LEAN MANAGEMENT PRACTICIES TO IMPROVE PERFORMANCES IN OPERATING ROOMS

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ABSTRACT
The proposed research work is meant to present a Surgical Department simulation model developed for a public healthcare facility in South Italy. Such work is grounded on a careful analysis of available data and of the entire surgical process whose components, activities and workflow have been mapped through specific charts. In the scope of the proposed research, after the simulation model has been developed and validated, specific analysis on actual and potential capacities have been carried out. In particular, the potential impact of Lean Management principles and methods are explored with a focus on the "Pull method". As a result the paper contribution is twofold: from one side it comes up with a tool devoted to streamline decision-making processes and from the other side it explores the possibility to apply Lean Management practices in domains that are different from Manufacturing. The main results show, indeed, that the pull method can bring substantial benefits in terms of patients waiting times reduction, increased productivity and better resources allocation.

Keywords: Modeling, Simulation, Healthcare Facilities, Lean Management, Pull method.

1. INTRODUCTION
The Lean approach featured by lower costs, higher quality and customer service is an interesting but challenging research area. To date, it has been mainly applied to manufacturing systems and therefore, within the scope of this research, a particular effort has been done to evaluate the potential applicability of lean practices to healthcare facility management processes. On the other hand, Modeling and Simulation has been used as investigation tool providing the playground for almost unbiased evaluations and analytical assessments before implementation in the real system. Particular attention has been paid to the “Pull method” application and related effects in Operating Rooms management. As Operating Rooms are among the most costly units within a hospital, increasing productivity while preserving cares quality is a top priority and the main rationale behind the research discussed herein. Productivity can be assessed in terms of cases average duration, idle times, surgeries scheduling and resources level of use without overlooking the role human factors such as motivation and teamwork (R. Marjamaa et al., 2008). In particular, when dealing with elective surgery departments, both internal and external indicators need to be considered. External indicators include waiting times and waiting lists length, which impact on the perceived quality, while internal performance indicators include “throughput” time (time from arrival to dismissal), bed occupancy rate, dismissal rate and resources utilization rate. Needless to say that these parameters cannot be evaluated under emergency conditions given the impossibility, in such a case, of any scheduling activity. For the purposes of the study presented in this research work, a large public hospital located in South Italy has been considered. Here the Elective Surgery Department includes eight operating rooms and the main research effort has been oriented toward the definition of a reference model for surgeries planning and

scheduling. To this end, the approach being adopted is in two levels. The former, is mainly concerned with upstream planning while the latter is centered on how to best organize those activities that usually take place during the preoperative period. At this level, the Pull method, from Lean Management theory, has been applied and as a result pull systems have been created whenever a patient is moved from one point of care to the next. Here, according to Lean Management Principles, potential obstacles and/or sources of delay have been detected and removed.

As mentioned above, the proposed approach has been tested and validated in a tailor-made simulation environment that, as shown in Longo et al (2014), provides the ideal framework to look into possible achievable benefits and improvements before implementation in the real system.

Thus, from a methodological point of view, this work gives further evidence that Lean management and discrete-event simulation (DES) can be jointly used for process improvement and service delivery enhancement as already highlighted by Robinson et al. (2012). Moreover, it is worth noticing that simulation approaches have been successfully applied to health care facilities To mention a few, relevant contributions on this matter can be found in Holm et al (2013), Weerawat et al. (2013) and Bruzzone et al. (2013). Nevertheless, Lean Management practices are mostly related to the manufacturing sector with very limited applicability to healthcare facilities management.

2. CONTEXT ANALYSIS

After an internal audit, the operating room department considered in this research work, has been required to improve its overall performances especially in terms of resources utilization. The scenario under investigation is really complicated due to the numerous restrictions and interdependencies with other hospital functions and departments. Considering that scheduling activities have a not negligible impact over the main performances indicators such as waiting time, staff utilization, overtime and affect the performances of interrelated departments such as surgical wards, finding out best practices for scheduling and activities planning can substantially contribute to achieve the intended outcomes. However, creating a schedule that states which patients have to undergo a surgery and at which moment in time is a rather cumbersome task.

In general, a Surgical department includes four planning levels: strategic planning, tactical planning, offline and online operational planning. At the strategic level, capacities sizing and allocation is dealt with whereas at the tactical level, slots of operating room time are assigned to medical specialties and the surgical staff is planned. At the offline operational level, elective patients are scheduled in advance, and the staff is assigned to specific operating rooms. Lastly, at the online operational planning level, day-to-day disturbances such as unexpected delays or emergency surgeries are dealt with (Van Houdenhoven et al., 2006). This research focuses on the offline operational planning that entails patients allocation and scheduling seeking to minimize waiting times and wastes. Indeed, besides the hospital management purpose of improving performances, other stakeholders perceive different problems in and around the operating room, for example:

- the operating room personnel faces high variability in actual surgery duration with variable daily workloads;
- Surgical wards deal with large fluctuations in patient flows, which lead to low average bed utilization and frequent overstaffing as well as understaffing;
- The operating room planners deal with unexpected daily changes due to not received or wrong lists of patients;
- Surgeries scheduling is often tightly constrained by limited availability of additional equipment, sterile surgical instrument sets and/or anesthetist physicians;

In addition, other issues have been directly detected during the context analysis. Many of them are related to unsuitable organizational methods affecting the planning phase. For

instance, among the observed practices, any surgical ward is used to send the list of patients for surgery only the day before the surgery is required creating organizational difficulties related to staff and materials allocation.
Hence, a poor planning leads to downtime of Operating Rooms and prevents surgery from being cost-effective. Patients entering the Operating Block at the wrong time can slow down the whole process just as patients who cannot leave immediately after surgery due to complications upon wakening. Furthermore, keeping in mind that often there are fixed overheads and personnel costs as well as expensive and sophisticated equipment, it follows that the early closing of one or more Operating Rooms or an Operating Block, is an unrecoverable loss. A classic example of waste is the sudden cancellation of surgeries due solely to organizational reasons. Moreover a poor coordination prevents patients' shifts from being speedy and effective and causes operating rooms to be used longer than necessary. As a consequence, aside from an optimal use of equipment, it is also crucial to encourage synergies among the staff.

2.1 Offline Operational planning

From a patient's perspective, the process starts when, based on medical examination, the patient is required to undergo a surgery. At this point in time, the patient gets in touch with a medical specialist that fills in an admission registration form where relevant information for planning are collected. Such information consists of treatment description, expected surgery, expected length of stay in the hospital, urgency and relevant data for preoperative preparation. This form is the processed at the central planning department and, as a consequence, the patient is added to the current waiting list for admission at the surgical ward. Surgery and admission planning depend on the expected length of stay as well as on the bed occupancy level. Figure 1 shows the scheduling process.

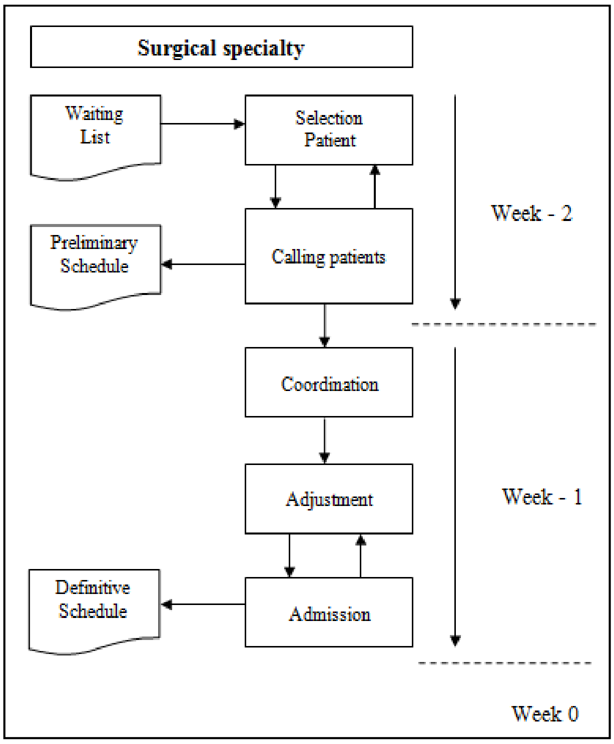


Fig.1: Flowchart process scheduling

- **Patients Selection**

Patients selection occurs two weeks ahead of the surgery week and is based on the information reported on the waiting list. This phase comes up with a preliminary operating room schedule where patients are randomly sequenced within a session. The planned duration is based on the information supplied by the surgeon.

- **Calling patients:**

After patients selection, planners inform the anesthesiology department since each patient requires a preoperative screening by the anesthesiologist before surgery. Screening are carried out in the week before the surgery is expected and if a patient is not fit for surgery, the surgery is cancelled and another patient from the waiting list is selected. Then the preliminary operating room schedule is updated accordingly.

- **Coordination:**

In the week before surgery is scheduled, the preliminary operating room schedule is sent to the operating room managers, the surgeons involved, the surgical wards and the radiology department to check and establish the right surgeries.

- **Adjustment:**

Communication with some actors may bring about the need to adjust the preliminary schedule, because of several reasons. Estimates of operation durations may be adjusted, surgeons may want to add patients to the schedule (e.g. in case of high urgency), surgical wards may foresee problems with accommodating all patients, etc. Such reasons require adjustment of the preliminary schedule, by shifting patients between wards, assigning patients to another day in the same week or removing patients from the week , etc. Adjustments can be done until Thursday (morning) in the week before surgeries. After this deadline, the operating room schedule is definitive.

- **Admission:**

After finalizing the operating room schedule, the operating room planners call the patients involved and inform them about the planned date and time for surgery providing details about preparation and time for check-in at the hospital.
However, changes are likely to occur. Indeed, it can happen that the patients in the definitive schedule cannot come at the planned time and therefore have to be immediately replaced by other patients from the waiting list. There can be also internal reasons (i.e lack of tools and medical products) that do not allow fulfilling the schedule. As a consequence, many last-minute changes can occur.

3. PULL SYSTEM APPROACH

Tools that support strategy and planning as well as those that help solving problems are numerous, but in this context, it is necessary to focus on those that are able to support day-to-day operations and to deal with the specific features outlined in Section 2. Therefore the "pull system method" has been considered. The basic idea this method pursues is to take up the operating room only when the patient is ready that is to say pre-operative activities have been carried out and resources (people and materials) are available. In a pull system of service, the timely transition from one-step in the process to the following is the primary responsibility of the downstream (i.e., subsequent) process that, in such a case, is the surgical department. In 'pull' systems rather than pushing patients into a waiting queue for the next step in their care, available resources are requested to 'pull' patients towards them.
At the offline operational planning level (that is referred to in this research work) , the "pull system" seeks to provide the information necessary to control and to speed up the flow of patients throughout the surgical process. Making the scheduling process a "pull system" may result in significant waiting time reductions and improved customer services. The pull method implementation will require specific scheduling rules as well as the possible redesign of supporting processes but not only. Greater involvement of the staff is also envisaged. Indeed, as mentioned before, synergies and coordination play a crucial role. To this end, substantial improvements can be achieved informing and involving surgeons, nurses and all the staff in:

- Scheduling rules and regulations;
- Consistent monitoring of processing times;
- Establishing quality indicators.

Furthermore, a proper implementation of the pull system may require processes re-engineering and activities streamlining (i.e. Supply processes). Responsibilities should be assigned, and procedures documented to allow performance monitoring.

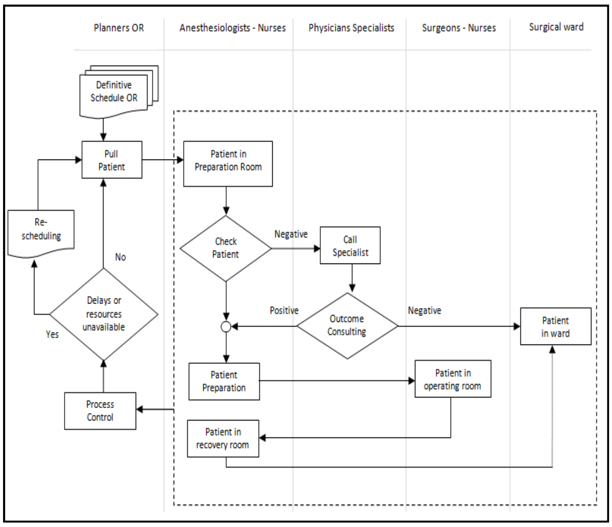


Fig.2: Pull system conceptual model

Surgical speciality	Average Process Time (APT) [min]	Average Surgery Time (AST) [min]	% AST on APT	Average Time pre - surgeries [min]	Average Time post - surgeries [min]	Non-Surgical Time (NST) [min]	% NST on APT
Neurosurgery	270	150	56%	80	40	120	44%
General Surgery	210	110	52%	75	25	100	48%
Vascular Surgery	165	80	48%	50	35	85	52%
Ortho Surgery	150	60	40%	60	30	90	60%
Ear-Nose-Throat Surgery	120	50	42%	40	30	70	58%
Gynaecology Surgery	170	90	53%	55	25	80	47%
Urology Surgery	180	95	53%	60	25	85	47%

TAB.1: Average Times Analysis

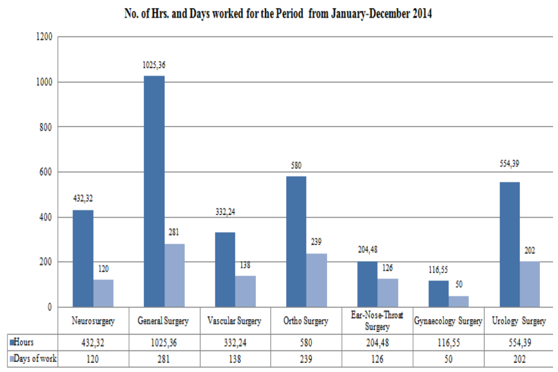
4. DATA ANALYSIS AND CURRENT PERFORMENCE

A common indicator for performance measurement in an operating room department is utilization. Although different definitions can be found in literature, commonly utilization measures the percentage of use compared to the resource capacity. As expected, the target value is 100% that means the highest utilization. Values below this threshold may be attributable to three different factors: starting late, finishing early or idle times between operations. For evaluating the actual performances of the Surgical Department, a dataset covering 52 weeks from January 1, 2014 to December 31, 2014, has been taken into account. Table 1 shows the current values of average process time, average surgery time, pre-surgery, post-surgery average time and average waiting time for each surgical specialty. In particular Process time results from three time components that include the pre-op time, the surgery time and the time interval between the surgery end and the transfer to the patient room. At first sight, it is possible to notice that in the current scenario, utilization levels are far below the target. Indeed, Average Non-surgical Time is over the 40% of the Average Process Time so that idle time percentage compared to surgery time is very high.

AUT for each Specialty [hours/Day]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Neurosurgery	4,20	6,50	6,50	5,20	7,00	6,40	7,50	6,30	7,50	7,40	6,40	7,50
n°surgeries	9	15	16	13	8	11	19	14	12	17	18	22
General Surgery 1	8,00	7,50	8,00	5,30	3,30	5,40	5,30	7,30	7,40	6,30	9,30	7,30
n°surgeries	30	37	35	27	8	23	33	29	33	41	48	32
General Surgery 2	7,40	6,00	6,40	4,00	4,30	4,00	4,40	8,00	7,40	6,40	7,40	7,40
n°surgeries	23	12	14	6	1	1	11	15	17	23	23	17
Vascular Surgery	2,30	4,40	4,40	3,30	2,40	3,30	5,40	5,30	5,00	4,40	6,50	4,40
n°surgeries	8	22	12	11	4	19	36	27	22	25	23	21
Ortho Surgery	6,30	6,00	5,40	3,40	4,30	5,40	6,30	7,00	6,20	7,40	6,20	5,40
n°surgeries	48	50	52	37	34	46	57	60	41	61	50	49
Ear-Nose-Throat Surgery	4,00	5,40	4,20	4,00	-	3,50	3,10	2,40	3,50	4,10	4,30	2,20
n°surgeries	22	26	31	24	-	17	20	18	20	25	20	15
Gynaecology Surgery	3,20	3,20	4,20	6,10	5,40	2,10	3,50	4,10	4,20	4,20	5,50	6,00
n°surgeries	5	1	4	2	1	3	6	9	11	4	17	14
Urology Surgery	4,50	4,50	5,20	5,30	3,10	5,30	5,20	7,00	4,50	5,30	6,40	5,50
n°surgeries	31	42	37	39	22	51	41	43	41	45	47	46

TAB. 2 - Average Time Utilization Daily – Operating Room

Table 2 shows the average utilization time in hours on a daily basis for each month. On average each operating room is open for less than a surgery/day. Therefore despite long waiting lists the available time (and resources) is only partially used. Inefficiency becomes even more evident when considering aggregated data over a one year period (see table 3 and 4). In such a case it is possible to notice that on average the utilization level is under the 50% of the total available time.



TAB. 3 - No. of Hrs. and Days worked

Operating Room	Total hours of surgery / year	% Utilization
Neurosurgery	432,32	29%
General Surgery 1	712,16	47%
General Surgery 2	313,2	21%
Vascular Surgery	332,24	22%
Ortho Surgery	580	39%
Ear-Nose-Throat Surgery	204,48	14%
Gynaecology Surgery	116,55	8%
Urology Surgery	554,39	37%

TAB. 4 - Utilization – Operating Room

5. SIMULATION MODEL DEVELOPMENT

To come up with an effective and easy to deploy solution for both performance monitoring and what-if analysis, a discrete event simulation tool has been developed. The simulation model is specifically designed to support the Surgical Department in evaluating operating rooms current and potential capacities enabling a preliminary and cost effective evaluation of the potential benefit that can be achieved integrating the "pull method" from Lean Management into offline operational programming processes.

5.1 Simulation Model Flow Chart

The simulation model flow chart is centered on flows of patients scheduled ahead of time for elective surgery. The available types of surgeries include Neurosurgery, General Surgery (two operating rooms), Vascular Surgery, Orthopedic Surgery, Ear-Nose-Throat Surgery, Gynecological and Urological Surgery (one operating room for each). The Operating Block that has been modeled as part of the simulation model consists of eight pre and post-operating rooms and eight operating rooms. While preparation rooms can be used by patients of any type, operating rooms are distinct for each specialty and come equipped with special instruments enabling particular types of surgery. The simulation model takes as input the final schedule that is used to evaluate which resources (humans and machines) are required to comply with all the activities in it. To this end, human resources in the operating block have been modeled. In greater detail, the simulation model includes two teams dealing with four operating rooms each. As depicted in figure 3, each team, includes:

- Anesthesiologists
- Nurses anesthetists
- Operating Block Nurses (or Circulating Nurses)
- Operating Room Nurses (or Scrub Nurses)
- Surgeons (for each specialty surgical)

By default assignments are as follows: an anesthesiologist for two operating rooms, a sterilized nurse (or scrubs) for each operating room, a scrub nurse for each operating room, a anesthetist nurse for two operating rooms. In addition, the number of health workers can be chosen in the initial settings of the simulation while surgeons are in a fixed number that is a first surgeon and an assistant surgeon for each operating room.

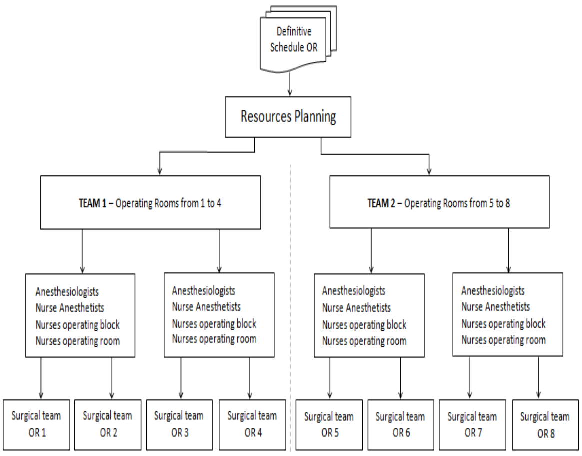


Figure 3 : Simulation Model Resources Organization

The first process implemented is the operating rooms preparation and checklist control process that starts every day at 7:00 AM and lasts one hour. In this process, which is shown in figure 4, are involved nurses in the operating room (sterilized, assistant surgeon) and nurses of operating block (non-sterilized).

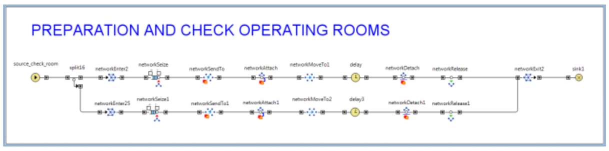


Figure 4: Simulation model Flow Chart: Preparation and Check Operating Rooms

In figure 5 is shown the simulation model flow chart of the Neurosurgery preoperative process. Nevertheless similar models have been built for the other specialties.

The pull method has been implemented within the simulation model. Hence, when the patient entity is generated some build-in controls are carried out. Such controls, have been implemented from scratch in Java and include:

- Checking for the operating room availability from the definitive schedule;
- Reading the start time and end time of regular working shifts for each operating room;
- Checking if there is an anesthesiologist ready to start the pre-operative stage;

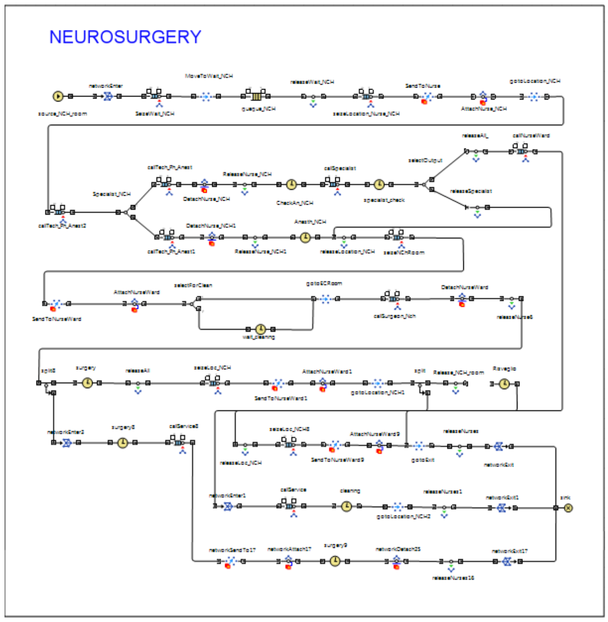


Figure 5: Simulation model Flow Chart: Pull System for Patient and preoperative process (NCH – OR)

- Comparing the remaining time before the operating room closes to the surgery estimated time. This comparison is necessary to prevent overtime. Indeed, if overtime occurs the system pulls another patient with lower estimated surgery time and postpones the patient that may cause overtime to the day after.

After such controls, the patient is treated (pulled) only when resources are available (as it happens in manufacturing systems where the pull method is applied). The advantages are the reduction the waiting time in the operating block, reduction of overtime work (and related costs), optimization of elective surgeries. Furthermore, as the simulation model is meant for what if analysis, several scenarios can be investigated changing the parameters in the input dialog window shown in fig. 6. Some of the basic parameters include:

- number of operating room nurses (for each team);
- number of operating block nurses (for each team);
- number of anesthetists nurses (for each team);
- number of anesthesiologists doctors (for each team);

- choice of weekly opening days for each operating room;
- time opening daily for each operating room;
- define the estimated time for each type of surgery (for each operating room);

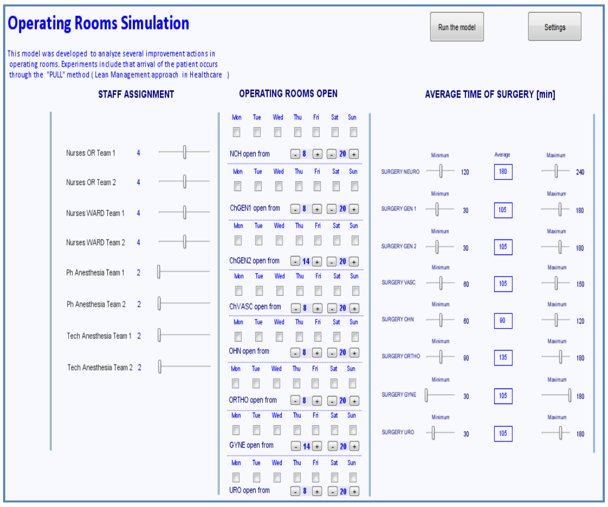


Figure 6 : Parameters input window

In addition, times for anesthesia induction vary according to the surgery type based on real data provided by the Department of Anesthesiology and Intensive Care of the Hospital.
It is worth mentioning that along the development process the simulation model has been extensively tested with real data about the estimated time of surgery, time of preparation of patients, the arrival times of the patients in the surgical unit, the time required for patients awakening after anesthesia, time for operating rooms preparation and cleaning. In addition, the model has been also validated with the Sanitary Direction.

6. SIMULATION ANALYSES AND RESULTS COMPARISON

The simulation model can be considered an accurate representation of the operating block, especially for the purpose of testing ideas and concepts. This model explores the dynamics of patients flows and of all healthcare operators involved in operating rooms processes. In order to facilitate the use of the simulation model, a graphic user interface has been added to provide the user with the possibility to monitor performance evolution during the simulation (see figure 7).

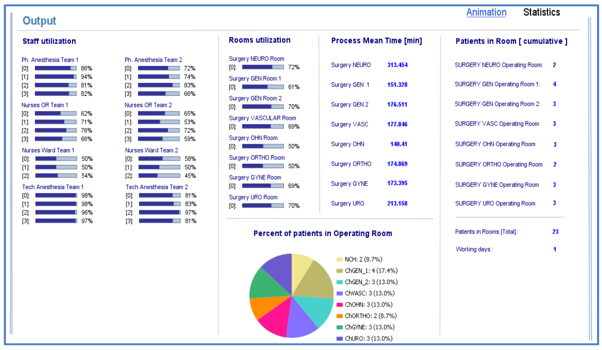


Figure 7 Output of the simulation model

In particular, the output section includes the measure of the following output parameters:

- operating rooms daily, monthly and yearly level of use (for each room and average value);
- waiting time before surgery (for each room and average value);
- waiting time after surgery (for each room and average value);
- circulating nurses level of use (for each nurse and average value);
- scrub nurses level of use (for each nurse and average value);
- auxiliary workers level of use (for each worker and average value);
- anesthetist nurses level of use (for each nurse and average value);
- anesthesiologist doctor level of use (for each doctor and average value);
- average process time (for each operating room and surgery type)
- patients rate for each operating room;
- daily , monthly and yearly number of patients for each operating room;

For the analysis that have been carried out as part of this research workand that will be discussed in the sequel, some basic settings include:

1. operating rooms standard opening times include: six hours in the morning assigned to four rooms and six hours in the afternoon assigned to the remaining four rooms;

2. Health care professionals assigned as shown in table 5.

Healthcare Professionals	**Assigned [8:00 am to 2 pm]**	**Assigned [2:00 pm to 8 pm]**
Anesthesiologist	2	2
Nurses anesthetist	2	2
Nurses circulating	4	4
Nurses scrub	4	4
Cleaning staff	1	1

Tab.5: Staff assigned to perioperative process

Simulation results allow ascertaining that compared to the actual performances, significant improvements can be achieved thanks to the "pull method implementation". Indeed, as shown in figure 8, comparing 2014 performance levels calculated in section 4 with those obtained in the simulated scenario, it results that the productivity is greatly increased. Some surgical specialties double the number of surgical procedures, such as Ear-Nose-Throat Surgery and General Surgery, while other specialties benefit from significant increases in productivity ranging from 20% to 40%

Operating Room	**Hours Utilization actual**	**OR Utilization actual**	**OR Utilization simulated**
Neurosurgery	6,00	41%	82%
General Surgery 1	6,30	55%	83%
General Surgery 2	6,30	55%	83%
Vascular Surgery	4,46	45%	68%
Ortho Surgery	6,00	58%	77%
Ear-Nose-Throat Surgery	3,52	33%	76%
Gynaecology Surgery	4,40	47%	70%
Urology Surgery	5,12	52%	78%

Tab.6 : Rate utilization Operating rooms

The simulation results reported in table 6, in particular, those reported in the third column of the table, provide an overall picture of operating rooms efficiency in the simulated scenario compared to the efficiency levels of the real facility.

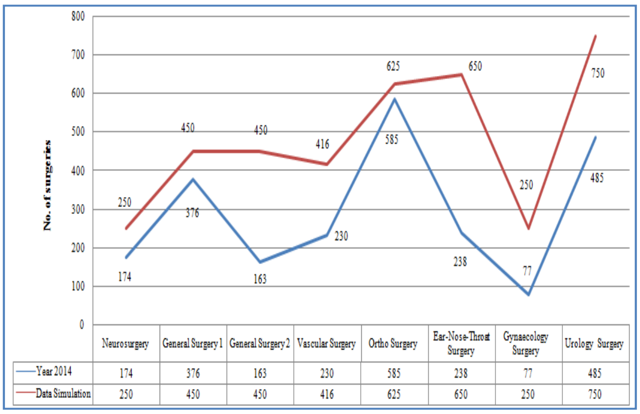


Figure 8: Comparison number of surgeries (Year 2014 – Simulated Data)

Furthermore another important outcome of the simulated scenario is the substantial reduction (60%) of patients waiting times before surgery. This result, that is analytically shown in table 7, is in line with the essence of the pull method. It is worth noticing that waiting times in the simulated scenario cannot be further reduced due to the activities that are required before the pre-anesthesia phase for preparing the surgery.

Operating Room	**Average waiting time [min]**	**Average Waiting Time Simulated [min]**	**% of improvement**
Neurosurgery	70	15	78,6%
G. Surgery 1	70	10	85,7%
G.Surgery 2	70	10	85,7%
Vascular S.	45	15	66,7%
Ortho S.	50	15	70,0%
ENT Surgery	40	10	75,0%
Gynae S.	50	10	80,0%
Urology S.	55	10	81,8%

Tab.7 : Waiting time improvement

CONCLUSIONS

This paper presents the results of a simulation study that has involved the Surgical Department of a public healthcare facility located in South Italy. After a preliminary work devoted to map the surgical process and after data collection and analysis, a simulation model of the operating rooms has been developed. The model, that has been validated by stakeholders and through comparison with real data, can be used for evaluating actual and maximum capacities but also for testing alternative scenarios before the implementation in the real system. Moreover, thanks to the model parametrization, the proposed tool can be easily adopted in other similar facilities or for evaluating different configurations in terms of resources allocation and availability. In addition, the simulation model has been equipped with build-in functions implementing the "pull method" from Lean Management practices showing that substantial performance improvements can be achieved . As a matter of facts, most healthcare organizations push patients from one area to another, from wards to operating blocks, without knowing when the patient will be treated. Instead, according the pull method, thanks to a definitive scheduling and some basic preconditions such as continuous checking and resources availability, patients are pulled when they are actually needed and as a result wastes are reduced and productivity is enhanced. The effects of the pull method implementation are accurately investigated in the simulated environment that has served as playground to assess the potential impact of the proposed approach.

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