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Outpatient optimization of performance utilizing simulation in an external orthopedic Department

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Abstract

Outpatient services are one of the most congested hospital divisions because they combine consultation, care and follow-up activities. These services are often confronted with several challenges such as inadequate resources and personnel management, the highly complex flow of patient information, and especially the long travel-time of patients inside the service. Indeed, the flow of patients into these services has become increasingly intensive, resulting in long waiting time for patients and a heavy burden on the service staff. In this paper, we address the problem of patient cycle time in the outpatient department of orthopedic surgery at Habib Bourguiba hospital in Sfax. The objective of this study is to minimize the average waiting time of patients with the minimum cost of services. An optimization approach based on simulation is proposed. Three mathematical models that describe the objectives related to waiting time and service cost are formulated and then implemented using the OptQuest tool of Arena software. The experimental results showed a great improvement of the service performance.

Keywords:

Outpatient service, Simulation, Optimization, patient flow, travel-time, average waiting time.

Introduction

The study and analysis of any health care system has become a necessity to improve its performance and meet the number of objectives that are often contradictory, such as maximizing the use of resources (material and human) with minimum cost, improving the quality of care by providing effective diagnostic systems or increasing the number of patients treated over a fixed time horizon. Currently, operating, maintenance and care costs are continually increasing due to the use of new techniques that involve new resources and methods. This news has added new constraints to health systems (Brailsford and Vissers, [1], Brandeau [2], Rais and Viana [3]). The goals of a health care system, as mentioned above, can be achieved, effectively, with the organization and implementation of appropriate care planning. This can be achieved using operational research methods, based approaches and through other quantitative techniques (Brailsford and Vissers, [1] and Rais and Viana, [3]).

In this work, we are interested in the problem of long waiting time in the outpatient services. As a case study we have chosen the outpatient service of the orthopedic surgery of the Habib-Bourguiba hospital of Sfax. This choice is justified by the high patient flow that characterizes this division compared to the other services. In fact, we proposed to apply the two techniques of system performance evaluation: simulation and optimization in order to treat the patients flow problem. As a first step, we proposed a simulation model that describes the patient's passage to the various tasks ranging from registration until leaving the system in order to detect the sources of dysfunction and the causes of long waiting times. Then, the optimization step is performed using the OptQuest tool of Arena software.

In the following section (2) we present a brief review of the literature related to our subject. Subsequently, section 3 describes the organization and current operation of the selected service. In Section 4, we have shown how our simulation model has been developed and validated. In Section 5, three mathematical optimization models are constructed. The simulation optimization procedures are then developed using OptQuest tool to solve the proposed models. Section 6 presents the results and discussions. Finally, section 7 draws the main conclusion of this work and gives some future perspectives.

1. Literature Review

In public hospitals, and especially in outpatient departments, the patients flow has become intensified, the number of patients entering the system far exceeds the number of the patients treated. In fact, the problem of scheduling appointments for outpatient services has attracted the interest of many academics researches and practitioners over the past 60 years. This interest began with the famous work of Bailey [4]. The aim of this work was to develop a planning system that satisfies the interests of consultants and patients: patients prefer to have the minimum waiting time, doctors like to spend a short period of inactivity and prefer to finish on time. Wang [5] studied the planning problem in two different ways, once as a static scheduling problem in which the number of patients expected is known, and once as a dynamic scheduling problem in which an additional number of patients are planned after a first batch of programmed patients. Author studied a single server system with exponential service time, the goal of which is to minimize the weighted sum of customer flow time and system completion time.

In the literature, it has been observed that simulation has widely been used for the resolution of problems of hospital organization in the last twenty years, whether for the emergency department (El Oualidi [6]; Achour [7]; Dehas [8]; Ping-Shun Chen [9]; Glaa [10]; Tao [11]; Belaidi [12]; Jlassi [13]), operating theater (Marcon[14]; Millard [15]; Ramis [16]; Tyler [17]), surgery (Vasilakis and Kuramoto[18]), nursing units (Gascon [19]), maternity care at home (Nidhal Rezg [20]), imaging (Mebrek [21], Moussa and Belkadi, [22]), hospital logistics (Aleksy [23]), the stomatology department (Belkadi, and Tnaguy [24]) and other units.

Simulation techniques are often used to model patient's flows in different hospital departments. Indeed, this technique is useful when it is used to model the complex patients flow systems and to test the scenarios resulting from the change of certain parameters. Among the services where simulation techniques are interesting are the emergency services where the flow of patient's is subject to the many sources of uncertainties. El Oualidi [25] presented a simulation model of the patient flow in the emergency department by the Structured Analysis and Design Technique method. This model has the aim of minimizing the average length of stay. Thanks to the simulation, a reorganization of the service made it possible to reduce the length of stay by 30%.

A frequently used method is the optimization based simulation. A first model developed in 2006 by Rohleder [26] to model patient service centers using simulation techniques. In fact, this method enables to simulate discrete events in a descriptive and flexible way and accommodate the demand structure of this particular situation. The results are used to analyze the configuration of the service centers and estimate the resources needed to meet the demand within the recommended waiting time. In addition, one objective of this research was to develop a model for a new, larger service center that would improve operations and resource utilization. After reviewing various scenarios and adjusting the data to the most recent information, a representative model was used when the new service center was created, but had to be readjusted due it is expected increase of demand. Hence, the importance of understanding that modeling a health system is an ongoing process and that a comprehensive dynamic model would be the best way to predict and understand real outcomes.

Jlassi [27] developed a simulation model to model the patient's journey within the emergency department of Habib Bourguiba hospital in Sfax, Tunisia. At the end of their study, they found a great disparity in the durations of various activities of the emergency department, in this respect they gave some explanation of these disparities, which are of human origin (medical and paramedical personnel infusing), Equipment (lack of radiology equipment) and infrastructure (emergency department too small) and then proposed scenarios for improvement.

Rohleder and Lewkonia [28] used a simulation model to reduce the patient's waiting time in an orthopedic outpatient department. For this purpose, they proposed scenarios for improvements that are based on adding new resources and reviewing appointments. Similarly, in the orthopedic service, Chantal [29] proposed a model based on discrete event simulation. This model generated three improvement scenarios in connection with the appointment planning, the patient's trajectory and the increase in the number of orthopedic surgeons in order to reduce the time spent by patients in the clinic.

Santos [30], in a center in British Columbia in 2013, focused on the problem of modeling the pathway of patients with acute spinal cord injury. By studying three typical scenarios, they found that modeling the system highlights the indirect impact of several medical and administrative interventions, both upstream and downstream of the continuum of care. The practical results reduced the length of stay and decreased the use of rehabilitation beds.

In 2010, Rodier [31] developed a model of patient flows in France, while taking into account several parameters such as the patient's journey, human and material resources, such as bed capacity. The proposed model is based on discrete event simulation method and allows defining and implementing performance indicators to facilitate decision-making from the point of view of the managers.

Ramis [32] used a Flexsim GP simulator to shorten the imaging center waiting time. In four hospitals in Chile, the researchers identified all the flows, resources, schedules and exams. After comparing seven configurations, they were able to reduce the total patient waiting time by 35% without changing the staff, but the assignment of common functions. Therefore, the productivity of a center can be increased by 54%, assuming infinite demand.

Al Araidah [33] studied outpatient consultations at a local hospital in Tehran, Iran. The researchers used a discrete event simulation model with total time and service time in the stations as data. The statistical comparison was also used to confirm the performance model proposed for the current system. The results showed that many improvement scenarios can be applied to the reduction of waiting time of up to 29% and a reduction in the total visit time by 19% without purchasing any new resources.

Ahmed and Alkhamis [34] developed simulation and optimization model to design an aid decision tool for an emergency service in a governmental hospital in Kuwait. The main contribution of this article is the increase of the patient's flow by 28% and the reduction of the average patient's waiting time by 40%.

Ping-Shun Chen [9] proposed simulation based optimization models to analyze the patient routing mechanisms. The objective of the study is to obtain the best possible number of patients with the minimum average waiting time and the maximize income of both hospitals in Taiwan. The results can build patient's referral mechanisms between two hospitals.

In this work, our objective is not to maximize the number of patients because the outpatient clinic must satisfy all the received demand. But, we aim to respond to this demand with the minimum average waiting time and therefore minimizing the average total time spend in the service. A discrete event simulation model is proposed and used to evaluate the sources of dysfunction of the actual system and to identify the components the most sensitive to change and to improve.

2. Description of service

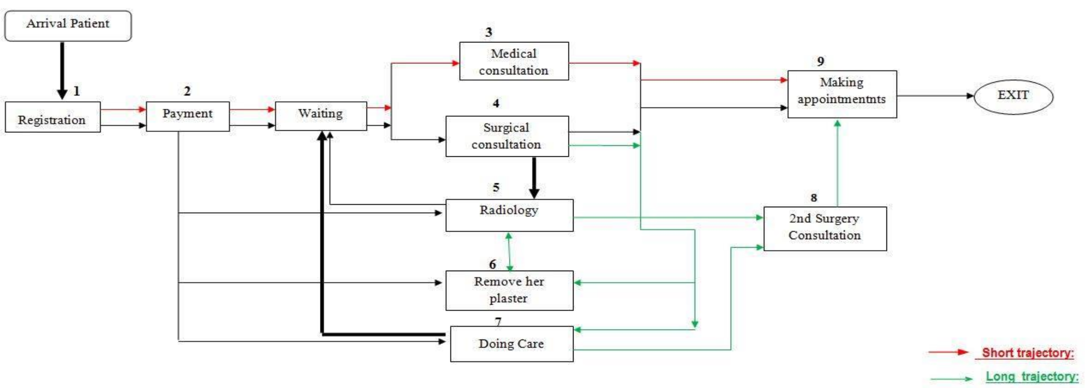
The study we conducted enabled us to understand the functioning of the actual system and identify the data necessary to model the patient trajectories. Indeed, from a structural point of view, the outpatient orthopedic surgery department has 7 functional sub-assemblies: admission, consultation of surgery (Resident), consultation of medicine (assistant), plaster room, radiology and treatment room. The table below shows the distribution of human and medical resources associated with each functional set.

Table N°1 . Breakdown of resources by outpatient department of orthopedic surgery

Rooms	Things to Do	Medical staff
Reception	Rgistration and payment	2 Input operator
		2 cashiers
Rooms For Surgery	Surgical consultation	Three residents
Medical consultation rooms	Medical consultation	2 assistants
Room service	Care	A nurse
Plaster room	Plaster	A nurse
Radiology	Radio	A nurse
Meeting room RDV	Making appointment	A nurse

The pathway of patients in the outpatient orthopedic clinic can be summarized in the following figure (Fig.1). The rectangles represent the steps of the process (tasks) while the arrows represent the movements within the service.

Fig. N°1 . The pathway of patients in the outpatient orthopedic clinic



Any patient arrives to this service must be registered. He then moves to the cashier, this action notifies the nurses that the patient has arrived. After that and depending on the case, the patient is called by the nurse to:

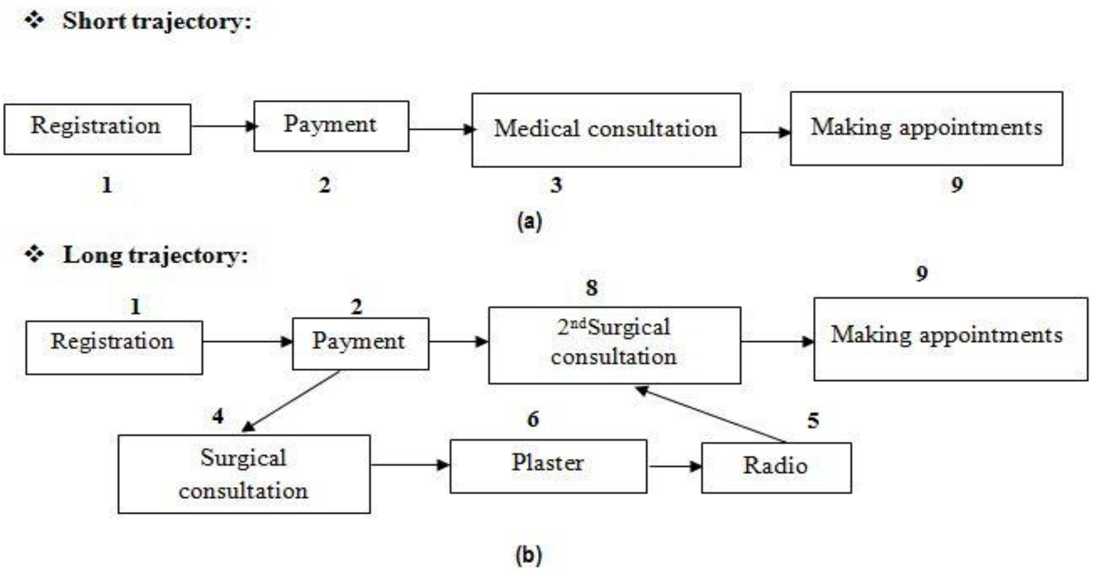
• To be referred to the radiology department,

• Remove the plaster and be directed to the radiology department or

• To directly meet the orthopedist (assistant or resident).

Once the patient has switched to radiology, he deposits a white paper to the payment for that purpose. This action, warns the nurse that the patient is ready to meet the orthopedic surgeon. Following his meeting with the orthopedic surgeon, if the consultant is resident, the patient may be redirected back to the plaster room and resume the same route until he returns to his orthopedist for a second visit in the following resident called 2nd passage). Alternatively, the patient may take an upcoming appointment (as required) and leaves the service. Two types of trajectories can be disengaged from this figure and schematized as follows (Fig. 2):

Fig.N° 2. Short (a) and Long (b) trajectories



3. Discrete event simulation model

Discrete event simulation is a technique used to model an observed process. On the basis of field data, it is possible to develop a basic model that reflects the observed reality. This basic model, when verified and validated, becomes an important decision-making tool because it helps visualize the changes without disrupting the activities of the observed process. In the table below we present the statistical distributions on which we are based on to model the service time at each stage of the process. This time includes the waiting time and the service time. These distributions are released using the "Input Analyzer" module of the ARENA simulation software, which is specially designed to adjust the theoretical distributions to the observed data by estimating their parameters (Table2).

Table N°2. Statistical distributions used in simulation model.

Task	Statistical distribution (minutes)
Arrival Patient	EXPO(5)
Registration	TRIA (1, 2,3)
Payment	TRIA (1, 2,3)
Medical Consultation	TRIA (5,10, 15)
Surgical Consultation	TRIA (5,10, 15)
Doing care	TRIA (5, 7,10)
Plaster room	TRIA (5,10, 15)
Radiology	TRIA (5, 7,10)
Making appointments	TRIA (0.5, 1,1.5)

The REAL model was used to validate our results and ensure that they represent the observed reality. The theoretical (basic model) model was used to generate improvement solutions. By running our simulation model during 100 replications of 24 hours, we obtained the different estimated times. A comparison is made, in terms of the time to be served (this variable contains the waiting time in front of each step of the process plus the service time), between what is observed and what is simulated to verify the validity of the model. The results of the comparisons are presented in the following table (Table 3).

Table N° 3. Comparison results between real and simulated models.

	Registration	Payment	Medical consultation	Surgical consultation	Radiology	Plaster room	Care	Making appointments
Average Observed Time (minutes)	122.04	56.63	53.00	150.01	14.93	24.86	11.01	1.0
Average simulated time (minutes)	122.08	56.00	53.33	153.10	14.15	24.63	11.00	1.75
Difference (in minutes)	0.04	0.63	0.33	3.09	0.78	0.23	0.01	0.75

As mentioned in table 3 differences between the times observed in the field during our data collection and the simulated ones (obtained according to the actual arrival times of the patients) are less than 5 minutes. These results confirm the validity of the simulation model.
After having detected the possible sources of the long total time passed in the service (that due to the long time spend in admission and consultation) and after confirming the validity of our simulation model, we can then suggest a set of propositions that can improve the functioning of the care process:

- Increase the number of registration officers.
- Increase the numbers of cashier agents
- Adding new medical assistant
- Adding new residents

4. Optimization Model

Our objective is to minimize the average patient's waiting time for both trajectories (long and short) with the minimum cost generated by the addition of new staff. Thus, we have three sub-objectives to achieve which are: the minimum waiting time for the short patient's trajectory, the minimum waiting time for the long patient's trajectory and the minimum cost of service.

4.1. Mathematical models

In this section, we describe in detail the mathematical models that formulate our sub-objectives:

Indices:

J: Types of the personnel in the outpatient orthopedic surgery.

I: Patient's index.

N: Number of patients.

L: number of tasks in the outpatient orthopedic surgery.

LC: Long patient's trajectory.

CC: Short patient's trajectory.

D: Duration of a session

Parameters:

Q: Maximum waiting time in the outpatient orthopedic surgery

X_i: Average cycle time of patient i.

Y_j: Number of staff j in the outpatient orthopedic surgery.

Uj: Represents the upper limit of the number of staff j in the outpatient orthopedic surgery.

Decision variables:

WT_i: average waiting time of patient i.

$WTLC_{il:}$ Average waiting time of patient i at task l in long trajectory.

$WTCC_{il}$: Average waiting time of patient i at task l in short trajectory.

TOT Cost: The total cost of adding new staff.

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Optimization model 1:

Z_1 = Min E (WTLC) (1)

S/C:

$WTLC = (\sum_{i=2}^{N} \frac{WTLCil}{6})$ $\forall\ i = 1 \dots N;\quad l = \{1,2,4,5,6,9\}$ (2)

$0 \leq\ Xi \leq D$ $\forall\ i = 1 \dots N$ (3)

$WT_i\ \leq Q$ $\forall\ i = 1 \dots N$

(4)

$Y_j \leq U_j$ $\forall\ i = 1 \dots N;\ \ \forall\ j = 1 \dots J$ (5)

The objective function (1) seeks to minimize the average waiting time in the long patient's trajectory. The constraints (2) determine the waiting time in the long patient's trajectory. Constraints (3) determine the average cycle time of patients at a session time. Constraints (4) represent the mean waiting time of patients in the outpatient department of the orthopedic surgery, which must be less than or equal to the maximum allowable waiting time, Q. The constraints (5) ensure that the number (Y_j) of added personnel in the outpatient orthopedic surgery should not exceed the upper limit (U_j).

Optimization model 2:

Z_2 = Min E (WTCC) (6)

S/C:

$0 \leq\ Xi \leq D$ $\forall\ i = 1 \dots N$ (3)

$WT_i\ \leq Q$ $\forall\ i = 1 \dots N$

(4)

$Y_j \leq U_j$ $\forall\ i = 1 \dots N;\ \ \forall\ j = 1 \dots J$ (5)

$WTCC = (\sum_{i=2}^{N} \frac{WTCCil}{4})$ $\forall\ i = 1 \dots N;\quad l = \{1,2,3,9\}$ (7)

The objective function (6) consists of minimizing the average waiting time of short patient's trajectory. The constraints (7) determine the waiting time for the short patient's trajectory. Constraints (3, 4 and 5) are common constraints between model1 and model2.

Optimization model 3:

Min Z = TOT Cost

(11)

S/C:

WTLC $\leq$ 93

(12)

WTCC $\leq$ 78 (13)

The objective function (11) aims to minimize the total cost caused by the addition of new staff to the outpatient orthopedic surgery. The constraint (12) ensures that the average waiting time of long patient's trajectory should be less than 93 minutes on average. Constraint (13) ensures that the average waiting time for short patient's trajectory should be less than 78 minutes on average. In fact, these values (93 and 78) correspond to the real average waiting time spent by patient (in short, respectively long, patient's trajectories) in the outpatient orthopedic surgery.

4.2. Simulation-based optimization

To reflect these advances in simulation-based optimization, simulation software publishers have integrated experimental research and optimization research modules into their simulation packages. Examples: AutoStat, AutoMod, Witness optimizer and OptQuest tool of Arena. The objective of using simulation-based optimization to improve performance and meet a number of objectives that are often contradictory, such as reducing cost with maximizing the use (Physical and human) resources, improving the quality of care by providing effective diagnostic systems. The majority of researchers used the Arena OptQuest tool and followed the simulation optimization algorithm formulated by Klassen and Yoogalingam [35].

In this work, we apply the discrete event simulation (DES) using the ARENA software. This includes collecting and editing data, constructing DES models and checking them. At the same time, the optimization part of this study is carried out using the OptQuest optimizer. Relevant steps in this phase include determining system variables, defining objective functions and specifying linear constraints on system variables, and some performance measures (sometimes called objective functions). Then, a search algorithm is applied to find the optimal solution. The last step occurs at the end of each cycle of the simulation model used for objective function evaluation.

Through direct interviews with some officials in the department and with the financial director of the hospital, the most important indicators that we need to take into account in our study are:

- The cost of each new agent or added specialist
- Waiting time for a patient

Table N°4 . Lower and upper bounds of personnel in the outpatient orthopedic surgery.

Variable	Lower bound	Upper bound
Registration	2	4
Cashier	2	4
Assistant	2	4
Resident	3	4
Plaster	1	2
Radiologist	1	2
Care	1	2

Table 4 defines the lower and upper bounds of each type of personnel in the outpatient orthopedic surgery. These values allow us to fix the upper limits in OptQuest resource's parameters.

5. Results and discussions

5.1. First objective: minimizing the average wait time for short patient's trajectory

In the following table (table 5) we indicate the best results obtained for the short patient's trajectory using OptQuest. The proposed solutions are too closer to each other's. They are ranging from 55.98 to 56.83 minutes.

Table N° 5 . The list of best solutions for the short patient's trajectory obtained by OptQuest.

	Registration	Payment	Resident	Assistant	Short- trajectory
solution1	3	2	3	2	56.37
solution2	3	3	3	3	56.37
solution3	3	4	3	3	56.37
solution4	3	2	4	2	56.83
solution5	2	2	3	3	55.98
solution6	4	2	4	2	56.83
solution7	3	2	4	3	56.83
solution8	4	2	4	3	56.83

5.2. Second objective: minimizing the average wait time for long patient's trajectory

We indicate the result using the OptQuest for the long patient's trajectory in the following table (Table 6):

Table N°6. The list of best solutions for the long patient's trajectory obtained by OptQuest.

	Registration	Payment	Resident	Assistant	Long- trajectory
solution1	3	2	3	2	80.19
solution2	3	3	3	3	80.62
solution3	3	4	3	3	80.62
solution4	3	2	4	2	81.30
solution5	2	2	3	3	81.60
solution6	4	2	4	2	81.30
solution7	3	2	4	3	81.30
solution8	4	2	4	3	81.30

The table above gives a list of eight best solutions generated by OptQuest tool. Similarly to table 6, solutions are also too closer to each other's and ranging from 80.19 to 81.30 minutes.

5.3. Third objective: minimizing the outpatient orthopedic surgery service cost

After running the OptQuest for the third sub-objective, we gathered the following results presented in the table below (Table 7). Solution is ranged from 10200 and 13800 Dinars per month.

Table N° 6. The obtained result using the OptQuest for cost.

	Registration	Payment	Resident	Assistant	Cost

solution1	3	2	3	2	10200
Solution2	3	2	4	2	11400
Solution3	2	2	3	3	11400
Solution4	4	2	4	2	12000
Solution5	3	3	3	3	12600
Solution6	3	4	3	3	13200
solution7	3	2	4	3	13200
solution8	4	2	4	3	13800

5.4. results for a multi-objective problem

Our problem is multi-objective in which we aim to simultaneously minimize the average waiting time in the short and long patient's trajectories and minimize the potential additional cost generated by adding new personnel to the outpatient orthopedic surgery. Therefore the solution consists of finding a compromise between these three sub-objectives in order to meet patient's satisfaction and respond to administration restrictions.

Table 8 below gives the different best solutions of the 3 objectives:

Table N°7. Result of the 3 objectives using Optquest.

	Registration	Payment	Resident	Assistant	Average waiting time		
					Short- trajectory	Long-trajectory	Cost
Based solution	2	2	3	2	77,86	92,62	9600
solution1	3	2	3	2	56,83	81,3	10200
Solution2	4	2	4	2	56,83	81,3	12000
Solution3	3	3	3	3	56,37	80,62	12600

Table 8 gives a list of three best solutions that minimizes simultaneously the average waiting time for both short and long trajectories with the minimum cost, the best scenario remains conditioned by the budgetary constraint

Conclusions and future research

In this paper, we are interested in patient's trajectories within the outpatient department of the orthopedic surgery in Habib Bourguiba Sfax Hospital. The aim of this work is to reduce the average patient's waiting time with the minimum cost of service. In this context, we present a description of the outpatient service and the patient's trajectories during the care process. The system is described and imitated using a DES model developed with ARENA software. A comparison was conducted between the collected data and the simulated ones in order to validate this model and ensure that it represents the observed reality. A set of scenarios are proposed to improve the functioning of the care process. The obtained results have shown a reduction of the average waiting time in the two types of trajectories with a minimum cost and the choice of the best scenario remains conditioned by the budgetary constraint. In future work, we will focus on the coordination between the emergency and the orthopedic services in order to well manage the patients flow and for a best appointment scheduling system.

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