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Simulation and multi-criteria evaluation of hospital emergency department: A case study

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***Abstract*—The performance of the hospital is strongly attached to the overall performance of its departments, including the emergency department. The emergency department is the most usable, touched and solicited place that has as objective to be able to immediately treat symptoms of urgent aspect. Therefore, studies and research must be directed to the improvement of the various services provided by the latter. The main challenge of this research is to develop a model that gives the possibility to use it to diagnose the current system and the proposed improvement actions. A real emergency department in Tunisia is modeled and simulated using ARENA simulation software. After the generation of several improvement actions with the ARENA software and in order to help the decision-makers to choose the action that achieves their objectives, a decision support method (AHP) is implemented. The latter takes action which has the highest importance score as the suitable solution.**

***Keywords*—Emergency department, modeling, simulation, AHP, decision criteria**

I. Introduction

In recent years, hospitals have been faced with a change imposed by their users. This change should guide their management in setting up a more effective organization and forcing them to move towards a much more objective and scientific management of resources. Emergency is an essential mission of the hospital, one of the characteristics of which is its ability to cope with all the needs expressed by the population whatever the nature of treatment. Indeed, the emergency department (ED) is one of the most complex health care systems, which presents a large part of the economic budgets for health services.

The ED is seen as one of the main health systems for improving access to health services. It is open 24/24h and every day. It allows taking charge, under the responsibility of a qualified and experienced doctor, any person present in emergency service.

The objective of an emergency department is to ensure rapid and qualitative care of patients while managing the resources of the hospital system.

II. Interest of Simulation to Improve Health Systems from Literature

According to Sheldon et al. [1], discrete event simulation has been shown to be effective as a decision support tool for optimizing resources and improving patient flows in the health care system.

Lowery [2] explained how discrete event simulation is more suited to health care systems through both the inherent uncertainty and the potential complexity of interaction of the parties in the modeled system.

Discrete event simulation (DES) has been widely used to solve organizational problems in hospitals over the past 20 years [2].

According to Günal and Pidd [3], for many years, a DES has been used extensively in modeling health care systems and an analysis of simple citations shows that the number of published articles has clearly increased since 2004. Also, Mustafa et al. [4] produced a depth study on the simulation of health in the literature. They found that no fewer than 51 articles published between 1970 and 2007 have used DES in application to health.

A DES was presented as a health care management analysis tool to support health care resource planning [5]. Brailsford et al. [6] considered that a DES allows healthcare managers in their decision-making to invest in potential treatments and technologies.

Jun et al. [7] used DES because of its ability to easily model sequential events and the availability of DES software. Kumar and Kapur [8] too used the simulation model in their study of nurses' time.

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Rossetti et al. [9] developed an Arena model to optimize physician planning in the emergency department. Another study [10] analysed the functioning of an emergency department with a management of patient flows. In [10], the authors attempted to focus on the simulation of an emergency service, taking into account the immediately related services. This study was carried out in anticipation of the construction of a new emergency department in order to increase the capacity of the hospital and to examine the flow of patients and especially their waiting times. A distribution of patients at admission was determined, depending on the mode of arrival (personal vehicle, ambulance, etc.) and complexity of the patient state.

Emergency departments in hospitals are still suffering from the accumulation problem, as indicated by numerous studies such as [11] and [12]. This leads to longer waiting times for patients and poor utilization of hospital resources, hence the need for studied management of the patient flow as well as the human and material resources used to provide patients. The organization, optimization and improvement of this service have been the subject of numerous research.

Lubicz and Mielczarek [13] developed a simulation model for a rural emergency services system in Poland. The main results of the model for decision support are total service time, call answer time as well as the average ambulance use. According to these authors, one of the advantages of using a simulation model is the incorporation in the model of several qualitative aspects which are very difficult to incorporate into an analytical model and which are very important for the final decisions at the strategic level (change of operating mode, purchases of new equipment, decentralization of functions, etc.).

Sullivan [14] provided a discrete event simulation model using ARENA software for an emergency casualty system. The model gave a decision support for how to do in the event of a tornado, evaluating different scenarios to determine the effect of different levels of disaster on decisions made. The author showed how the ambulatory response for tornado victims can be simulated.

Savas [15] proposed one of the first models for an ambulance system in New York. The author used a simulation model because of the complexity of the system and the level of required data to evaluate the values of important factors. they considered different level of data: the geographical distribution of calls, the frequency of calls, the location of the hospital, the time of the call, the number of teams, etc. this simulation can be an interesting tool to make the correct strategic decisions to improve the system. All of this research is based on a concrete emergency service influenced by local health policies, such as the organization of health, the management of hospitals and the allocation of human and material resources.

Wang et al. [16] used a simulator developed to evaluate improvement proposals in the context of the reorganization of emergency flows and the reallocation of resources such that the exploitation of simulation results not only highlights the efficiency and effectiveness of good proposals but also the counterproductive effect false proposals for improvement. The six proposals improvement have been modeled and simulated in an integral way in the simulator, the decision maker can choose a single scenario or a combination of several scenarios out of a total of 256 possibilities.

Belaidi et al. [17] proposed the hybridization of enterprise modeling and flow simulation methods to reorganize emergency services and, ultimately, to improve their performance. This approach is applied within the university hospital of Saint Etienne and it has identified a set of weak points of the current organization. Then, the authors proposed a new organization dedicated to control the flow of patients. This organization characterized by the introduction of a so-called rapid unit, it has brought good results in terms of reduction in take-over time and average length of stay.

In [18], an approach to help managers of emergency systems was proposed. This approach, coupled with flow simulation, allows to analyze the functioning of the emergency structure and to determine the parameters influencing the emergency management process.

Tao et al. [19] also presented an eight-step model (recording, triage and care, boxing, consultation and diagnosis, observation, patient mutation, hospitalization, follow-up care, exit formalities). This model made it possible to specify the process of patient flow in the emergency department of the hospital Saint Josef and Saint Lux. The simulation of this process was carried out using the Aris Simulation software. Taking into account the results of this simulation, they proposed the creation of a process of rapid management for the less urgent patients. This proposal requires the establishment of a physician in permanent post as well as a box.

Hannan et al. [20] analyzed different policies of administrative decision for the management of the emergency department.

In [21], a well-known problem of physical organization of emergency service is addressed. In order to reach at an optimal configuration of the service, a standard approach is described. Second, the constraints on the service itself (staff numbers, number of emergency

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beds) and patients (number of required beds, length of stay in the service) were fixed. Several optimizations can be proposed (duration of taking or laboratory examinations, assignment of beds, elimination of downtime, etc.).

III. MODELING AND DIAGNOSTIC OF THE CURRENT SYSTEM

III.1 DESCRIPTION AND MODELING OF ED: A CASE STUDY

Emergency department of Gabes in Tunisia is a non-profit public institution. It contains an administrative service window where patients register and pay. It also contains multiple rooms of different services: a waiting room, two monitoring rooms, a care room, two general practitioner consultation rooms and a specialist medical office, two internal rooms with multi-purpose services and a severing room intended only for serious illnesses, a suture room and a plaster room.

Each room is served by a single agent that served only one patient at a time. The emergency department is open 24/24 hours and every day. For this, the work does not end and must be organized in a very meticulous way. In addition, there are cases where the patient is referred to a hospital department other than the emergency department.

The studied emergency department can be modeled as in the following figure.

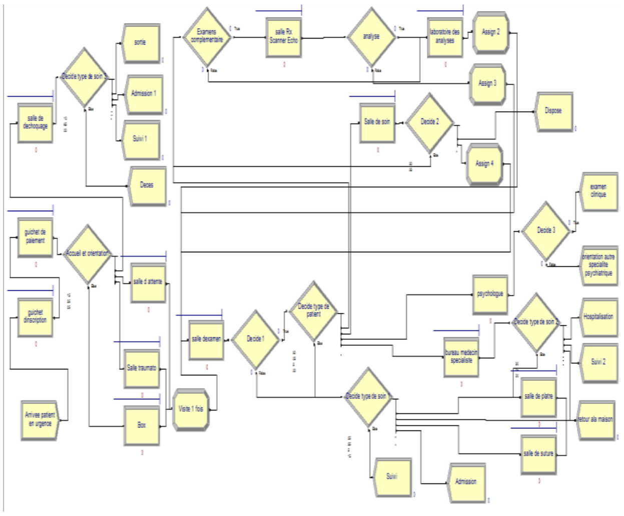
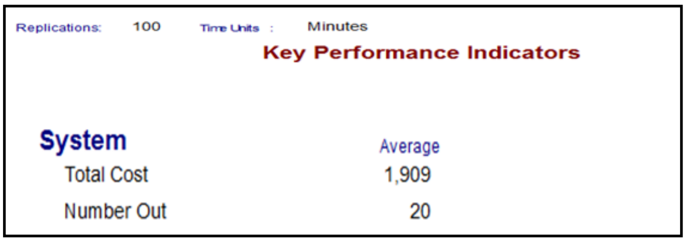


Fig. 1 Model of the current emergency department

III.2 DIAGNOSTIC OF THE CURRENT SYSTEM

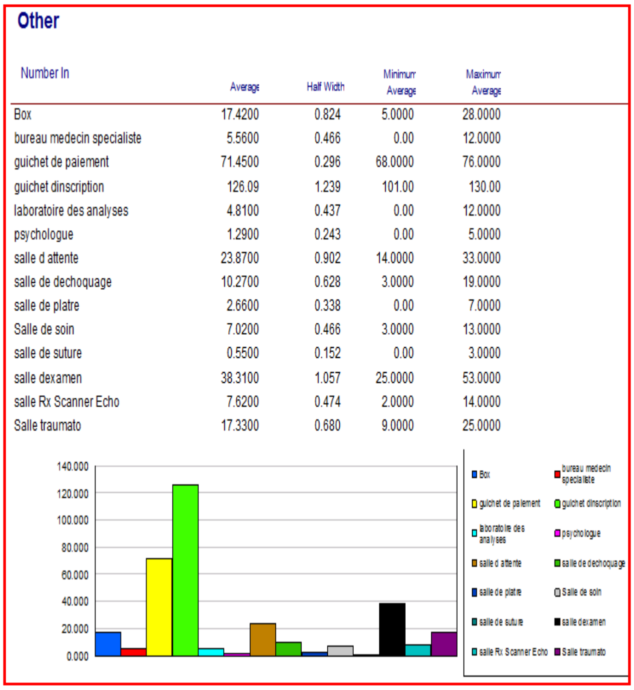

Replications: 100 Time Units : Minutes

Key Performance Indicators

System	Average
Total Cost	1,909
Number Out	20

Fig. 2 Total cost and number of patients discharged from a session

On average, the number of patients leaving the system is 20 during a session. A session costs 1909 DT.


Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Box	17.4200	0.824	5.0000	28.0000
bureau medecin specialiste	5.5600	0.466	0.00	12.0000
guichet de paiement	71.4500	0.296	68.0000	76.0000
guichet dinscription	126.09	1.239	101.00	130.00
laboratoire des analyses	4.8100	0.437	0.00	12.0000
psychologue	1.2900	0.243	0.00	5.0000
salle d attente	23.8700	0.902	14.0000	33.0000
salle de dechoquage	10.2700	0.628	3.0000	19.0000
salle de platre	2.6600	0.338	0.00	7.0000
Salle de soin	7.0200	0.466	3.0000	13.0000
salle de suture	0.5500	0.152	0.00	3.0000
salle dexamen	38.3100	1.057	25.0000	53.0000
salle Rx Scanner Echo	7.6200	0.474	2.0000	14.0000
Salle traumato	17.3300	0.680	9.0000	25.0000

Fig. 3 The number of input per session to each process block

During 6 hours of emergency work, there are an average of 126 patients oriented to the registration window service, 71 patients oriented to the payment window service, 17 patients oriented to the box room, 17 patients oriented to the traumatic room, 5 patients oriented to the specialist physician office, 38 patients oriented to the examination room, 10 patients oriented to the dissection room, 7 patients oriented to the Rx Scanner Echo room, 6 patients oriented to the treatment room and 23 patients oriented to the waiting time room.

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Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Box	7.9659	0.039	7.4345	8.3333	6.0146	9.8
bureau medecin specialiste	58.6534	2.005	0.00	88.2073	0.00	88.2
guichet de paiement	4.9928	0.020	4.7066	5.1921	3.0462	6.9
guichet dinscription	4.9972	0.018	4.7073	5.2134	3.0197	6.9
laboratoire des analyses	125.38	6.234	0.00	176.14	0.00	176
psychologue	32.3439	4.046	0.00	54.3371	0.00	56.2
salle d attente	24.9487	0.141	23.3172	26.8347	20.1547	29.8
salle de dechoquage	30.5517	0.603	24.1083	37.6868	15.5326	44.7
salle de platre	22.6887	1.468	0.00	28.1275	0.00	29.8
Salle de soin	29.4354	0.843	19.2492	43.5821	10.6805	57.5
salle de suture	4.1951	1.071	0.00	14.0219	0.00	14.0
salle dexamen	9.9744	0.072	8.8315	10.7420	5.1338	14.8
salle Rx Scanner Echo	56.5589	1.257	45.9539	72.3862	20.4686	88.3
Salle traumato	11.0180	0.117	9.8574	12.1943	8.0718	14.9

Fig. 4 Average time during which the patient is in service

The figure 4 indicates the average time spent by a patient in a specific service:

• The patient spends an average of 4.99 minutes to register in the emergency department.

• In the first time, the patient spends an average of 9.97 minutes in the examination room in the emergency department.

• To do a specialized consultation, the patient requires an average time 58.65 minutes.

• For the patient who requires further examination, the required average time to complete radiology is 56.55 minutes.

Process

Accumulated Time

Accum Wait Time	Average	Half Width	Minimum Average	Maximum Average
Box	213.41	38.428	3.4524	1033.82
bureau medecin specialiste	151.44	21.918	0.00	456.68
guichet de paiement	307.49	39.793	46.9930	925.54
guichet dinscription	5624.05	199.125	3160.32	8229.05
laboratoire des analyses	28.0927	7.922	0.00	118.81
salle d attente	843.72	46.852	358.11	1378.51
salle de dechoquage	259.71	37.204	0.00	843.93
salle de platre	7.1976	3.009	0.00	79.0118
Salle de soin	67.6706	18.542	0.00	489.12
salle de suture	1.3302	0.935	0.00	26.4908
salle dexamen	775.36	83.969	66.6757	1819.63
salle Rx Scanner Echo	150.96	23.329	0.00	466.09
Salle traumato	635.31	52.127	154.30	1528.74

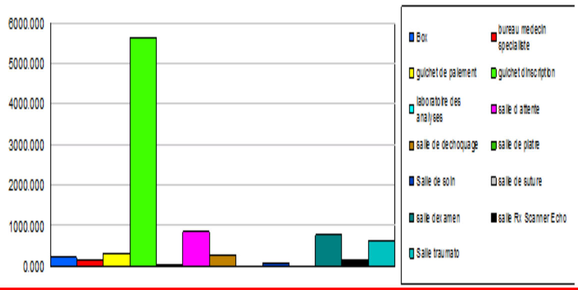

Fig. 5 The result report of the total waiting time spent by a patient in the waiting room

This figure 5 indicates that patients directed to the Box wait an average of 213.41 minutes, patients directed to the specialist physician office wait an average of 151.44 minutes, patients needed examination wait an average of 775.36 minutes, patients directed to the registration wait an average of 5624.05 minutes, patients directed to payment wait an average of 307.49, patients directed to the waiting room spent an average of 843.72 minutes, patients directed to the dissection room wait an average of 259.71 minutes, patients directed to the trauma room expect an average of 635.31 minutes, patients directed to the RX Scanner Echo room wait an average of 150.96 minutes to be served, patients directed to the treatment room wait an average of 67.67 minutes. On the other hand for the other rooms, the waiting time of the patients is almost negligible.

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Process

Cost per Entity

Total Cost Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value
Box	0.9294	0.005	0.8674	0.9722	0.7017
bureau medecin specialiste	24.4389	0.835	0.00	36.7531	0.00
guichet de paiement	0.5825	0.002	0.5491	0.6057	0.3554
guichet dinscription	0.5830	0.002	0.5492	0.6082	0.3523
laboratoire des analyses	22.9866	1.143	0.00	32.2918	0.00
psychologue	0.00	0.000	0.00	0.00	0.00
salle d attente	2.9107	0.016	2.7203	3.1307	2.3514
salle de dechoquage	24.9506	0.493	19.6885	30.7776	12.6849
salle de platre	12.1007	0.783	0.00	15.0013	0.00
Salle de soin	3.4341	0.098	2.2457	5.0846	1.2461
salle de suture	0.4894	0.125	0.00	1.6359	0.00
salle dexamen	2.8261	0.020	2.5023	3.0436	1.4546
salle Rx Scanner Echo	6.5985	0.147	5.3613	8.4451	2.3880
Salle traumato	1.2854	0.014	1.1500	1.4227	0.9417

Fig. 6 Total cost per entity of resources

For 6:30 hours and on average, the services provided by the examination room cost 2.82 TD, the services provided by the specialist doctor's office cost 24.23 TD, the services provided by the dissection room cost 24.95 TD, services provided by the registration window service costs 0.85 DT, the services provided by the payment window service cost 43.62 DT, the services provided by the Echo RX Scanner room cost 6.59 DT, the services provided by the plaster room cost 12.10 DT.

Regarding the use of resources, we have the following report:

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
infirmier	0.1914	0.023	0.00	0.4559
infirmier 1	0.9572	0.004	0.8909	0.9774
infirmiere	0.9976	0.001	0.9669	1.0000
infirmiere 1	0.9642	0.004	0.9114	0.9895
infirmiere 2	0.6889	0.027	0.4104	0.9583
infirmiere 3	0.5144	0.033	0.1952	0.8805
medecin des analyses	0.6508	0.041	0.00	0.9305
medecin generaliste	0.3329	0.032	0.06422892	0.8184
medecin generaliste 1	0.8605	0.013	0.6696	0.9530
medecin orthopediste	0.1752	0.023	0.00	0.4302
medecin speciallste	0.8517	0.018	0.4714	0.9734
technicien radiologue	0.7348	0.027	0.1928	0.9289

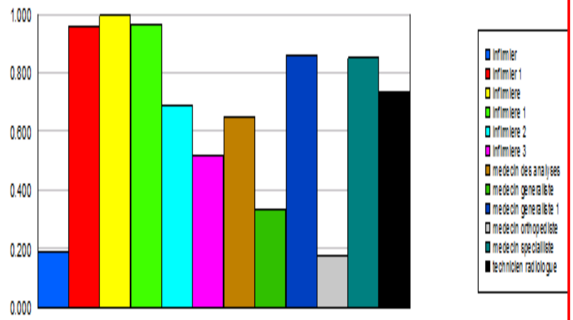

Fig. 7 utilization rates of resources in the current emergency service

The utilization rates of the nurses, the general practitioner and the specialist physician, the nurses and the radiologist have a good utilization rate. However, utilization rate of the specialist physician and the general practitioner are lower.

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Resource

Usage

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
infirmier	3.1700	0.359	0.00	7.0000
infirmier 1	18.4000	0.329	15.0000	22.0000
infirmiere	72.4500	0.296	69.0000	77.0000
infirmiere 1	69.8900	0.251	67.0000	73.0000
infirmiere 2	20.3600	0.745	11.0000	31.0000
infirmiere 3	6.6200	0.398	3.0000	11.0000
medecin des analyses	2.3200	0.143	0.00	3.0000
medecin generaliste	4.1200	0.393	1.0000	10.0000
medecin generaliste 1	31.6200	0.481	25.0000	36.0000
medecin orthopediste	2.6300	0.329	0.00	6.0000
medecin specialiste	7.6200	0.254	5.0000	10.0000
technicien radiologue	5.1100	0.206	2.0000	7.0000

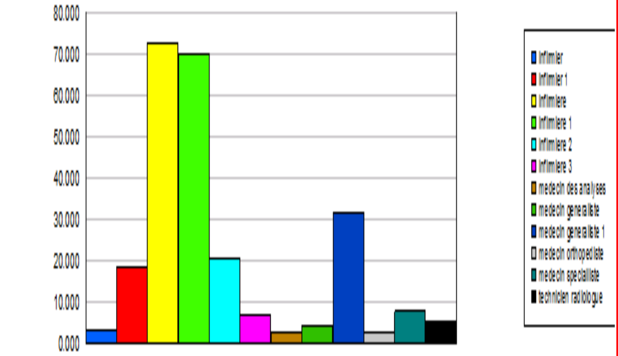

Fig. 8 Number of patients served by different resources

On average, numbers of served patients are: 72.45 by registration, 69.89 patients by payment, 31.62 patients by the exam, 18.40 patients in the waiting room or trauma room, 20.36 patients by the treatment room and 7.62 patients by the specialist office.

IV. Alternatives for improving the current system

In this section we will first present the criteria for of the emergency service performance. Secondly, we will rank the proposed alternatives of the simulation model by a multicriteria method.

IV.1 Criteria of decision-making

Today's hospitals seek to offer patients a good quality of service. To achieve this objective, the human and material resources must be properly managed. So, we suggest a set of solutions that will satisfy this need and we will rely for each of the following four criteria:

- Number of Served patients (NS).
- Waiting Time per entity within the ED (WT).
- Utilization of Resources (UR).
- Total Cost of a work session (TC).

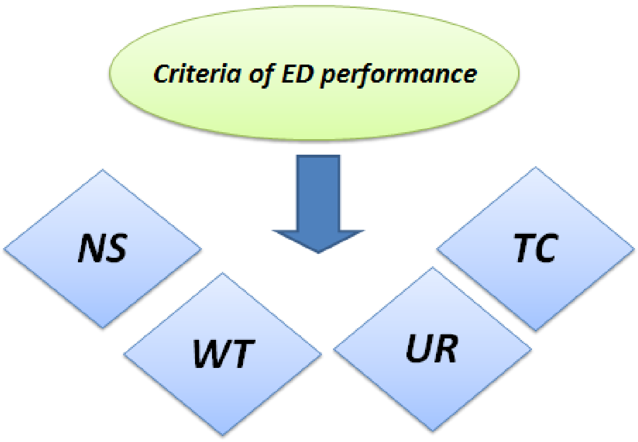

Fig. 9 Decision-Making Criteria

IV.2 Proposed alternatives

The number of patients served per session is 20, which is considerably less than the number of patients who come to the emergency department per day. In addition, it is noted that for each type of patient, the waiting time is too long during the registration and payment step. Also, there is a congestion of the patients in front of the examination room, the dissection room, the specialist doctor's office and for the complementary examinations (radiology or analysis), which causes the existence of a waiting problem.

So, we propose to evaluate the possibility of adding human and material resources to improve the actual performance of the ED. We proposed the following alternatives:
Alternative1: Decentralize the registration and payment windows service.
Alternative 2: Add a triage phase for all patients.

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Alternative 3: Decentralize the registration and payment windows service and add a triage phase for patients.
Alternative 4: Add a general practitioner
Alternative 5: Add a room RX Scanner Echo
Alternative 6: Add a new material to the dissection room.
Alternative 7: Add a new material to the dissection room and an RX echo scanner room
Alternative 8: Decentralize the registration and payment windows service and add a new general practitioner. (Alternative 5 + Alternative 6)
Alternative 9: Decentralize the registration and payment windows service, add a new generalist doctor and add a triage phase for patients and an echo RX scanner room and new equipment at the dissection room. (Alternative 3 + Alternative 4)
Alternative 10: Decentralize the registration and payment windows service and add a triage phase for patients and add a new generalist doctor and add a RX Echo Scanner and new equipment to the dissection room. (Alternative 3 + Alternative 4 + Alternative 7)

TABLE 1
OBTAINED RESULTS BY THE 10 ALTERNATIVES

Alternative	NS	WT	UR	TC
1	25	99.24	0.884	2043
2	25	106.05	0.880	2018
3	25	98.55	0.912	2140
4	26	105.73	0.354	1970
5	25	113.29	0.872	2134
6	28	104.27	0.864	2460
7	29	104.93	0.883	2787
8	30	81.41	0.435	2261
9	30	83.37	0.376	2367
10	42	48.15	0.451	3134

The next step is to apply the binary comparison between the different levels. For this, we propose the application of the AHP method.

V. DECISION MAKING WITH THE AHP METHOD

For the classification of these alternatives to choose the suitable solution, it is first necessary to determine the relative importance of the criteria in the form of a decision matrix. Then, calculate the weights of each alternative. These weights are given by the managers of the studied emergency department.

The AHP methodology requires comparing the criteria and sub-criteria in pairs in order to determine their relative weight. The matrix of binary comparisons are completed after interviews with certain nurses of the department and with the financial director of the hospital to determine the weights related to the measures of importance.

According to these interviews, paired comparisons were made on the basis of nine scales of AHP proposed by Saaty [21]. Therefore, the criterion "Patient Number Out" is more important than the criterion "Patient Waiting Time" and the criterion "Patient Waiting Time" is a little more important than the criterion of "Resource utilization" and the "total cost" is of importance Equal to the "Patient Number Out".

In our case study, the hierarchical structure consists of three levels: the first comprises the final objective and the second comprises the performance measures which represent the criteria by which the alternatives placed in the last level.

Indeed, MATLAB (MATrix LABoratory) has been developed to facilitate matrix calculations and the basic element is the matrix. Using the MATLAB software, the classification of the proposed alternatives by AHP method is presented in following table.

TABLE 2
THE CLASSIFICATION OF THE TEN ALTERNATIVES PROPOSED USING THE AHP METHOD

Alternative	Final results X_V	Score
1	0.043	9
2	0.044	8
3	0.047	7
4	0.041	10
5	0.058	6
6	0.102	3
7	0.148	2
8	0.082	5
9	0.089	1
10	0.305	4

The alternative10 takes the biggest score of importance. So it is selected as the suitable solution of the studied ED. The application of AHP has shown that to improve the current emergency department performances, it is important to add a general practitioner in the ED.

VI. CONCLUSION

Hospital services need to be assisted by decision-making tools to better improve their structure by guaranteeing patients a adapted service, quality and with the minimum. Therefore, we must direct our studies to improve the various services provided by the hospital. In this paper, we highlighted on the emergency department. W modeled and simulated a real Tunisian emergency department that shows a large demand for high quality care services under limited numbers of staff and in a small establishment.

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This problem is highly dignified in a context of resource deficit, increasing demand for care and an incentive to control the quality of care. Our suitable solution to improve the performance of the studied emergency department is to add general practitioner.

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