A Business Process Reengineering (BPR) of a radiology department of an Italian middle size hospital

Roberto Revetria [I, a)], Anastasiia Rozhok [I, b)], Lucia Fossati [I, c)] and Carlotta Patrone [I, d)]

I. Dipartimento di Ingegneria meccanica, energetica, gestionale e dei trasporti - DIME, University of Genoa, Via Opera Pia 15, 16145 – Genoa – Italy

a. roberto.revetria@unige.it
b. anastasiia.rozhok@edu.unige.it
c. lucia.fossati01@gmail.com
d. patronecarlotta@gmail.com

Abstract: The diagnostic imaging service is a fundamental and unavoidable area in any hospital. In addition, these services are needed for both the patients' staging phase and emergencies coming from First Aid. Long waiting times for diagnostics services are a significant Italian healthcare problem. This study aims to define an organizational model for optimizing resources, reducing waiting times, and improving hospital services. An in-depth analysis of data within a medium-sized hospital context has been conducted. The Anylogic software has been used for diagnostic patient flow modeling. The model refers to a radiological department with high technological content such as TAC, RM machine, PET-TC and linear accelerators, ECO, image intensifier, and RX machine. Five years of data have been analyzed for a total of 479.354 performances. Those data refer to the process that follows the patient, such as the provenience (i.e., emergency room or hospitalized), reservation tracking, and the machine used for the exam. The Anylogic model consists of three steps: entry (characterized by source, day, and date), service (represented by the type of machine), and exit (marked by date).

Keywords: Business Process Reengineering (BPR); Lean Healthcare; Radiology patient flow; Anylogic.

I. INTRODUCTION

In the last thirty years, we have witnessed significant developments in diagnostic imaging, driven by a progressive improvement of image detectors in computer science and general technology [1].

Diagnostic imaging consists of techniques and procedures that allow you to see, explore, and monitor areas inside the body that are not visible.

A working group of the auditory steady-state response (ASSR) states that the consecutive medical development has made diagnostic imaging a fundamental tool of diagnosis, prognosis, and disease monitoring and indispensable for some diagnostic and therapeutic interventional procedures [1]. These tools are used in the simplest and most common examinations and emergencies.

This study aims to reengineer critical processes and improve productivity through Business Process Reengineering (BPR) with Lean Management. So, we need to start with analyzing the current organizational model of the patient flow that requires imaging diagnostic examination within the context of Galliera Hospital to identify weak points in the system. The analysis of the as-is model is divided into a data analysis and a simulation of the model through the Anylogic program. The analysis data aims to clean up the data provided by the hospital and derive the necessary information for the simulation model.

An interesting study, "The Hospital Radiology Service Redesign, By Using Business Process Re-engineering and Information Systems Approach," argues that a critical problem of the radiology department is the excessive waiting time for diagnostic results, which leads to severe consequences for patients' health [2]. However, this critical issue will not be addressed here; this paper will focus on the process steps before reporting, such as waiting times to perform examinations, precedence systems, and resource utilization.

The simulation model needs to represent the process and simulate its operation; that way, we can identify the critical point where the system loses efficiency intuitively.

Anylogic software enables the development of simulation models and can combine multiple simulation techniques to address complex systems. In this way, Anylogic allows various strengths of each method to be leveraged and integrated into the same model. Several texts demonstrate the usefulness of this software in healthcare environments through hybrid simulation, the most frequently integrated simulation techniques being DES (Discrete Event Simulation), Systrem Dynamics (DS), and Agent-Based Modelling (ABS). Because of this approach, we can study patient flow in the hospital setting by exploiting the combination of DES and SD methodologies. [7]

Anylogic is a powerful and flexible tool that can adapt to multiple development contexts but requires specific programming and modeling skills, especially in the case of hybrid simulations. The software must also have clean and reliable inputs for model building, which will then be subjected to verification examinations.

Modelers highly value Anylogic because it combines different approaches and simplifies them. It offers the ability to create custom libraries, i.e., model libraries that facilitate the creation of hybrid models [8]

Lean Management, born by Toyota Production System in the 40', is based on applying the principles of Lean Thinking: the analysis of the waste of time within a company and its reduction or elimination [2]. The fundamental principles of lean management include eliminating redundancies and consolidating standard processes that help business efficiency [3].

Taiichi Ohno is considered one of the founding fathers of Lean Think. During his studies, he identified the seven significant wastes (called MUDAs) that must be mitigated or eliminated to save costs and make the work process more efficient. These seven muda have, over the years, been applied to the healthcare world and identified as:

1. Transportation waste: unnecessary movement of patients, test samples, and supplies within the hospital.
2. Inventory waste: excess of materials and supplies or understock of the same.
3. Movement waste: unnecessary movements of staff within the hospital.
4. Waiting waste: excessively long waiting times for patients.
5. Overproduction waste: overproduction or production in advance of actual demand.
6. Overprocessing waste: excessive processing or unnecessary procedures.
7. Defect waste: errors that compromise service quality.

The wastes considered most critical in the hospital setting are waiting, transportation, movement, and defects. As they directly affect customer satisfaction, they are widespread in hospitals and are the significant causes of inefficiency in the system. [9]

The Lean philosophy applied to the healthcare system became a primary management strategy in the sector and brought clear improvements so we can talk of Lean Healthcare.

Lean healthcare entirely fits the principles of Lean thinking, as it pays attention to the patient's well-being and service quality and directly involves hospital staff to find solutions and improvements proactively and dynamically [2].

The BPR is an improvement process consisting of actions to achieve lean management.

The BPR was born in the '90s by Hammer and Campy, who defines it as "…the fundamental rethinking and radical redesign of the business processes to achieve dramatic improvements in critical, contemporary performance measures, such as cost, quality, service, and speed".

It is a reengineering of business processes to increase productivity and improve uptime and quality. [4]

The BPR is a managerial approach that is based on the reengineering of processes and is divided into seven main phases [4]:

- Visioning: The main business problems are identified, a new business vision is sought, and the main goals of process reengineering are determined.
- Identify: An analysis is applied to the workflow, inefficiencies are identified, and opportunities for improvement are determined, thus identifying critical business processes that need reengineering.
- Analyzing: A more in-depth analysis of the current system focuses on the critical processes to determine additional weaknesses and potential benefits due to reengineering. In this phase, process time, cost, and performance are studied.
- Redesigning: Possible solutions are identified, and processes are redesigned, respectively. New solutions must create better and more efficient processes and are often identified through innovative and revolutionary approaches using advanced tools and technologies.
- Evaluating: An evaluation of possible solutions is carried out. The goal is to choose the best option by analyzing each alternative's costs, benefits, and advantages.
- Implementing: This phase consists of implementing the planned changes, performing process reengineering, and launching the new system. It also tries to involve employees as much as possible so that they will adapt more quickly to the change.
- Improving: The last phase of BPR consists of monitoring the new processes and continuously improving them [10].

An essential tool of Lean is Value Stream Mapping, a visual map that shows all steps from the start to the end of the process. It allows a full view of the System and all its activities, by which we can identify unnecessary and critical [5].

At first, BPR and Lean were applied to the manufacturing sector and sanitary systems. More dissertations have shown the feasibility and benefits of using BPR and Lean Management (or Lean healthcare), especially in secondary care [6].

For example, "Using Value Stream Mapping to Improve Quality of Care in Low-Resource Facility Settings (Det)" by R. Ramaswamy [7] shows the Value Stream Mapping and Lean implementation for encouraging staff involvement in prioritizing opportunities to enhance clinical outcomes and patient-centered quality of care.

The paper "Business Process Reengineering at the Hospitals: A Case Study at Singapore Hospital" By Arun Kumar and Linet Ozdamar [8] studies the application of Business Process Reengineering in the surgical department. It aims to find and analyze solutions to reduce system costs, inefficiencies, or bottlenecks. This study is limited to an operating theatre suite within a Singapore hospital.

There is also more Literature review about the BPR method of healthcare, like "Business Process Reengineering in Healthcare: Literature Review on the Methodologies and Approaches" by Musa & Othman [9]; this paper expresses the importance and success of BPR and explores the current development level of BPR.

Studies have been conducted in the United States that aim to address the problems of congestion and improper distribution of labor through BPR. A lack of personnel equipment and a high demand for emergency medical services led the system to oversaturation, resulting in an average waiting time of 90 minutes per patient. This study pursues the goal of reducing waiting time and allocating workload equitably and economically among resources. It creates five possible process reengineering scenarios, each with different characteristics leading to other improvement solutions. It is shown how integrating process change and resource allocation optimization is the optimal solution to improve performance in the emergency department. This solution is the balanced redistribution of work among physicians, physician assistants, and nurses to reduce patient waiting time and ensure resource availability. However, disadvantages include implementation costs, difficulty implementing the new process, and other potential risks. [12]

Organizational and engineering issues in the healthcare world have been addressed by many, and this has generated an excessive amount of scientific research and possible solutions to the topic. Through a review of the literature, we have identified an exciting solution, artificial intelligence, which aims to solve the problem of inefficiency of healthcare personnel. This new perspective wants to use AI to facilitate diagnosis and decision-making procedures. In addition, this tool is excellent for analyzing large amounts of data and facilitates administrative procedures. The weakness of this solution is the resulting ethical and legal challenges that would be generated. There could be several issues due to the use of AI, for example, the responsibility for a possible error of causing harm to the patient or the new relationship between doctor and patient. Indeed, it is essential to remember how empathy and care are part of medical practice and cannot be replaced by computerized systems.[11]

II. METHODS AND MODELS

In this study, we will analyze the specific case of process reengineering in the radiology department of Galliera Hospital in Genoa, a medium-sized hospital.

The hospital has the following machines:

- 4 CT scans, each set up primarily for one type of examination. (Machines A).
- 2 MRIs, one dedicated to cranial/column examinations and one to total body examinations. (Machines B).
- 4 angiographs. (Machines C)
- 3 traditional radiology devices. (Machines D).
- 1 gamma chamber, nuclear medicine. (Machine E).
- 1 pet TC, nuclear medicine. (Machine F).
- 2 echoes. (Machines H)
- 5 brightness amplifiers, including four referred to different surgical specialties and one portable. (Machines I).
- 1 portable RX. (Machine L).
- 1 orthopantomography. (Machine M).

To each machine, we assigned a letter-number abbreviation. The letter identifies the type of machine, while the number distinguishes different machines of the same kind. For example, the 4 CT machines were named A1, A2, A3, and A4.

Three flows of patients can be distinguished within the system according to their source.

Patients who come from the emergency department perform the visit on request radiography by an ER doctor. The staff then transports the patient to the "radiological ready," where they wait to conduct the examination that will then be reported in real-time.

Outpatients book their visit through the Unique Booking Center (Centro unico di prenotazione – CUP), which assigns them an appointment. The patient must report to the hospital on the day and time provided by the Cup and wait in the waiting room to perform the examination.

Internal patients, on the other hand, are transported by internal staff to various diagnostic rooms depending on the type of examination. After the test, they are returned to the hospital rooms, and the report is available during the day.

At 12.00 of each working day, the computer closure of the exam booking for the next day, providing to fill any available space with external urgent examinations, and the list of patients needing movement is made available to the Stretcher. In the case of urgent service requests, the reservation is provided on the same day by telephone agreement between the hospital room and the medical manager responsible for diagnostics.

After defining our machines and understanding the priority orders, we move on to an analysis and reprocessing the data.

Five Excel files were provided as starting data, each covering a year from 2019 to 2023. These files contain data on all patients who performed diagnostic examinations at the hospital in the given year. These files also contain irrelevant data or may have been filled in with untrue information, so they must be cleaned up. Each file includes a patient number, type of booking, i.e., the origin of the patient, day and time of entry, diagnostic suspicion, examination code, type of examination, date and time of execution, and the date and reporting time.

First, all examinations that do not refer to diagnostic imaging examinations must be eliminated.

In each Excel file, we add a new column called "machines" that assigns to each examination the machines on which the latter can be performed. Each acronym identifies a series of machines, and each series of machines corresponds to a type of examination.

For each patient, we calculate the duration in minutes of their stay in the service, from when they start the exam to when they finish the exam.

So, we would have a different patient exam duration for multiple examinations of the same type.

For each table, we have the patient code, the exam they have to perform, the machines on which it is possible to complete it, and the exam duration. Thanks to these times, we will determine a trend for each unique exam type (for each table). That is, we establish a value around which there is a greater distribution. Thanks to trends, we can see which values are untruthful, thus unreliable, and therefore can be eliminated. We also draw classes of exam duration for each type of exam and the percentages with which these times occur. This data is fundamental for the Anylogic model construction.

Finally, we have calculated the monthly frequencies for each type of examination: the arrival time of patients who have to perform examinations of the same kind.

III. Discussion

To build the model on Anylogic, all examinations are brought back to 25 examination types depending on the machines they use to be performed. For example, the "brain CT" exam can only be performed on the A1 machine, so it will belong to the exam type named "A1," whereas the "target TC detection" exam can be performed on the A1, A2 or A3 machine so it will be assigned to the exam type "A1_2_3." The monthly frequency with which these are carried out was calculated for each examination type based on data collected over the past five years. In addition, with the same data, the examination type duration times and corresponding probabilities were derived for each type. This means that all examinations belonging to the examination typology "A1_2_3" are characterized by the same parameters.

Thus, in our model:

- each exam is assigned to an exam type
- according to the type to which it belongs, the examination can be performed on more than one machine
- multiple exam types can be performed on each machine.

The Anylogic model consists of two main processes. The first consists of the generation of the examination request. It involves entering patients into the system, assigning them to an exam type, and then assigning the machine on which the exam wants to be performed; this is based on the queue length of the machines associated with the relevant exam type. The patient will be assigned the machine with the least queue length. The process follows the FIFO (First In, First out) method; the first patient entering the system will be turned into the first exam request, corresponding to the machine name.

The second process represents service on imaging machines. The patient enters the system, queues, performs the examination, and exits. We have as many systems as there are resources, i.e., machines, available to us. The patient-system assignment is not random but is the one assigned in the previous step. The examination request enters the system, which figuratively represents the patient.

Using our model, we have derived the examination running times and waiting times with their rates for each machine.

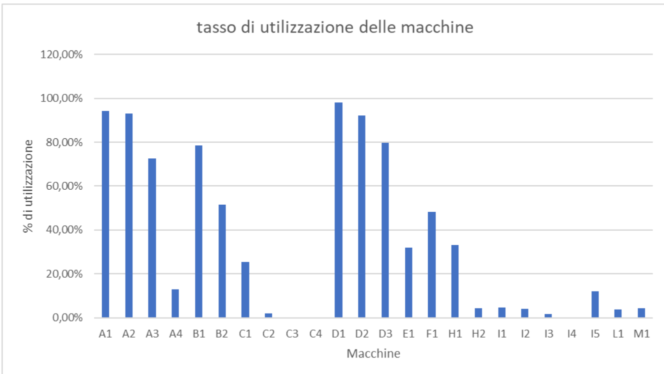

Figure 1. The utilization rates for each machine.

From the utilization rates, we can see a clear distinction between machines; some have very high rates, for example, the A2 machine with 93.1 percent; the utilization rate indicates how much the machine is used. Other machines, however, have meager rates, if any, such as the C3 and C4 machines.

Let us take the A2 machine as an example and look at its data referring to waiting time: 32.6 percent of patients wait up to 32 minutes before performing the examination, 27 percent of patients wait between 32minutes and 64 minutes, 14.8 percent wait between 64 minutes and 97 minutes, and finally the remaining patients wait more than 97 minutes to perform the examination.

Consider excessive waiting times of more than 30 minutes, meaning that 70% of patients on the A2 machine do not receive efficient service. There can be multiple causes for this criticality, considering that human activities influence and drive the hospital environment, making it inherently less standardizable. This additional feature implies greater complexity in the system optimization process.

On the other hand, we notice an underutilization of unused resources such as C3 and C4 machines. This situation is caused by the low saturation of C1 and C2 machines, which is why C3 and C4 are not used. The unused machines incur costs to the hospital, such as wasted time due to low saturation of service capacity, resulting in increased waiting times for patients with scheduled examinations. In addition, healthcare machines represent a substantial investment for the hospital, and their non-use also leads to direct costs, i.e., costs related to depreciation and maintenance. Other costs can be attributed to the payment of skilled employees despite the machine not being in use, space occupied by the machine, energy resources, and depreciation.

To optimize our system, we decided to increase the A-type machines by including in the system the A5 machine, which performs more examination types, and the A1b machine, which performs the same examinations that the A1 machine performs. Thanks to this operation, we have improved the condition of the system; for example, the A2 machine has gone from a utilization rate of 93.1% to a rate of 87.7%, and if before 70% of the patients had to wait for a time longer than 30 minutes before performing the examination, now the rate has been lowered to 37%.

To correct the underutilization of the C-type machines, we eliminated the C2, C3, and C4 machines so that only the C1 machine was loaded. In this way, our machine went from a utilization rate of 25.7% to a rate of 27%. As for waiting time, only 21% of patients wait for a time longer than 35 minutes.

IV. CONCLUSION

The study aimed to investigate the organizational model of the radiology department of Galliera Hospital, find its critical points, and reengineer the system where necessary. Our aim was achieved through an in-depth data analysis and the construction of a model that consistently represents the as-is system. The critical points we were able to identify are, on the one hand, performance overload for some machines, leading to long waiting times for the patient, and, on the other hand, underutilization of some machines, leading to idle costs. Regarding the first point, the cause was assumed to be low resource availability, so the number of machines was increased, and the system was shown to have improved significantly by decreasing overutilization rates and excessive waiting times. As for the under-saturated machines, we can attribute the cause to excessive resource availability, so the number of machines for the types with low saturation decreased. Thus, the saturation rate increased for the remaining machines, and consequently, the costs attributed to their underutilization decreased. To study this critical issue further, a review of the procedures for compiling waiting lists is recommended. In such a way as to increase the saturation of machines but still maintain low waiting times.

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