complex network of institutions, health care professionals (both clinical and administrative), information systems and materials such as equipment and medications. Interactions between such entities are required to provide better access, continuity and quality of care to patients, better working conditions for health care professionals, while compressing operating costs and investments in new technology and infrastructures. At the same time, the aging population benefits high quality of care and more and more pathologies can be cured (e.g. cataract surgery). In this context, new patient clinical pathways are created to face the growing demand for care; among those, ambulatory care becomes a standard for taking care of patients while compressing costs in the hospital.

Nowadays, a surgery can be performed in two different ways: (i) the patient is taken into care in a surgery unit and stays in the hospital ward during several days, or (ii) the patient comes to the hospital only the day of his/her surgery and can go home the same day. The latter is called ambulatory or outpatient surgery. New technics of anesthetic and surgery allow the patient to recover in a short time and are less invasive, allowing people having enough energy to be autonomous at home in the evening right after the surgery. Furthermore, ambulatory let the hospital save money as there are fewer beds and fewer nurses for the same number of patients. For all these reasons, the Saint-Etienne hospital (Centre Hospitalier Universitaire of Saint-Etienne, CHUSE) decided to develop its outpatients unit.

Discrete-Event Simulation (DES) has been widely used in the literature for modelling health-care systems for various purposes: performance evaluation, optimization, demand forecast… Several literature reviews (Jun et al. 1999; Fone et al. 2003; Günal and Pidd 2010) are strongly indicated to get a complete landscape of the scientific contributions using such method. Outpatient facilities and services are a subject of growing interest since hospital managers push for the increase of ambulatory surgery, which is cost effective. Outpatient clinics case studies are frequent (Wijewickrama and Takakuwa 2005; Takakuwa and Katagiri 2007), providing guidelines for patient flow management; ambulatory surgery is also a hot topic, where DES provides optimal sizing of ambulatory services connected to the operating theater (Ramis et al. 2001; Ferrin et al. 2004). Recent studies are related with orthopedic clinic performance evaluation (Baril et al. 2014) or appointment scheduling taking into account the operating theater plan (Saremi et al. 2013). Impact of the Post-Anesthesia Care Unit (PACU) on the patient care pathway has also been studied (White et al. 2003). To the best of our knowledge, no research has been conducted on the whole outpatient pathway through both the ambulatory service and the operating theater and the optimization and design of the ambulatory service.

In this paper, we propose a methodology to design and reengineer the ambulatory service of the CHUSE through a performance analysis using discrete-event simulation. The CHUSE plans to extend the ambulatory service to face the increasing demand, so we propose a design of experiment to calculate at the same time: (i) the optimal number of patient that can be taken into surgery in the service taking into account regular surgeries to be performed in the operating theater; (ii) the number of staffed beds (number of beds and associated human resources) required to optimize the patient flow. Finally, a risk analysis is also performed to detect sensitive steps in the new patient pathway after service extension.

The paper is organized as follows. System description, project objectives and methodology are presented in Section 2. Data collection and simulation inputs are summarized in Section 3. Simulation model and results are detailed in Section 4. A discussion of the study outcomes is given in Section 5. Finally, conclusions and perspectives are given in Section 6.

2 POSITION OF THE PROBLEM

2.1 System description

When a patient must be operated, he/she has first a consultation with a surgeon. If the surgery is necessary, it is planned according to the operating theater schedule. Another consultation with the anesthetist is also performed at least two days before the day of the surgery. We consider two types of surgery:

- Regular surgery: the patient arrives one day before the surgery and stays in the hospital several days after the end of the surgery for recovery and surveillance.
- Ambulatory surgery (or outpatient surgery): for light interventions, the patient arrives in the morning, is operated and leaves before evening the hospital. Such procedure requires rigorous organization to avoid delays for patient discharge and medical complications at home.

Figure 1 summarizes both pathways. Recent progress in surgery allow more and more patient to be operated and hospitalized in the same day. Such organization is also less costly and allows the hospital to keep beds for “heavy” patients. Both types of surgeries are performed in the same operating theater, requiring a rigorous scheduling of both types of patients. In this study, we focus on ambulatory patients and consider that the operating theater surgery schedule is fixed.

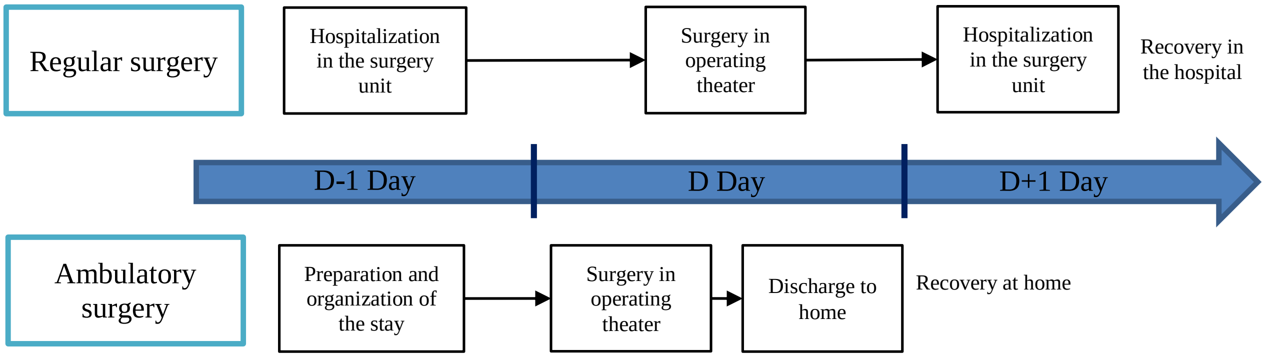

Figure 1: Regular surgery vs Ambulatory surgery patient pathway.

On the day of the surgery, the patient is taken into care by the ambulatory unit. Nurses prepare the patient for the surgery right after his/her arrival in the service. Then, a transport team brings the patient into the operating theater, where he/she waits for the release of the operating room and the operating team. The patient is taken into care by the operating team and the surgery is performed in an appropriate operating room. After that the patient is transferred into the Post-Anesthetic Care Unit (PACU) where he/she is monitored and under surveillance until end of recovery. Finally, the patient is brought again into the ambulatory unit where nurses keep a close watch on him. As soon as he/she is able to leave, the patient eats a snack and is allowed to go home if the surgeon already came to check his/her health. The whole patient pathway is summarized in Figure 2.

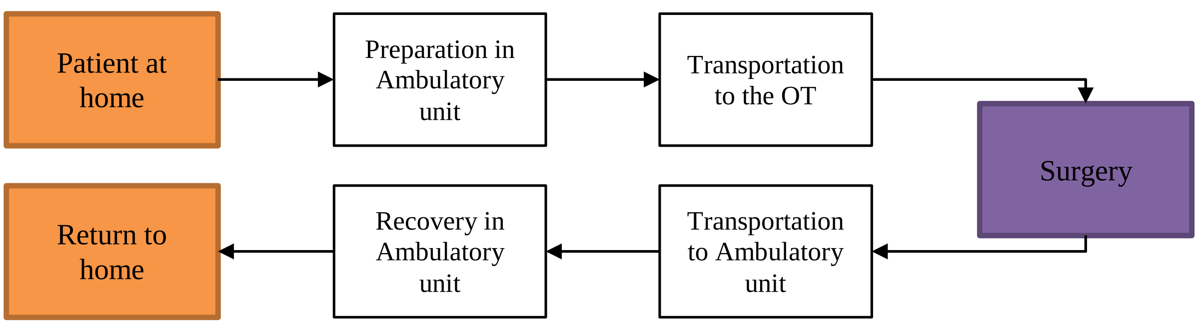

Figure 2: Ambulatory surgery patient pathway.

The ambulatory unit of the CHUSE is composed of two zones where patients may be installed in either beds or stretchers. Patients installed in beds must be transferred to stretchers before being transported to/from the operating theater, whereas patients installed in stretchers can be directly transported to/from the operating theater. Usually, beds are dedicated to patients having a heavier surgery and requiring a longer recovery.

Two types of ambulatory surgeries are considered: surgeries requiring local anesthesia and surgeries requiring global anesthesia. General anesthesia (GA) lengthen the stay of the patient in the operating theater and in the PACU compared to local anesthesia (LA). Thus we consider two types of patient flows related to the required anesthesia: short stay flows (local anesthesia, 2 to 3 hours total length of stay) and long stay flow (global anesthesia, 5 to 6 hours total length of stay). In the following, we note GA patient (resp. LA patient) a patient having a surgery requiring a global anesthesia (resp. local anesthesia).

2.2 Objectives

The CHUSE plans to extend the existing ambulatory unit in order to increase the amount of ambulatory surgeries to be performed in one day. To achieve that goal, three sub-objectives are formulated as follows:

1. **Determine the optimal number of ambulatory surgeries that can be performed using the current ambulatory unit.** In order to improve the efficiency of the operating theater, the hospital direction is willing to increase the total number of surgeries (regular and ambulatory) in the operating theater. Since the activity of the ambulatory unit is linked to the activity of the operating theater, an increasing number of patients must be planed each day whereas the capacity of the unit has not been increased yet. To remedy this problem, we propose a new organization for the ambulatory unit and we determine the optimal number of outpatients that can be operated in one day (maximum capacity of the unit), taking into account the type of anesthesia (GA patients vs LA patients).
2. **Design the new ambulatory unit.** The maximum number of staffed beds will be adjusted in the new ambulatory unit. However we need to define the optimal number of patients the ambulatory unit could take into care. A similar study is also conducted on the type of anesthesia for outpatients. We also propose an estimation of required number of staffed beds (beds and associated human resources required to support patient care in the unit).
3. **Propose a risk analysis of ambulatory patient pathway to prepare change management.** The last objective is related to the awareness of the different actors, particularly surgeons and anesthetists. We propose a risk analysis to understand and support the implementation of the project in reality, and to point out the sensitive steps of the methodology.

The following assumptions are fixed by hospital organization and cannot be change:

- A1. The opening range of the ambulatory unit is fixed (between 7 am and 7 pm only). However, overtime is allowed for nurses and caregivers for exceptional late discharge (at most 7:15 pm).
- A2. The schedule of the operating theater is fixed and cannot be changed depending on the ambulatory unit needs. Thus the activity of the ambulatory unit is strongly dependent of the activity of the operating theater.
- A3. The number of nurses and caregivers working in the ambulatory unit is fixed.

2.3 Methodology

The project has been led into five steps:

1. **Observations:** the operations of the ambulatory unit and of the operating theater have been observed during four weeks in order to understand the details of the patient pathway. Interviews with the human resources were also performed.
2. **Data collection and analysis:** data related to the ambulatory unit and the operating theater were collected and analyzed in order to perform a first diagnosis of the system organization. Some problems in the PACU were identified, therefore we analyzed the data to better understand the phenomenon and to point out the functioning problems.
3. **Modelling:** patient flows were modelled in order to implement the simulation model using flow charts. Such models were useful to support our recommendations during meetings with health-care professionals.
4. **Scenario simulation:** several design of experiment have been proposed and relevant performance indicators taking into consideration the study objectives were collected and discussed.
5. **Restitution:** organization of several meetings to present the results to the staff of the CHUSE.

3 DATA COLLECTION AND PROCESS MODELLING

Thanks to our observations, we were able to describe the process followed by the patient. We have detailed the time, the actors, the particularities and the explanations of each step. Then, these descriptions have been validated by the chief of each unit.

Data of the PACU were obtained using paper copybooks which are filled each time a new patient enter this room. Nurses stick the label of the patient, and inform the type of surgery, the unit of hospitalization, the hour of entrance and the hour of exit. Two periods were selected in order to extract relevant data (September 2014 and November 2014). For all patients having a surgery in these periods, information about the type of anesthesia were extracted from the information system of the operating theater.

Detailed yet simple patient pathway models in the outpatient unit and in the operating theater were also provided after system observations in order to support discussions with the hospital staff and implement the simulation model. Such models take into account medical aspects of the patient care and are presented in Appendices of this paper.

4 SIMULATION AND RESULTS

4.1 Model validation

Since the process description has been validated, we were able to implement the model. We used ROCKWELL Arena® 14.5 to implement the simulation model. To validate the model, real date were injected and simulation results were compared with the same data using the following performance indicators: patient total length of stay, duration of activities (time spent in the outpatient unit, surgery, recovery…), and ratio of surgery/anesthesia types. We adjusted the model in order to achieve the best reproduction of the reality as possible. Eventually, the difference was fewer than 10% with simulated activities durations longer than in reality. We decided that this model was admissible and we could use it to test our different scenarios since the hospital staff was interested in worst-case situations. That decision was taken in collaboration with the practitioners who considered the simulated results are realistic.

Simulation length is fixed to one day and does not require any warm-up period, since the system is reset each day. The number of replications has been adjusted depending of the type of analysis. 95% confidence intervals were considered in our results, so that the numerical values are always presented along with the half-width of that interval.

4.2 Current system analysis

The current system analysis consists in determining the optimal number of patients per day for the ambulatory unit and the optimal ratio of GA patients vs LA patients.

The first analysis we made on the current unit was the maximum number of patients the unit could take into care. The design of experiment consists in 6 scenarios having a different number of planned patients for the ambulatory unit. We increased this number of patients and we analyzed how many of them were able to go home before 7 pm, which is the closing hour of the unit. If too many patients cannot go home at the end of the day, the corresponding scenario should be rejected. The results are presented in Figure 3. According to the simulation results, the maximum number of patients admissible during one day is 29. (no late discharge over 50 replications). However, taking into account the flexibility of the nurses in the ambulatory unit (admissible overtime), the maximum number of patients proposed is 30 (latest discharge at 7:15pm). Such results were validated by the hospital staff.

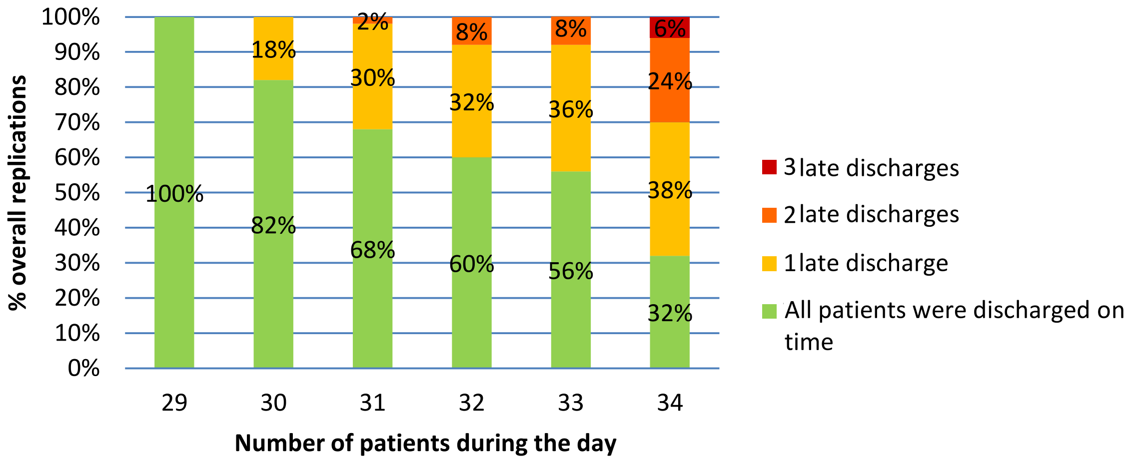

Figure 3: Maximum number of patients taken into care in the current ambulatory unit.

As said before, ambulatory surgery require either general anesthesia or local anesthesia. General anesthesia lengthen the stay of the patient in the operating theater and in the PACU compared to local anesthesia. In order to optimize the outpatient flow throughout the ambulatory unit and the operating theater, a mixed set of surgeries requiring both general and local anesthesia is proposed. To do so, we fix the total number of outpatients to be seen during the day and a design of experiment is built by varying the number of GA patients among all planned patients. Thus we can determine the maximum number of patients while maintaining a certain quality of service, i.e. ensuring the last patient is discharged before 7pm. The results are presented in Figure 4.

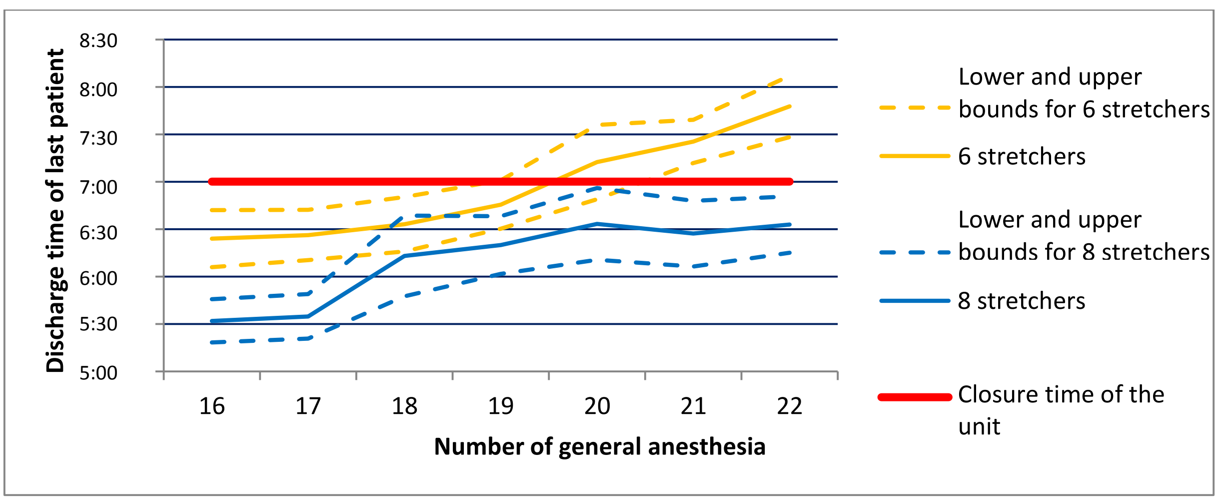

Figure 4: Maximum number of GA patients (total 30 patients).

According the results, the maximum number of GA patients is 19. However, if we take into account the number of porter teams, the results does not allow to conclude about the utility related to the increase of available beds. If the number of available space is higher, we may treat more patients and discharge them faster. However, the subsequent steps are saturated and the length of stay remains the same.

4.3 To-be system analysis

Similarly, we performed the same analysis for the to-be ambulatory unit. We extended the input data in order to have a surgery schedule realistic in terms of proportion of medical specialties. The to-be ambulatory unit will be characterized by an increase of the total number of available slots (from 14 to 23). However, the number of beds will be reduced (9 to 5) and the number of slots for stretchers will be increased (5 to 18). Thus the patient rotation will be higher since they will be directly installed in stretchers. We will consider in the following short stays and long stays, referring to stretchers patients and bed patients respectively.

Figure 5 presents the design of experiment performed to optimize the number of patients to be seen each day. With 40 patients and 2 short processes, too many patients are not discharged at closure time; however, all late patients went into a surgery requiring general anesthesia. Thus, with 40 patients and 4 short processes, all patients are discharged at 7pm. The increase in the number of short processes does not improve the performances of the system after a certain threshold, that is 41 patients and 5 short processes (taking into account the flexibility of human resources).

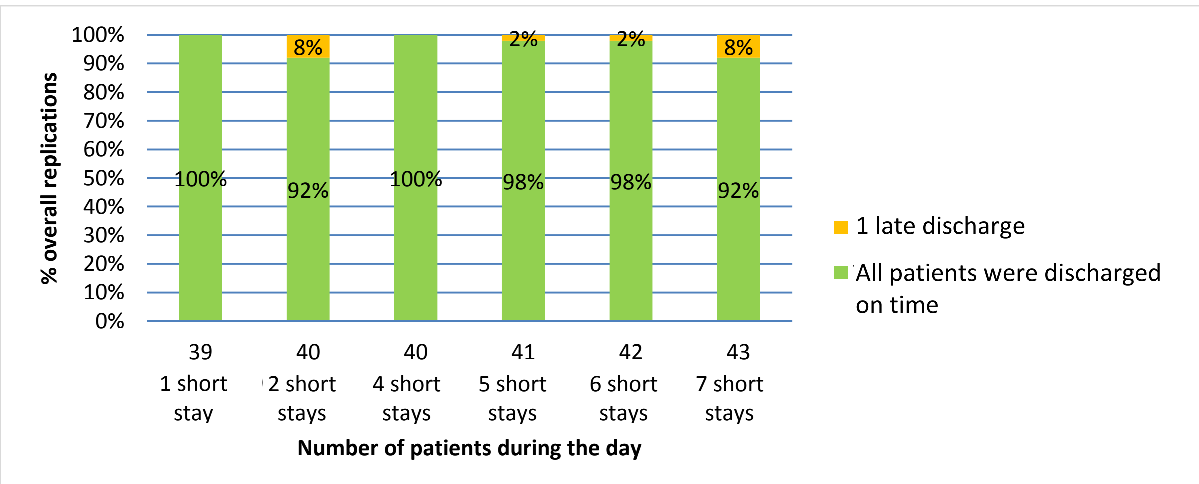

Figure 5: Max. number of patients and short processes taken into care in the current ambulatory unit.

The same approach was performed to calculate the maximum number of surgeries requiring general anesthesia to be performed in the to-be unit. Results are presented in Figure 6. For a fixed value of 41 patients per day, 30 general surgeries requiring general anesthesia may be performed. We consider that 31 and 32 GA patients is still possible to take into care with a high risk of late discharge since the upper bound of the error interval exceed 7pm.

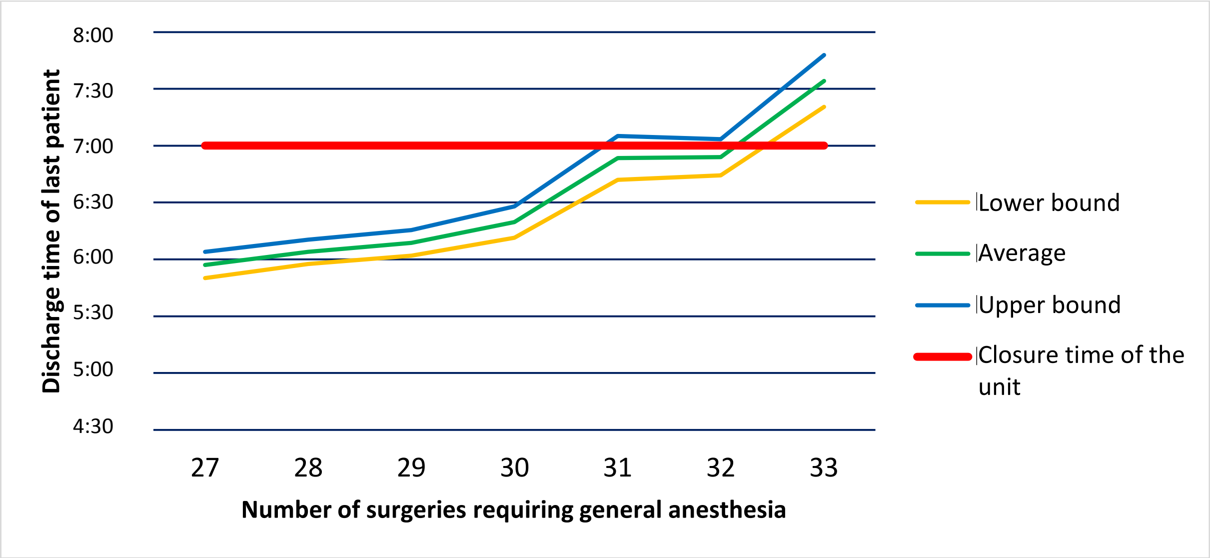

Figure 6: Maximum number of surgeries requiring general anesthesia (total 41 patients).

Finally, we propose a resource sizing analysis for stretchers: since the number of available slots for stretchers will be higher in the to-be organization, the ambulatory unit will need more stretchers to satisfy the demand and minimize waiting times. The number of available slots and the number of planned outpatients is fixed in order to model a busy day (41 patients and 31 surgeries requiring general anesthesia). We use the simulation model to determine the maximum number of transportation teams required in the worst case, as presented in Figure 7. The maximum number of busy stretchers is 29 in that scenario. Since the 29th stretchers is used in the middle of the day, we consider that an admissible threshold for the optimal number of stretchers to perform all transportations is 28.

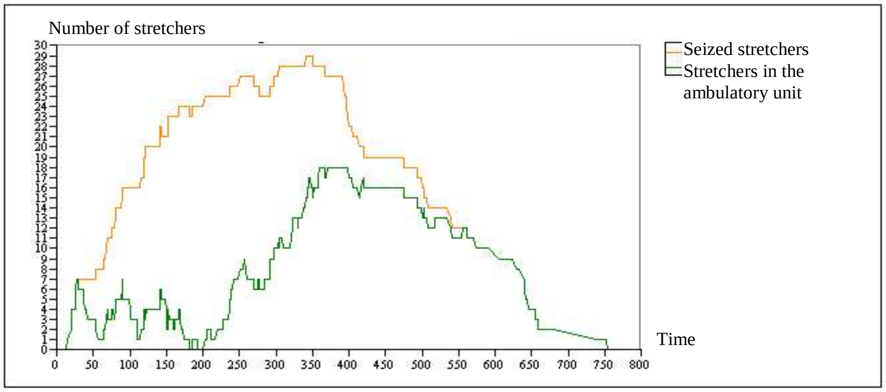

Figure 7: Stretchers utilization in a worst-case scenario.

5 DISCUSSION AND FEEDBACK FROM THE HOSPITAL STAFF

When the project with the CHUSE and its ambulatory unit started, the increasing of the unit size had already been decided. The interest of our study was to confirm that the evaluation done by the chiefs of the units was relevant and to support its implementation. Formal yet simple modelling using flow charts turned out to be a good method to reproduce reality and support discussion with the hospital staff. Indeed, we could test hypothesis without modifying the reality, and implement several scenarios using simulation without any impact on the real system. Cost-effective scenarios taking into account the selected performance indicators could be selected using such method.

We have tested a large diversity of cases, more than if we had to test them in reality. It was a good opportunity to reinvent the working habits of the hospital staff and to evaluate precisely what are the real needs. Usually, a deficit in human resources is pointed out in health-care organizations. Using our approach, it was possible to focus on material resource sizing (stretchers) and propose new solutions to the reevaluated demand taking into account a constant amount of human resources (assumption A3).

Eventually, once the modifications are implemented on the system, we have to measure the impact on the real unit. This phase is very important, allowing the detection of any subsequent problems and the adjustment of the performances of the system. It is also a powerful support for change management, allowing the durability of the proposed organizational reforms. A risk analysis was also provided in order to help hospital managers and head of units to be vigilant during the implementation of the new organizations. The risk analysis was built on the basis of the models proposed in Appendices. Table 1 summarized the proposed analysis.

Table 1: Risk analysis summary.

Step	**Vigilance points**	**Proposed actions**
All	Patient identity monitoring	Questioning the patient all along the pathway
Medical file preparation for the surgery	Incomplete files	- Implementation of electronic records - Staff training courses
Installation of the patient at the entrance of the operating theater	Patients arrive too early and have to wait, inducing a stress increase before the surgery	Change the state of mind of the health-care team to ease the patient (surgeons in particular)
Phone calls	Information transmitted by phone, inducing a risk of information loss	Unique and centralized information system implementing communication
Transfers, patient transportation	Medical record forgotten	Electronic records implementation

Concerning the feedback of the CHUSE, the chiefs of the units were satisfied of the proposed approach and results, allowing the establishment of relevant quantified results. We realized that medicine and informatics can work together with the same purpose. Thanks to the credibility of our results, our propositions have been implemented in the CHUSE. Future works include a rigorous change management with all classes of health-care professionals, in particular surgeons and anesthetists. Indeed, tough recommendations related to surgeons practice and recovery duration minimization could not be implemented yet.

6 CONCLUSIONS AND PERSPECTIVES

In this article, we propose a new methodology to: (i) evaluate the performances of the current ambulatory unit of the CHUSE by determining the optimal number of patients to be operated during a day and the optimal number of complex surgeries (i.e. requiring general anesthesia) to be treated during a day while minimizing the discharge time of the last patient; (ii) design the new ambulatory unit of the CHUSE, taking into account organizational constraints such as the number of available slots for beds and stretchers. We also propose a risk analysis to accompany the hospital staff during the reengineering of the unit. The methodology is novel because it includes in the same approach the design, performance evaluation, risk analysis and change management. Hence it is combining expertise from various areas such as industrial engineering, management sciences and operational research. Also the complete patient pathway is taken into account, from the admission in the hospital to the discharge. All proposed decisions for the design and control of the new ambulatory unit have been accepted and will be implemented on the short term. The proposed simulation model is flexible enough to be applied to any ambulatory unit and takes into account multiple special features such as: (i) type of process (long for heavy surgery, short for light surgery); (ii) type of anesthesia (global or local); (iii) mixed resources in the ambulatory unit (beds and mobile stretchers).

For future works, we plan to design a decision aid tool to better schedule patients taking into account the master schedule of the operating theater: currently, patient arrivals are dependent on the activity of surgeons without taking into account the organization of the ambulatory unit. Additional scenarios should also be tested to address the impact of organizational changes on human resources activities (nurses). The risk analysis should also be expanded. Finally, change management will be conducted to help practitioners to consider organization optimization and performance evaluation as a crucial part of their medical activities.

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A APPENDICE: PATIENT FLOW MODEL IN THE AMBULATORY UNIT

The medPRO modelling framework (Augusto and Xie 2014) has been used to model the patient flow in the ambulatory unit. Figure 8 describe the caption of the model: modified UML activity diagrams are used to model patient flows. Figure 9 presents the pre-surgery process in the ambulatory unit and Figure 10 presents the surgery process in the operating theater. Such process model are easy to understand and were used during meetings with the hospital staff to validate the patient pathway before implementation for the simulation. Moreover, comments have been added to explain in detail what is happening in each step, identify the waiting queues and information transmission. The model was used to build the risk analysis and support the change management presented in Section 5. For example, many phone calls are made after the surgery (Figure 10), inducing waiting queues for the patient. Due to space limitation, all models (pre-surgery process in the ambulatory unit, patient transportation, patient surgery and recovery in the operating theater, and post-surgery process in the ambulatory unit) are not presented in this paper. AU stands for Ambulatory Unit, OT for Operating Theater, OR for Operating Room, PACU for Post-Anesthesia Care Unit.

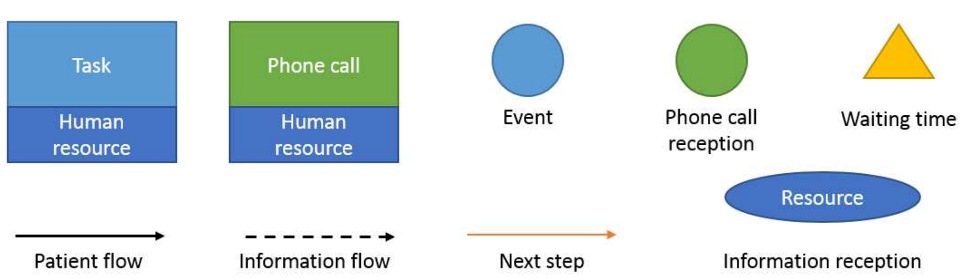

Figure 8: Model captions.

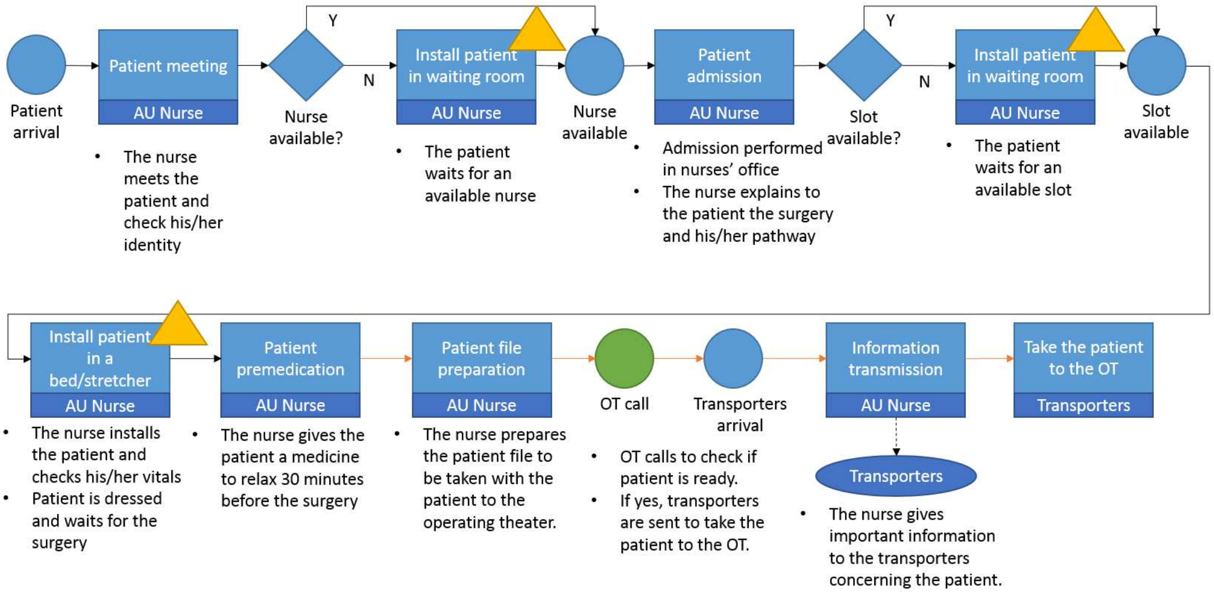

Figure 9: Pre-surgery process in the ambulatory unit.

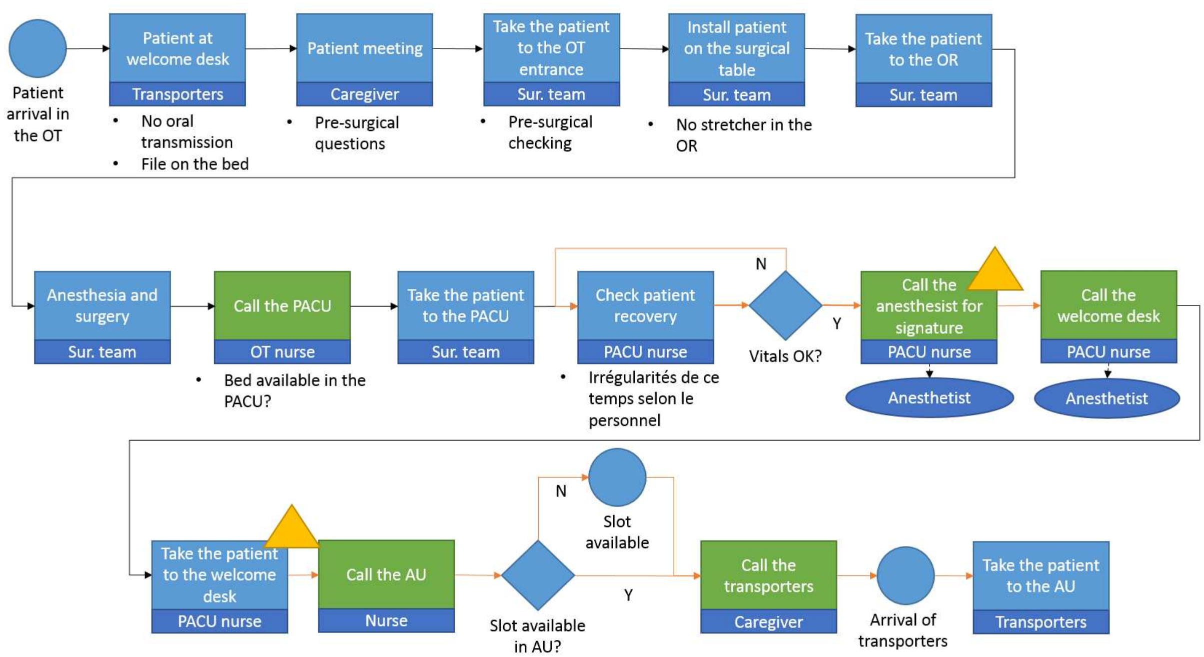

Figure 10: Surgery process in the operating theater.

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