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Simulation based optimization models to allocate personnel and reduce the expected waiting time in an outpatient medical service

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Abstract— ***Outpatient services are one of the most congested hospital divisions because they combine consultation, care and follow-up activities. In such system, as in the external orthopaedic surgery department of the Habib Bourguiba in Sfax, patients have to wait for too long and this for several stages of the process such as registration, consultation and payment.***

A major problem in this case is the adequacy between the current and the required number of personnel. Indeed, allocating a number of personnel more than the need may lead to reduce the waiting time of patients but the related cost may increase and vice versa. Furthermore, the staffing level i.e. number of personnel, depends on the number of patients arriving at each day as well as the task requested to serve each one. In fact, in such system, the arrival of patient is random and the most of operation are unpredictable. Thus, it will be difficult to define the appropriate number of personnel to allocate for this type of system.

In this paper, we present a mathematical model and a simulation optimization method to define the number of personnel to allocate in the external orthopaedic surgery department of patients in Habib Bourguiba Hospital of Sfax. The proposed method permits to take into account the stochastic behavior of the system induced by random times and unexpected operations.

The objective of this study is to minimize the average waiting time of patients with the minimum cost of services. The result of this problem can be used to improve the ambulatory care clinic with better quality care.

Keywords: ***surgery consultation service, Simulation, Optimization, patient flow, average waiting time.***

I. Introduction

Patient waiting time for healthcare services is identified by the World Health Organization (WHO) as one of the key measurements of a responsive health system. 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 orthopaedic surgery of the Habib-Bourguiba hospital of Sfax.

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present a mathematical model and a simulation optimization method to define the number of personnel to allocate in the external orthopaedic surgery department of Habib Bourguiba Hospital in Sfax. The proposed method permits to take into account the stochastic behavior of the system induced by random times and unexpected operations.

The remainder of the paper is organized as follows: In section (2), we present a brief review of the literature related to our subject. Section 3 states the problem definition. Section 4 depicts the architecture of the proposed methods and the design of experiments for testing and presents analysis of results. Section 5 present the conclusions and gives some future perspectives.

II. 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 academic's researches and practitioners over the past 60 years. This interest began with the famous work of Bailey [1]. 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 [2] 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. The author studied a single server system with exponential service time, with the objective of minimizing 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 [3]; Achour [4]; Dehas [5]; Ping-Shun Chen [6]; Glaa [7]; Tao [8]; Belaidi [9]; Jlassi [10]), operating theater (Marcon[11]; Millard [12]; Ramis [13]; Tyler [14]), surgery (Vasilakis and Kuramoto[15]), nursing units (Gascon [16]), maternity care at home (Nidhal Rezg [17]), imaging (Mebrek [18], Moussa and Belkadi, [19]), hospital logistics (Aleksy [20]), the stomatology department (Belkadi, and Tnaguy [21]) 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 [22] presented a simulation model of the patient flow in the emergency department by the Structured Analysis and Design Technique. 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 [23] 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 [24] developed a simulation 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 [25] 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 orthopaedic service, Chantal [26] 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 [27], 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.

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Vol.11 pp.40-48

In 2010, Rodier [28] developed a model of patient flows in France, while taking into account several parameters such as the patient's journey, human and material resources, 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 [29] 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 [30] studied outpatient consultations in 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 [31] 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 [6] 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 to 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. Simulation and Optimization have been considered by several authors for this type of problem. The difference is always in the way these techniques are used. Usually simulation is used to reproduce the behavior of health care system in order to evaluate its performance and analyse the outcome of different scenarios. In this paper, we used a discrete event simulation tool to evaluate the sources of dysfunction of the actual system and to identify the most sensitive components to change and to improve. Approximate mathematical model of the system was derived using the OptQuest tool of Arena software. The later is used to give a list of feasible solution that contains the best one of them for each of objectives.

III. PROBLEM DESCRIPTION

A. DESCRIPTION OF SERVICE

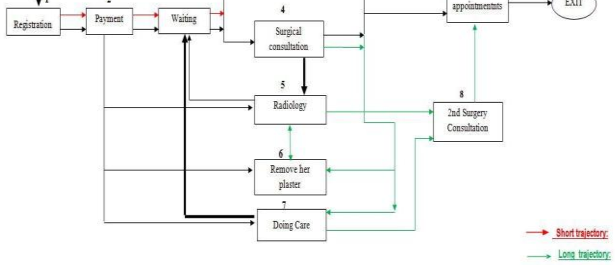
In order to understand the functioning of the actual system and identify the data necessary to model the patient paths in the orthopedic outpatient clinic of Habib Bourguiba Hospital, we conducted an on-filled survey from 04/01/2016 to 05/02/2016 for an average of 200 patients per day. This survey allowed us to collect statistics on patient's arrivals and service times that helped us to determine the arrival rates of patients during different days of the week and the distribution of service times at each stage of the service. 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 (table 1) shows the distribution of human and medical resources associated with each functional set.

TABLE I

BREAKDOWN OF RESOURCES BY OUTPATIENT DEPARTMENT OF ORTHOPAEDIC SURGERY (ABDELMONEEM [32])

Rooms	***Things to Do***	***Medical staff***
Reception	*Rgistration and payment*	*2 Input operators* *2 Payments*
Rooms for Surgery	*Surgical consultation*	*3 residents*
Medical consultation rooms	*Medical consultation*	*2 assistants*
Room service	*Care*	*A nurse*
Plaster room	*Plaster removal*	*A nurse*
Radiology	*Radio*	*A nurse*
Meeting room RDV	*Making appointment*	*A nurse*

As mentioned in section (1) patient may have to follow different paths through the same set of services. These moves may be divided into two mains pathways as summarized in the following figure (figure1). The rectangles represent the steps of the process (tasks) while the arrows represent the movements within the service.



ISSN 2356-5608

Fig. 1 The pathway of patients in the outpatient orthopaedic clinic Abdelmoneem [32]

Any patient arrives to this service must be registered. He then moves to the payment; 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:

- 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.

B. PROBLEM FORMULATION

The notation of the model is presented as follows:

- Indices:

i: index of patients.
j: index of the number of service in the external service of orthopaedic surgery
M: Number of service
N: Number of patients.

- Parameters:

B: the upper limit of the budget available to operate the service
Q: the upper limit of waiting time in the service
L j: the lower limits of the number of service j in the service
U j: the upper limits of the number of j in the service
Decision Variables:
X_j : represents the number of service.
C_j : represents the external service cost of orthopaedic surgery

WT_i: the average service time of patient i.

- Optimization model 1: minimizing the service time

$$Z = \text{Min} \sum_{i=1}^{M} WT_i \qquad (1)$$

S/C:

$$\sum_{j=1}^{N} C_j X_j \leq B \qquad (2)$$

$$\sum_{i=1}^{M} WT_i \leq Q \qquad (3)$$

$$L_j \leq X_j \leq U_j \qquad (4)$$

The objective function (1) seeks to minimize the average service time of the patients. Constraints (2) ensure that the total cost of adding new personnel staff should not exceed the upper bound of the budget available to operate the service.

Constraints (3) determine the mean service time of patients i, which must be less than or equal to the maximum allowable service time, Q. The constraints (4) ensure that the number X_j of added new staff personnel j should not exceed the upper limit U_j.

IV. METHODOLOGY

A. SIMULATION-BASED OPTIMIZATION

Simulation is increasingly used in the design and organization studies of complex systems. 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.

To reflect these advances in simulation-based optimization, simulation software publishers have integrated experimental research and optimization research modules into their simulation packages. Examples: Auto Stat, Auto Mod, Witness optimizer and OptQuest tool of Arena Klassen and Yoogalingam [33]. The majority of researchers used the Arena OptQuest .

OptQuest is a generic optimizer that makes it possible to separate successfully the optimization solution procedure from the simulation model. The optimization procedure uses the outputs from the simulation model to evaluate the inputs of the model. The optimization procedure then uses a search algorithm, where the successively generated inputs produce varying evaluations, not all of them improving, but which over time provide a highly efficient path to the best solutions. The process continues until it reaches some termination criterion.

OptQuest uses the elements of controls, responses, constraints, and objectives in searching for optimal solutions. These elements are discussed in the following section.

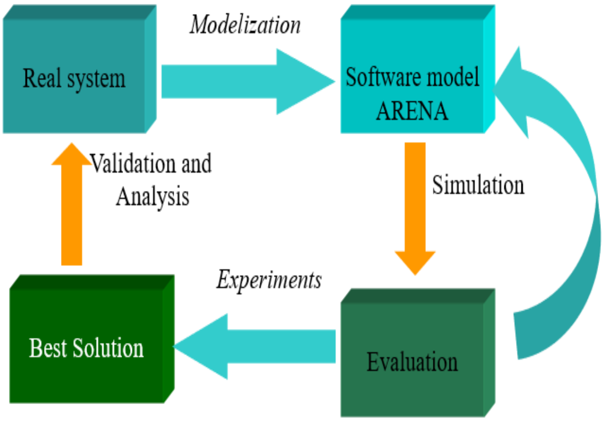


Figure 2 Framework for Simulation-based optimization

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.

B. 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 II

Statistical Distributions Used in Simulation Model

Task	**Statistical distribution (minutes)**
Arrival Patient	*EXPO(5)*
Registration	*UNIF(1, 5)*
Payment	*UNIF(1,5)*
Assistant	*UNIF(5,20)*
Resident	*UNIF(5,20)*
Doing care	*TRIA (5, 7,10)*
Plaster removal	*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 model (basic 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).

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 6 minutes. These results confirm the validity of the simulation model.

TABLE III

Comparison Results Between the Real and the Simulated Model

ISSN 2356-5608

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

C. Results

Given the objective, design constraints and response constraints, OptQuest within ARENA was used to implement the optimization approach proposed in this study. This was done by firstly using the design variable values in the present system as an initial solution. The feasibility of this solution is determined by checking if the design constraints are satisfied, otherwise a new set of design variable values that satisfy the design constraints is searched at a given step size. After selecting appropriate values for the design variables, OptQuest must invoke Arena to run a simulation and determine whether or not the current trial solution is feasible with respect to the response constraints, otherwise a new solution that satisfies both the design and response constraints is searched. If a feasible solution is found, a new solution that yields better system performance results is sought. This process continues until all the design variable possibilities are exhausted or a predetermined time limit is reached.

Task	**Average Observed Time (minutes)**	**Average simulated time (minutes)**	**Difference (in minutes)**
Registration	170.5	171.5	0.5
Payment	112.0	114	2.0
Assistant	70.0	72.85	2.85
Resident	112.0	113.69	1.69
Doing care	8.0	8.93	0.93
Plaster removal	13.0	13.03	0.03
Radiology	8.00	8.93	0.93
Making appointments	1.00	1.09	0.09

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.

TABLE IV

LOWER AND UPPER LIMITS OF THE NUMBER OF DIFFERENT PERSONNEL RESOURCES

Variable	**Lower bound**	**Upper bound**
Registration: X_1	*1*	*3*
Payment: X_2	*1*	*3*
Assistant: X_3	*1*	*4*
Resident: X_4	*1*	*5*
Plaster: X_5	*1*	*2*
Radiologist: X_6	*1*	*2*
Care: X_7	*1*	*2*

TABLE V

TABLE OF SALARIES (TND/MONTH)

	Agent	**Assistant**	**Resident**	**Nurse**
Salary	*600*	*1800*	*1200*	*900*

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Management of Business Process (ESMB)
Vol.11 pp.40-48

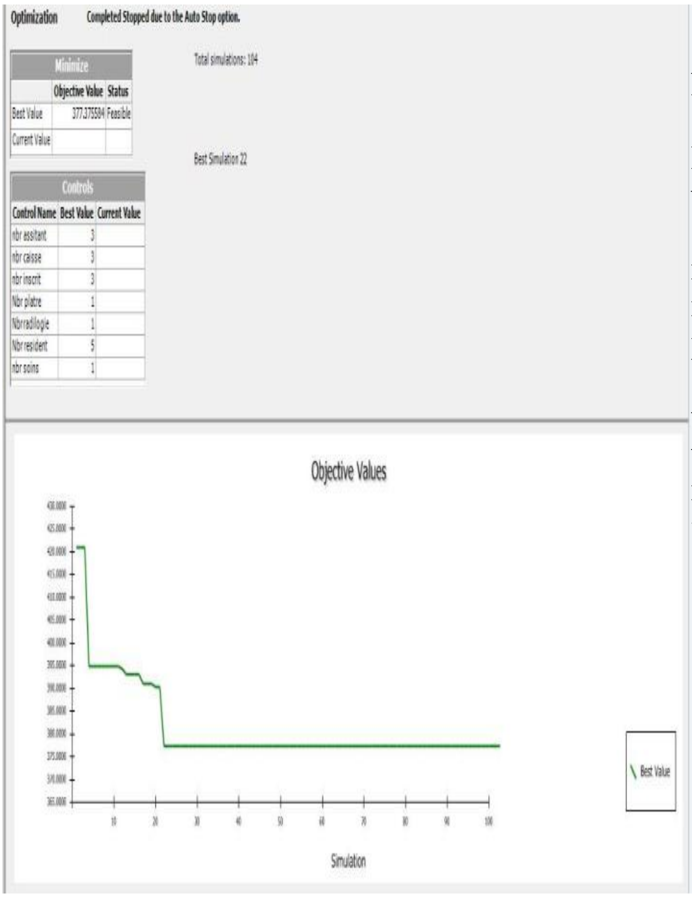

Figure 3.View the optimization results as OptQuest searches for the optimal result.

The theoretical model (basic model) was used to generate improvement solutions. By running our simulation model during 100 replications of 24 hours, we obtained the different estimated times.

In the following table (table 6) we indicate the list of feasible solution obtained for the patient's waiting time using OptQuest. The proposed solutions are too closer to each other's. They are ranging from 377.37 to 403.94 minutes. Results of model simulation and optimization showed that performance of the optimized department of the orthopaedic surgery was better overall compared to the current department. Consequently Solution 1 is the best solution, waiting time was reduced the most by 377.77min on average, the total revenue for the optimized department of the orthopaedic surgery was increased by 17700 TND/MONT.

TABLE VI

THE LIST OF FEASIBLE SOLUTION OBTAINED FOR THE PATIENT'S WAITING TIME USING OPTQUEST

ISSN 2356-5608

	Registration: X_1	**Payment: X_2**	**Assistant: X_3**	**Resident: X_4**	**Plaster: X_5**	**Radiologist: X_6**	**Care: X_7**	**Average waiting time**	**cost**
Based Solution	*2*	*2*	*2*	*3*	*1*	*1*	*1*	*418,31*	*12300*
Solution1	*3*	*3*	*3*	*5*	*1*	*1*	*1*	*377.37*	*17700*
Solution2	*2*	*3*	*4*	*4*	*1*	*1*	*1*	*383.5*	*17700*
Solution3	*2*	*2*	*2*	*5*	*1*	*1*	*1*	*388.34*	*14700*
Solution4	*2*	*3*	*3*	*5*	*1*	*1*	*1*	*390.23*	*17100*
Solution5	*3*	*2*	*4*	*5*	*1*	*1*	*1*	*390.33*	*18900*
Solution6	*3*	*3*	*2*	*5*	*1*	*1*	*1*	*391.08*	*15900*
Solution7	*2*	*3*	*2*	*5*	*1*	*1*	*1*	*391.54*	*15300*
Solution8	*2*	*2*	*3*	*5*	*1*	*1*	*1*	*391.91*	*16500*
Solution9	*3*	*2*	*3*	*5*	*1*	*1*	*1*	*392.14*	*17100*
Solution10	*2*	*2*	*3*	*4*	*1*	*1*	*1*	*393.08*	*15300*
Solution11	*3*	*3*	*1*	*5*	*1*	*1*	*1*	*393.09*	*14100*
Solution12	*3*	*3*	*1*	*4*	*1*	*1*	*1*	*394.31*	*12900*
Solution13	*3*	*3*	*3*	*4*	*1*	*1*	*1*	*394.67*	*16500*
Solution14	*3*	*3*	*4*	*5*	*1*	*1*	*1*	*394.9*	*19500*
Solution15	*3*	*2*	*1*	*5*	*1*	*1*	*1*	*395.06*	*13500*
Solution16	*3*	*2*	*2*	*5*	*1*	*1*	*1*	*395.21*	*15300*
Solution17	*1*	*3*	*3*	*5*	*1*	*1*	*1*	*396.75*	*16500*
Solution18	*1*	*2*	*3*	*5*	*1*	*1*	*1*	*397.71*	*15900*
Solution19	*3*	*2*	*2*	*4*	*1*	*1*	*1*	*397.95*	*14100*
Solution20	*2*	*3*	*2*	*4*	*1*	*1*	*1*	*398.11*	*14100*
Solution21	*2*	*2*	*4*	*5*	*1*	*1*	*1*	*399.69*	*18300*
Solution22	*3*	*1*	*4*	*5*	*1*	*1*	*1*	*401.92*	*18300*
Solution23	*2*	*2*	*4*	*4*	*1*	*1*	*1*	*402.9*	*17100*
Solution24	*1*	*1*	*3*	*5*	*1*	*1*	*1*	*403.57*	*15300*
Solution25	*3*	*2*	*1*	*4*	*1*	*1*	*1*	*403.94*	*12300*

V. CONCLUSIONS

This article elaborates an approach for enhancing the performance department of the orthopaedic surgery in Habib Bourguiba Sfax Hospital.

The department of the orthopaedic surgery was represented by a DES model developed with the aid of ARENA software and supplemented with the gathered and fitted experimental data. OptQuest of ARENA was used to implement the optimization for the selected design variables to improve performance of the current system.

The optimization process included defining a suitable objective function is to reduce the average patient's waiting time of service.

Results of model simulation and optimization showed that performance of the optimized department of the orthopaedic surgery was better overall compared to the current department. Consequently Solution 1 is the best solution, waiting time was reduced the most by 377.77min on average, the total revenue for the optimized department of the orthopaedic surgery was increased by 17700 TND/MONTH.

Future studies can continue this line of research by focusing on the coordination between the emergency and the orthopaedic services in order to well manage the patients flow and for a best appointment scheduling system.

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