Designing an integrated information system to reduce the patient waiting list for elective surgical interventions at a local hospital in Ecuador

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***Abstract*– A public hospital in Ecuador reported a monthly average of 700 patients in the waiting list for elective surgical interventions. This value exceeds the maximum average of 600 patients allowed by the Ministry of Public Health. One main cause for such long list is the use of multiple, unconnected databases in different stages of the process. In this work, we analyzed the system using Lean Six Sigma tools to clearly define the problem statement, its root causes, and to determine improvement actions that will contribute to reducing the average length of the waiting list. We designed an integrated information system to standardize and speed up the process. This system will serve as a foundation to future improvement actions to assist in decision making processes for elective surgical interventions.**

Keywords—lean six sigma, DMAIC, process improvement, healthcare, surgeries

I. Introduction

Public health centers in Ecuador are regulated by the Ministry of Public Health. One of such regulations is the length of the waiting list for elective surgeries, which should not exceed an average of 600 patients per month [1].

To control patient flow for elective surgeries, the public hospital where this work was performed relied on manual activities to update the waiting list for elective surgical interventions, as well as to complete activities from processes linked to scheduling such surgeries. Data was captured on different hand-written documents, e-mails and Microsoft Excel matrices. One main issue with these practices is that physician cannot know the real, precise number of patients waiting to be scheduled for their elective surgeries. By august 2019, an average of 700 patients were reported monthly, which significantly exceeds the maximum allowed by the regulation entity in the country.

Lean Six Sigma offers several tools that are wildly used in the industry to define root causes and implement solutions that are sustainable in time. Its DMAIC methodology (Define, Measure, Analyze, Control) guide project leaders in the improvement process to reduce variability and streamline processes [2,3]. DMAIC, and Lean Six Sigma tools in general, have been applied in healthcare settings with favorable results, in this local hospital and other hospitals around the globe [4, 5, 6].

Therefore, in this work, we applied Lean Six Sigma's DMAIC methodology to design a system that will contribute to reducing the average number of patients in the waiting list for elective surgical interventions at the public hospital, in order to meet regulations by the Ministry of Public Health in Ecuador. Particularly, the aim is to speed up the surgical scheduling process, reduce waiting times of patients in the surgical waiting list, promote a data-driven management at the hospital, and simplify information processing for the surgical supporting processes.

The rest of the paper is organized as follows. Section II describes the application of each of the five stages in the DMAIC methodology. Section III summarizes the results obtained when prototyping and implementing proposed solutions, and provides an analysis as well. Finally, Section IV detail the main takeaways of this study and provide recommendation for future work.

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II. DMAIC Application to Improve the Planning Process for Elective Surgeries

In this section we provide a description of the work performed on each of the stages of the DMAIC methodology to improve the surgical scheduling process for elective surgical interventions. This process belongs to the Admission Department at the hospital.

A. Define

In this stage we identified the areas with most improvement opportunities, established a baseline, project constraints and scope.

Interviews were carried out to understand the characteristics of the surgical scheduling process, what inconveniences are present and where they happen. Findings are summarized using the Voice of Customer (VOC) tool (Table I).

TABLE I
VOC Summary

Interviewed stakeholders	Comments
Surgical Scheduling Assistant	Physicians schedule their elective surgeries last minute on due date. There are mistakes in the database that need to be corrected manually.
Information System Assistant	Not all data field are filled out. There are errors in data that affect indicators, delaying the generation of daily reports.
Admissions Coordinator	Statistical reports are ready by the end of each month, which is too late. The information presented in the reports is not 100% reliable.
Surgical Center Assistants	The files that are used need to be modified several times due to errors.
Physicians	The need to physically go to the Admissions department to schedule their surgeries. They do not know which patients are in the waiting list for more than 3 months (period after which medical exams are no longer valid).

Findings from the VOC were transformed into needs to later identify critical factors to address using a Critical-to-Quality Tree (CTQ). Two main factors are that the surgical patients waiting list should not exceed 600 patients, and the number of patients rescheduled due to expired exams should be zero (Fig. 1).

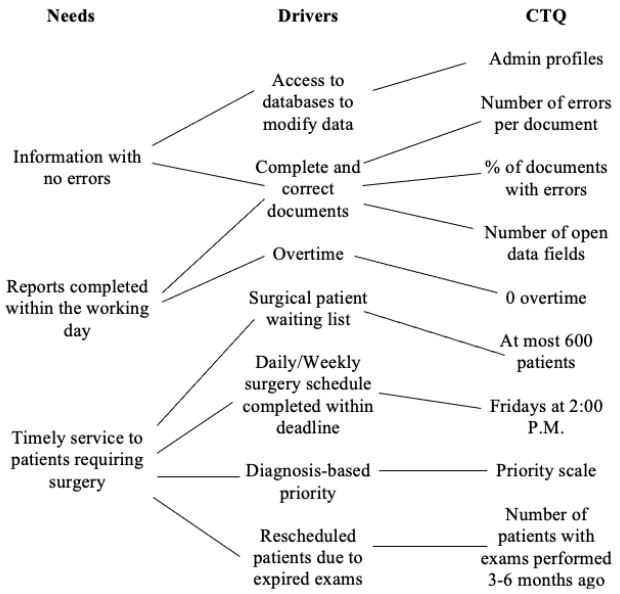

Fig. 1 CTQ tree for the surgical scheduling process

With this information, the problem statement was defined as: "*The high number of surgical patients in the waiting list is 700 on average, and the maximum allowed by the Ministry of Health in Ecuador is 600.*" The response variable Y was defined as the number of patients in the waiting list, considering those surgical patients rescheduled, waiting, and scheduled.

B. Measure

In this stage, historical data was collected to determine the time it takes to complete the surgical scheduling process, considering documents required, errors, and delays. A data collection plan was established, data was validated, and the process was mapped. Among the data collected are:

- Monthly patients in the surgical waiting list
- Monthly patients in the surgical waiting list for more than 3 months
- Time the habilitating surgical document (PQ) is submitted to the Admissions Department
- Waiting time before surgical scheduling
- Costs for clinical exams
- Patients that are rescheduled, waiting, and scheduled
- Errors in surgical waiting list database
- Time to fill out habilitating surgical document (PQ)

The data collection plan included details about who collected the data, where, how, when, and why. These data were important to understand the overall surgical planning process. Data from January 1st, 2019 to October 22nd, 2019 was considered for this work.

With respect to the process map, a flow diagram was built, starting by the submission of the PQ until the database is updated to reflect that the patient underwent the scheduled surgery.

C. Analyze

In this stage, data collected in the Measure phase is analyzed to determine root causes of the problem statement.

In order to build cause-effect diagrams, a brainstorming session was held with stakeholders from the Admissions Department to identify potential causes. These cause-effect diagrams (also known as Ishikawa diagrams) were built considering those specialties with more patients in the waiting list (Gynecology, General Surgery and Urology account to approximately 80% of patients in the surgical waiting list), as well as staff from the Admissions Department that are involved in the surgical planning process.

The information from the Ishikawa diagrams was then used to define potential causes and their corresponding effects, as shown in Table II.

TABLE II
POTENTIAL CAUSES FOR THE PROBLEM STATEMENT

#	Potential Cause	Effect
1	Surgery times are estimated based on the physicians' experience.	Surgeries are cancelled due to delay in earlier surgeries of the day.
2	Instructions to patients are given via phone calls.	Surgeries are cancelled due to patients not following medical instructions.
3	Some equipment are damaged.	Patients prefer to cancel their surgery because the procedure is changed (usually involving longer intervention and recovery times).
4	Some members from the surgical team are absent.	Surgeries are cancelled because the team is not complete by the scheduled time.
5	The physician only checks the updated surgical waiting list when scheduling his/her surgeries.	Patients stay in the surgical waiting list.
6	Patients with incorrect phone numbers are not contacted before their surgeries.	Patients stay in the surgical waiting list.
7	Some patients that had their surgeries are still shown as "waiting" in the surgical waiting list.	Patients who had their surgeries are rescheduled and later the surgery is cancelled.
8	Admission to the OR is delayed when the patient does not have the admission order.	Surgery is cancelled as "patient absent".
9	Floor beds are occupied by other specializations.	Surgery is cancelled or delayed until a floor bed is available for the patient.
10	More health centers have been opened in the city.	The amount of referral cases has increased.
11	Surgical team arrives after the scheduled starting time.	Surgery is cancelled.
12	Demand information for surgeries by specialties is incomplete.	Surgical capacities by specialties are fixated and independent from real demand.

Each of the potential causes in Table II were valued based on their impact on the problem statement and how viable it was to actually change the cause. All stakeholders were involved in the evaluation of each potential cause. From this evaluation, potential causes 1, 2, 11 and 12 were considered for further analysis.

A cause-verification plan was carried out to check for root causes. Cause 1 (surgery times are estimated based on the physicians' experience) was verified by validating the surgical scheduling process (Gemba work). It was found and confirmed by the Admissions Coordinator that these times are registered but only to be archived and not monitored.

Cause 2 (instructions to patients are given via phone calls) was verified by analyzing historical data related to instructions given over the phone and surgery cancellations. Looking at the data, cancelled surgeries were related to "wrong preparation" for two specialties, thus it was concluded that this cause does not affect the problem statement.

Cause 11 (surgical team arrives after the scheduled starting time) was verified by performing a statistical analysis to check if there is correlation between physicians' arrival times and surgery starting times. It was concluded that there was not enough statistical evidence to reject the null hypothesis (there is correlation between arrival times and starting times), and thus, this cause does affect the problem statement,

Cause 12 (demand information for surgeries by specialties is incomplete) was verified through interviews to the Admissions Coordinator and specialties leaders. It was found that each specialty carries out an internal control system for their surgical waiting list. They stated that this practice is done because they do not think the data provided by Admissions is reliable, and also to collect particular data that the habilitating surgical document (PQ) does not contain.

For each verified potential cause, a 5-Why's analysis was done to establish root causes. Findings are reported in Table III.

TABLE III
5-WHY'S ANALYSIS TO ESTABLISH ROOT CAUSES

#	Verified Potential Cause	Root Causes
1	Surgery times are estimated based on the physicians' experience.	There is no digital record and control of post-surgical, cleaning, and documentation times. Pre-surgical times are not recorded anywhere.
11	Surgical team arrives after the scheduled starting time.	Arrival times to the OR are not controlled.
12	Demand information for surgeries by specialties is incomplete.	The habilitating surgical document (PQ) is a physical document that physicians fill out using their (illegible) handwriting. In order to check the surgical waiting list, the current process requires the physician to physically go the Admissions Department and wait until the surgical scheduling assistant is available.

D. Improve

In this stage, solutions were proposed, evaluated, and built, in order to assess root causes and contribute to the problem statement described earlier. All stakeholders were involved in the process. Table IV shows results from the brainstorming session.

TABLE IV
BRAINSTORMING SOLUTION IDEAS

#	Root Causes	Solution ideas
1	There is no digital record and control of post-surgical, cleaning, and document-preparation times.	Establish a digital system to record post-surgical, cleaning, and document-preparation times.
2	Pre-surgical times are not recorded anywhere.	Establish a procedure to record arrival times of patients to pre-surgical area.
3	Arrival times to the OR are not controlled.	Acquire a biometric clock to record and control arrival time of physicians to the surgical center. Establish a penalty policy for the surgical center staff according to their late arrival times. Establish a cancellation policy for surgeries for when physicians are running late.
4	The habilitating surgical document (PQ) is a physical document that physicians fill out using their (illegible) handwriting.	Build a digital system in which the PQ can be directly filled out by the physician.
5	In order to check the surgical waiting list, the current process requires the physician to physically go the Admissions Department and wait until the surgical scheduling assistant is available.	Build a digital system in which physicians can directly access the surgical waiting list. Build an integrated digital system that connects and streamlines all steps in the surgical scheduling process.

Stakeholders evaluated all solutions from the brainstorming session, to determine which ones are more impactful and feasible to implement. Winner solutions were: establish a procedure to record arrival times of patients to pre-surgical area; build a digital system in which the PQ can be directly filled out by the physician; build a digital system in which physicians can directly access the surgical waiting list; and build an integrated digital system that connects and streamlines all steps in the surgical scheduling process. It is worth noting that the latter solution, if implemented, has the potential to address all root causes found in this work.

To quantify their impact in the problem statement, all four winner solutions were prototyped using Microsoft Visual Studio. An implementation plan was built to guide the hospital in turning the prototypes into final products once the budget for the implementation becomes available. Information in the implementation plan includes information regarding which root causes are associated to each solution, which areas are to implement solutions, who should be involved in implementation, and timeframes. This plan was accompanied

by user manuals that clearly detail how each solution should work.

Prototypes for all winning solutions are described below. It is noteworthy to highlight that these final prototypes were approved after validation with users. Table V details the user profiles created with their corresponding permissions to access the system.

TABLE V
USER PROFILES FOR THE INTEGRATED SYSTEM

User Profile	Description
Surgeon	Will be able to check surgical waiting list, patients that are suggested for scheduling, and scheduled patients. Surgeons will also have access to register new patients to the surgical waiting list.
Head Surgeon	Will be able to check surgical waiting list, patients that are suggested for scheduling, and scheduled patients. Head surgeons will also have access to register new patients to the surgical waiting list and to suggest patients for scheduling.
Subdirector of Surgical Center	Will be able to check surgical waiting list, patients that are suggested for scheduling, and scheduled patients. Subdirector will also have access to register new patients to the surgical waiting list, suggest patients for scheduling, and to remove patients from scheduled and suggested lists.
Scheduling Assistant	Will be able to check referee surgical patients to be scheduled and their contact information.
OR Assistant	Will be able to record the patient's surgical safety checklist.
Anesthesiologist	Will be able to record the patient's data list from the surgical center.
Nurse	Will be able to record surgery cancellations and causes of cancellations.
Admissions staff	Will be able to download the surgical waiting list.
Pre-surgical area staff	Will be able to record surgery delays and causes of delays.

Solution 1: Establish a procedure to record arrival times of patients to the pre-surgical area. An interface was designed to record when a surgery is delayed due to delays in the pre-surgical area (Fig 2).

In this interface, the user enters the patient ID and the following data will load: date, specialty, surgeon, name of patient, diagnosis, surgical procedure, scheduled time, OR floor, OR number. Data fields to fill out include: time in which patient arrives to pre-surgical area, checklists with types of delay if any (institutional, staff, personal-patient, clinical-patient), field to fill out any necessary observation.

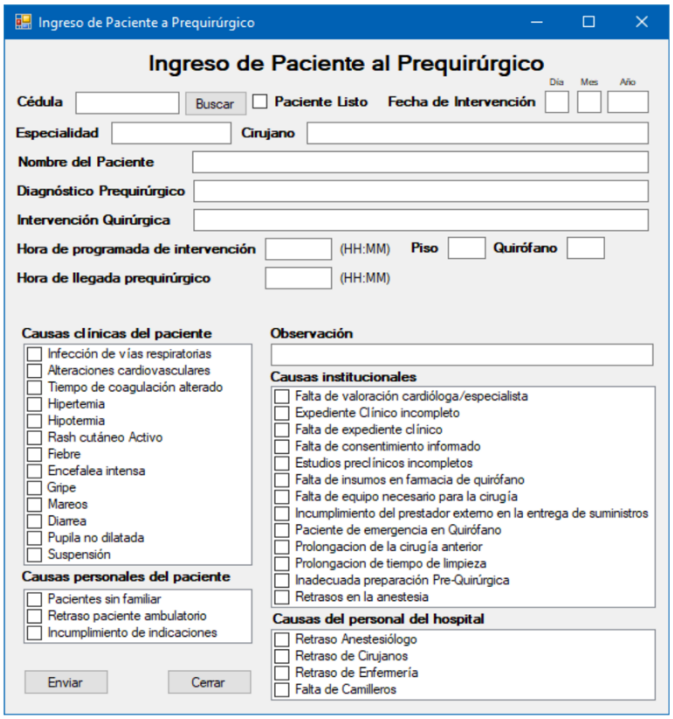

Fig. 2 Interface for registering arrival times of patients and causes of delays in surgical area

Solution 2: Build a digital system in which the PQ can be directly filled out by the physician. An interface was designed based on input from 10 physicians from different specialties (Fig. 3).

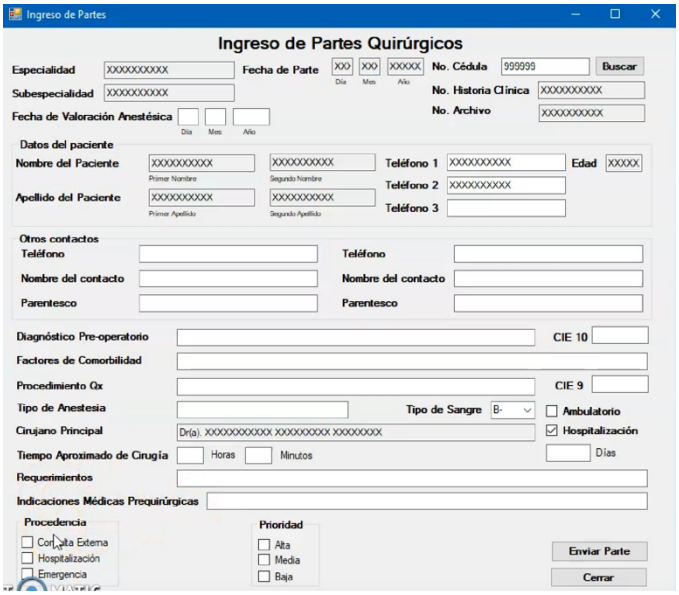

Fig. 3 Interface for registering PQs

The user enters the patient ID and the following data will load: date, specialty, surgeon, name of patient, and contact information. Data fields to fill out include: additional contact

information, diagnosis, type of anesthesia, estimated surgical time, if procedure is ambulatory or requires hospitalization, among others. Data fields likes type of patient (outpatient, inpatient, emergency) were not considered in the original form but added based on needs specified during validation stages.

Solution 3: Build a digital system in which physicians can directly access the surgical waiting list. An interface was designed to allow the physician to check the surgical waiting list from their office or other available computers inside the hospital (Fig. 4).

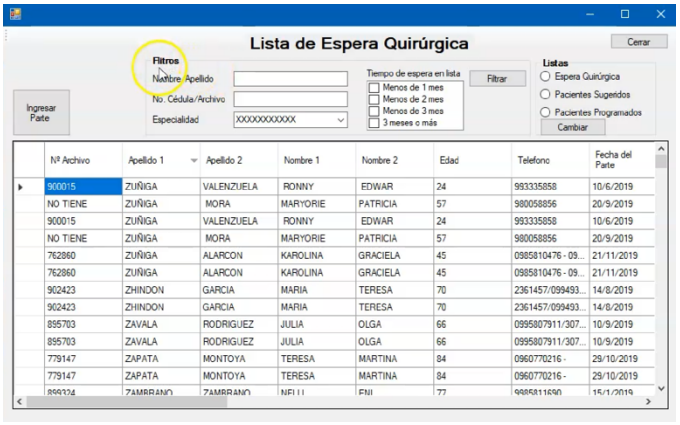

Fig. 4 Interface for accessing surgical waiting list

This new interface allows the user to look up patients, filter by specialty or time in the waiting list, and generates different lists depending on what is needed (surgical waiting list, suggested patients to schedule, or scheduled patients).

Solution 4: Build an integrated digital system that connects and streamlines all steps in the surgical scheduling process. This solution includes all three solutions described earlier and additional interfaces, as well as additional interfaces for other activities of the process.

The system considers a structured and organized contact information list (Fig. 5), a tracking form for canceled surgeries (Fig. 6), a surgical patient form with auto-filled data fields for the Surgical Center (Fig. 7), and a safe-surgery checklist connected to patient data (Fig. 8). All these interfaces considered current existing methods to register data in physical forms at the hospital. Details were adjusted during validation stages to optimize process times, and to build buy-in from users.

E. Control

This last phase of the DMAIC methodology deals with sustaining solutions in time. A control plan was made to address what activities should be carried out to fulfill objectives, why it is necessary to control them, who are responsible to carry out control activities, and where the control will be made.

The activities considered in the control plan are described in Table VI.

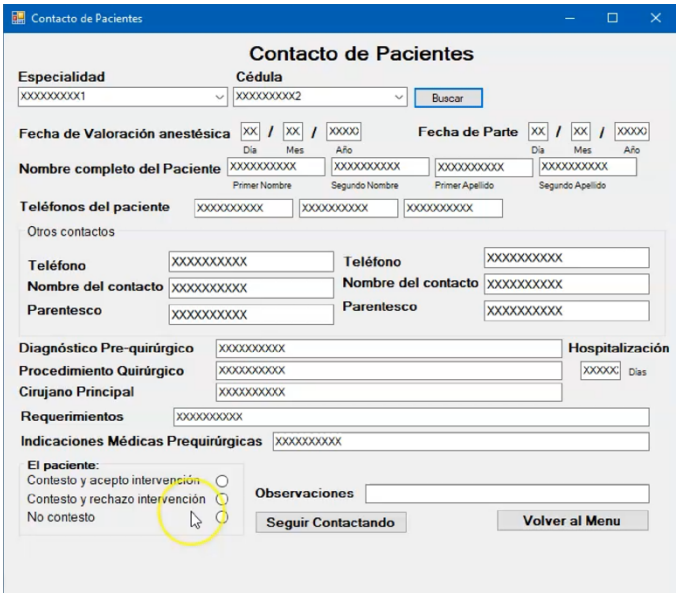

Fig. 5 Interface for accessing a patient's contact information

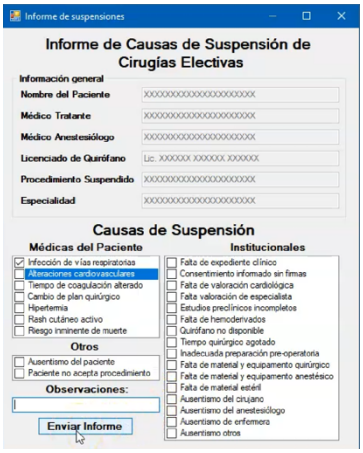

Fig. 6 Interface for registering information of cancelled surgeries

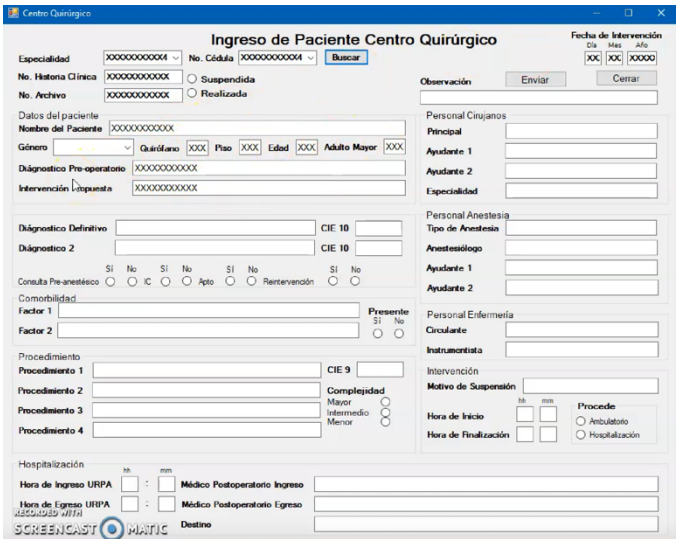

Fig. 7 Interface for registering patient surgical information

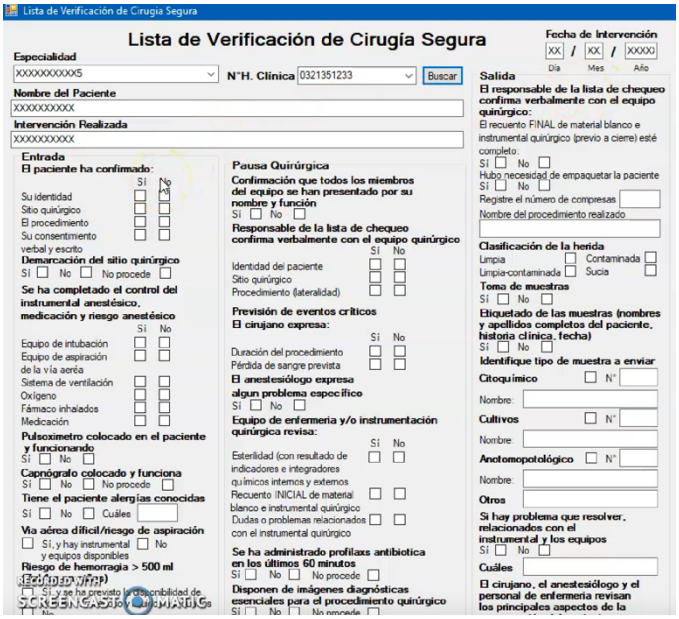

Fig. 8 Interface for the safe-surgery checklist

TABLE VI
ACTIVITIES CONSIDERED IN THE CONTROL PLAN

Solution	Control activities
Establish a procedure to record arrival times of patients to pre-surgical area	Follow-up process and registration of process times. Improve forecast for surgical times.
Build a digital system in which the PQ can be directly filled out by the physician	Check possible errors that the system could present during implementation of the prototype and use of the system. Establish a system support process for any user experiencing difficulties with the system. Identify additional needs that should be included in the system.
Build a digital system in which physicians can directly address the surgical waiting list	
Build an integrated digital system that connects and streamlines all steps in the surgical scheduling process	

III. Results and Discussion

In this section, we will report the results we obtained from prototyping the four proposed solutions. A discussion of results will be provided for each solution as well.

A. Solution 1: Establish a procedure to record arrival times of patients to pre-surgical area.

Table VII summarizes the procedure to follow in order to measure times for the pre-surgical activities. The implementation of this solution used a template that records times in the pre-surgical area, as well as the causes that cause delays (when applicable). These causes are presented as a checklist in the corresponding interface of the integrated system. The information in this checklist considers findings in from previous project stages, when data was collected manually.

TABLE VII
PROCEDURE FOR MEASURING TIMES IN THE PRE-SURGICAL AREA

What	Time measurement in the pre-surgical area
Who	Nurses
How	Accessing the corresponding interface in the integrated system for pre-surgical time measurements
Where	Surgical Center at the hospital
When	The moment the patient arrives to the Surgical Center
Why	It is necessary to control pre-surgical arrival times to establish delay causes, if any, for each patient.

Before this work, no data related to arrival times to the pre-surgical area and causes for delays were recorded. Although surgical and post-surgical times were recorded, they were not considered for decision making to reduce delays in surgeries. Furthermore, the information was recorded in physical documents only with no more use than to keep records of interventions. By establishing the procedure to record arrival times to the pre-surgical area, this data, along with surgical and post-surgical data, can be used for decision-making; for example, to establish future policies to control delays. Also, this information allows to identify main causes to delays that, in the future, can be controlled, reduced or eliminated.

B. Solution 2: Build a digital system in which the PQ can be directly filled out by the physician.

This solution allows the PQ to be directly recorded in the system by the surgeon, during the medical appointment in which the patient receives green light for surgery. By digitalizing the document, the process is reduced to 5 minutes. To increase buy-in from users, the interface was designed considering the current template of the physical document; new fields were added, and the overall layout of information improved.

If implemented, this system will reduce time in 99.99% for this activity in the process. This means that, instead of taking an average of 10.64 days to have PQ information readily available for the patient list, it would take 5 minutes using the system. Additionally, this solution eliminates the need of physical documents, as well as errors associated to translating information from a manual, often illegible source.

C. Solution 3: Build a digital system in which physicians can directly address the surgical waiting list.

The digital system eliminates non value-added activities from the process. Without the system, in order to check the patient waiting list, the surgeon needs to get out of his or her office, get to the Admissions department, and wait for the assistant to be available. With the system, the surgeon can check the list anytime, with no waiting time incurred.

By implementing this solution, the time to check the patient list is completely eliminated (currently, it takes from 2.47 to 9.45 minutes to complete the task).

D. Solution 4: Build an integrated digital system that connects and streamlines all steps in the surgical scheduling process.

The design of the system involved various meetings with stakeholders, in order to receive feedback, validate and verify the design, as well as to prototype and test the corresponding interfaces. This solution includes all benefits from the previous three. Additionally, its implementation would reduce documentation times, it will eliminate unstandardized practices and errors from how information is currently manipulated. The implementation of this system will reduce non-value-added activities in 42% and value-added activities in 44%. Figures 7 and 8 show the value stream mapping (VSM) for the system before and after implementation of solution 4, respectively.

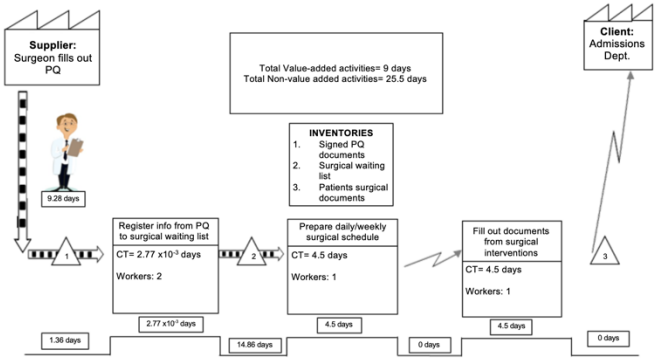

Fig. 7 VSM before implementation of proposed solutions

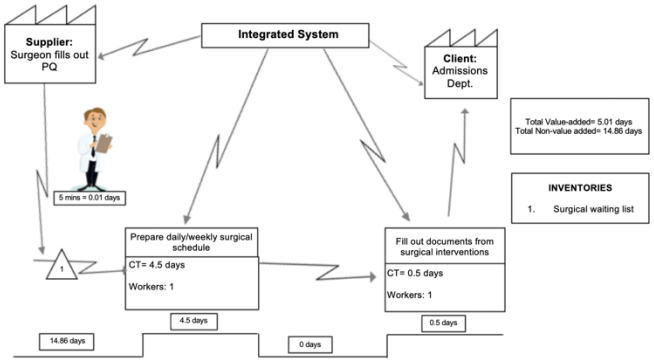

Fig. 8 VSM after implementation of proposed solutions

Table VIII summarizes implementation costs for building these solutions in-house. Costs were calculated considering staff, equipment and training requirements. It is worth noting that costs for solution 4 include costs for solutions 1, 2 and 3.

TABLE VIII
IMPLEMENTATION COSTS FOR SOLUTIONS

Solution	Quantity (hours)	Total costs (US dollars)
Solution 1: Establish a procedure to record arrival times of patients to pre-surgical area	101	682.14
Solution 2: Build a digital system in which the PQ can be directly filled out by the physician.	263	1,740.99
Solution 3: Build a digital system in which physicians can directly address the surgical waiting list.	113	722.87
Solution 4: Build an integrated digital system that connects and streamlines all steps in the surgical scheduling process.	1018	6,848.59

IV. CONCLUSIONS AND FUTURE WORK

In this work, the objective was to develop solutions to reduce the surgical patient waiting list of a local hospital in Ecuador. We eliminated non value-added activities from the process, and make data reliable and accessible.

Our proposed solution consists of an integrated system that eliminates hidden, inefficient activities, and allows stakeholders to register the patient information in the surgical waiting list immediately after the physician fills out a digitalized habilitating-document for surgery. This system also provides information with regard to delays in the surgical center, to account for surgeries that start late or get cancelled. All these efforts will allow in the future to increase OR utilization, speed up the scheduling process, and consequently, reduce the surgical waiting list to acceptable standards.

Since the implementation of the integrated system contributes to simplifying data processing and making information readily available for analysis, new improvement opportunities will be addressed more easily given that data will be available and reliable for decision making.

We devise as future work the inclusion of new areas to the integrated system. For instance, this system could include emergency surgeries. Once the system is implemented and running, data can be used to improve forecast for surgical times, and to develop scheduling models that contribute to increasing OR utilization and thus, decreasing more the surgical patient waiting list.

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