Impact of an approach combining optimization and simulation to improve the service quality of an emergency department

Impact d'une approche combinant optimisation et simulation pour améliorer la qualité de service d'un service d'urgence

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Abstract

Background: Emergency Department (ED) represents a complex system due to its limited resources and random patient arrivals. It is often saturated by a continuous flow of patients, which causes an excessive wait time and length of stay.
Aim: To evaluate the impact of the proposed combining approach (optimization with simulation) on improving the performance of an emergency department in terms of patients' length of stay and resources utilization balanced (physicians and nurses).
Methods: This study integrates simulation with optimization to design a planning decision support for an emergency department. First, we used a .stochastic mixed integer linear programing (MILP) to find the optimal number of staff and beds while considering the uncertainties on the patients' arrival and service times. Next, we construct a Discrete Event Simulation (DES) model to analyse and evaluate this resources allocation as well as different patient scheduling rules in order to minimize the length of stay and to balance resources utilization.
Results: The approach is applied to a case study at a Tunisian emergency department. Our analysis indicates that the proposed approach generates the best resources allocation that would significantly reduce the length of stay with an average of 44.55 % and balance the resources utilization.
Conclusion: This approach allows helping decision makers to improve the service quality of the ED via key performance indicators. DES and MILP prove to be an effective tool for studying the effects of different scenarios to optimize capacity allocation and to minimize patients' length of stay.

Keywords: management of emergency department, stochastic planning, discrete event simulation, length of stay, resource utilization.

Résumé

Introduction: Le service d'urgence (SU) représente un système complexe dû à ses ressources limitées et une arrivée stochastique des patients. Il est toujours saturé par un flux continu de patients, engendrant un temps d'attente et une durée de séjour excessifs.

Objectif: Evaluer l'impact de l'approche combinée (optimisation avec simulation) proposée sur l'amélioration de la performance d'un service d'urgence en termes de durée de séjour des patients et d'utilisation équilibrée des ressources (médecins et infirmières).

Méthodes: Un outil d'aide à la décision intégrant simulation et optimisation est proposé. Tout d'abord, nous proposons un programme linéaire mixte afin de déterminer le nombre optimal du staff et des lits tout en considérant les incertitudes liées à l'arrivée des patients et les temps des services. Ensuite, nous proposons un modèle de simulation à évènements discrets pour évaluer cette allocation des ressources en considérant différentes règles d'ordonnancement des patients. L'objectif est de minimiser la durée de séjour et d'équilibrer le taux d'utilisation des ressources.

Résultats: L'approche proposée est appliquée à un cas d'étude qui est le SU La-Rabta. Les résultats de nos expérimentations montrent que notre approche génère la meilleure allocation des ressources permettant de réduire significativement la durée de séjour avec une moyenne de 44.55% et d'équilibrer le taux d'utilisation des ressources.

Conclusion: L'intégration de la simulation et de l'optimisation permet d'aider les décideurs à améliorer la qualité de service de leur SU via des indicateurs clés de performance. C'est un outil efficace pour étudier les effets de différents scénarios afin d'optimiser l'allocation des capacités et de minimiser la durée de séjour des patients.

Mots clés: management d'un service d'urgence, planification stochastique, simulation à évènements discrets, durée de séjour, taux d'utilisation des ressources

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INTRODUCTION

An Emergency Department is a section of the hospital that is operating with limited resources and high levels of stochastic demands. It is often saturated by a continuous flow of patients, which causes excessive waiting times and lengths of stay for the patients (1–3). Therefore, the ED have to be more perform and agile while managing efficiently the allocated resources and patient demands. Indeed, resource allocation and patient scheduling have a major role in improving the performance of the emergency department and provide a good quality of service for patients while being more perform and agile.

Many reviews in this area already exist (4–11). Furthermore, we note many fruitful efforts in developing methods for improving the performance of ED. In the literature, the different models deal with problems related to ED can be classified as follows: 1. optimization models, 2. simulation models, and 3. combining optimization and simulation models.

In this context, we present an approach that combines optimization and simulation. First, we use a stochastic optimization model that finds the optimal sizing of staff and beds with operational constraints. Then, we evaluate more accurately our solution in a more realistic discrete event simulation model by taking into account other uncertainties not considered in the optimization model. Further, the objective of the DES model is to evaluate different key performance indicators and patients' scheduling rules. The main efficiency criterions considered are the total patient waiting time, patient length of stay and the rate of resources utilization. These indicators are good ones of patient service quality and ED crowding (12,13). We identify two main types of human resources in this study (physicians and nurses) and the main material resource, which is beds that define a major cause of overcrowding of the emergency department.

The remaining of the paper is organized as follows. Section 2 presents the related works in ED and the contribution of this study. In Section 3, we describe the ED model in details and explain the proposed approach. The analysis of the results is the subject of Section 4. Section 5 provides a discussion. Finally, Section 6 concludes this paper.

METHODS

Methodology

The problem of resources' sizing and patients' scheduling in ED (Emergency Department) remains hard to solve because of the numerous constraints and uncertainties taking into account. For this, we used an approach which combines two models. At the step I, we use the stochastic MILP (Mixed Integer Linear Programing) to find the optimal number of physicians, nurses and beds based on sizing of current configuration of La-Rabta hospital ED. Then at the step II, we use a DES (Discrete Event Simulation) model by considering uncertainties (the random arrival of patients, the service times and patients' severity level) to evaluate the resources' sizing and different scheduling rules by taking into account different key performance indicators (patients' length of stay and resources utilization).

Study setting and data collection

The data obtained for both the optimization and the simulation models are from the ED of the Tunisian hospital La-Rabta. The process begins when a patient arrives in the ED and ends when the patient is released from the ED. The arriving patient goes through the triage nurse, who collects the patient's health information (blood pressure, body temperature, and heart rate). After this initial examination, patients are oriented according to their severity level to one of four possible queues. We distinguish four patients' categories from 1 to 4 in decreasing order of severity.

- **Category 1:** The patient suffering from a vital trauma goes directly into one of the intensive care beds (reanimation),
- **Category 2:** The patient in vital distress is supported in the box of life-threatening emergencies "SAUV",
- **Category 3:** The patient is not in vital distress and need a surgery is oriented to box 3 to take the advice of a surgeon,
- **Category 4:** The patient is not in vital distress is oriented toward boxes 4 or 5 to take the advice of a physician.

During an internship spent in La-Rabta ED from May 1st, 2015, to September 30st, 2015, we observed the entire process of patients flow. We noted the number of patient arrivals per period, their waiting time in each queue, their service time in each box, the number of human resources present, etc. Based on these collected data, we generated the distribution of patient arrival and service time distributions in each queue. The tool ExperFit of the software FlexSim Healthcare was used to approximate all statistical distributions.

Optimization model

In this section, we present a stochastic MILP formulation of the problem of sizing human and material resources (physicians, nurses and beds). The goal of the proposed model is to find the allocation of these different resources in order to reduce the total patient waiting time in the ED, by considering the uncertainties on the patients' arrival and service times. The objective function of model is a discrete-time approximation of the total patient waiting time.

$$minimize\ E_{\omega}\left[\sum_{t=1}^{T}\sum_{q=1}^{Q}\left(W_{t,q}(\omega)-S_{t,q}(\omega)\right)\right]$$

Where ω is a random variable representing a scenario of an emergency arrival with Poisson distribution with corresponding parameter $\lambda = 3.13$, and the service time in each box. $W_{t,q}$ and $S_{t,q}$ are respectively the number of patients waiting in queue q at the period t, and the number of patients in queue q that have been served during period t.

We consider constraints that define the number of patients waiting and the number of served patients in each queue. We consider also constraints that define the number of each type of resources. The optimization model is given by Daldoul et al. (14).

Simulation model

The simulation model is created using the simulation software FlexSim Healthcare 5.1 (HC). The model is constructed to observe the investigated system and to simulate patients moving through an ED that includes six primary areas: triage, general assessment, surgical assessment, SAUV (structure of life-threatening emergencies), auxiliary exams (X-rays and/or clinical lab tests) and assignment to beds. Accordingly, four different patient categories with their corresponding treatment stages are modeled. Each patient, in the box of the triage, follows a path in ED according to his severity level and waits in the corresponding queue: general assessment, surgical assessment, SAUV or assignment to a bed.

We consider 7 different types of agents in the simulation model (triage nurse, SAUV nurse, lab nurse, X-ray nurse, surgical physician, general physician and SAUV physician) that might be assigned to one of patient categories, or all. The details are given in Table 1. We consider 7 different types of agents in the simulation model (triage nurse, SAUV nurse, lab nurse, X-ray nurse, surgical physician, general physician and SAUV physician) that might be assigned to one of patient categories, or all. The details are given in Table 1.

Table 1. Types of medical personnel in the ED.

Medical personnel	Patient category
Triage Nurse	1,2,3 and 4
SAUV Nurse	2
X-ray Nurse	1,2,3 and 4
Lab Nurse	1,2,3 and 4
General Physician	4
Surgical Physician	3
SAUV Physician	2

RESULTS

Numerical experiments

Preliminary experiments are performed by varying the number of simulation replications. The results show that 30 runs are needed for each solution instance using a 95 % confidence interval. We first consider the current solution of the ED of La-Rabta hospital (configuration 1) and execute the optimization model to obtain configuration 2. This configuration represents the inputs for the execution of the simulation model. Based on the key performance indicators (length of stay and resources utilization), we adjust the number of resources and we obtain a new configuration taking into account numerous uncertainties and scheduling rules (configuration 3). Table 2 represents the size of medical resources for each configuration. These sizing are given for a 6 h shift, because it is the schedule strategy adopted in the La-Rabta hospital ED.

Table 2. Resources sizing for each configuration

Designation	Configuration	Triage Nurse	SAUV Nurse	Exams Nurse	General Physician	Surgical Physician	SAUV Physician	Beds
Configuration 1	Current configuration	1	1	2	2	1	1	12
Configuration 2	Configuration obtained	2	2	3	2	2	2	12
Configuration 3	Configuration obtaine⊕ with optimization model simulation model	2	1	2	2	2	1	12

Comparing configurations 2 and 3, we note that by considering patients' scheduling rules there are boxes that requires fewer human resources. For example, in the SAUV box we need 1 nurse and 1 physician for the configuration 3 compared to the configuration 2 where we need 2 nurses and 2 physicians.

Statistical analysis

Figure 1 presents the length of stay for each configuration. We note that the length of stay (LOS) (minimum, average and maximum) obtained with configuration 2 and 3 decreases compared to the configuration 1. It is especially clearer for the indicator "Average LOS" which decreases from 113.96 min to 60.27 min in configuration 2 and to 63.18 min in configuration 3. Indeed, Table 3 illustrates the improvement of length of stay for configurations 2 and 3 compared to configuration 1 (current configuration) ; i.e. a reduction of 47.11% for configuration 2 and 44.55% for configuration 3.

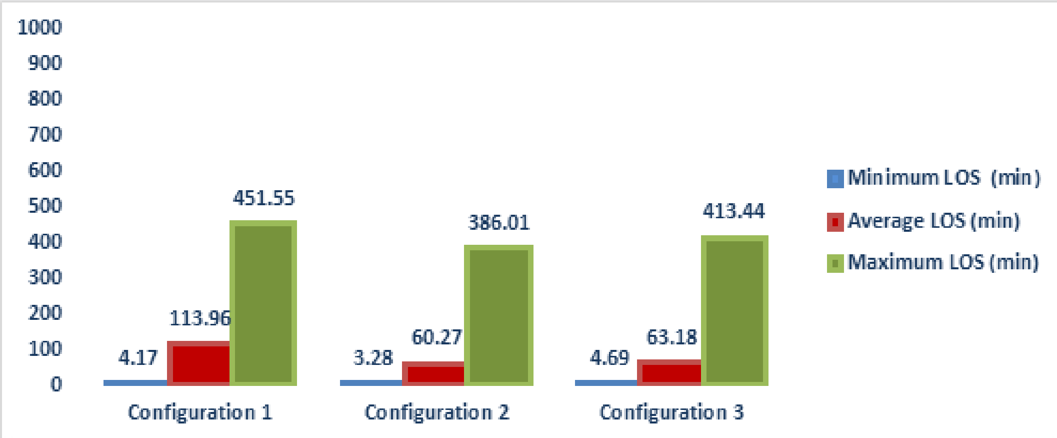

Figure 1. Simulation results for key performance indicator "LOS".

Table 3. Resources sizing for each configuration.

Configuration	Configuration 1	Configuration 2	Configuration 3
Average LOS (min)	113.96	60.27	63.18
Improvement of length of stay (%)		47.11	44.55

Figure 2 presents a comparison of the three configurations for resources utilization key performance indicator. It is clear that configuration 3 has a more stable load on all the periods and for the different resources, compared to the other two configurations 1 and 2 where the load fluctuates considerably. We noted that the resource utilization rate is better balanced in configuration 3. For this reason, we retain in the rest of the experiments the configuration 3 to evaluate different patients' scheduling rules.

• Third scheduling rule ***Fast track***: patients of high severity

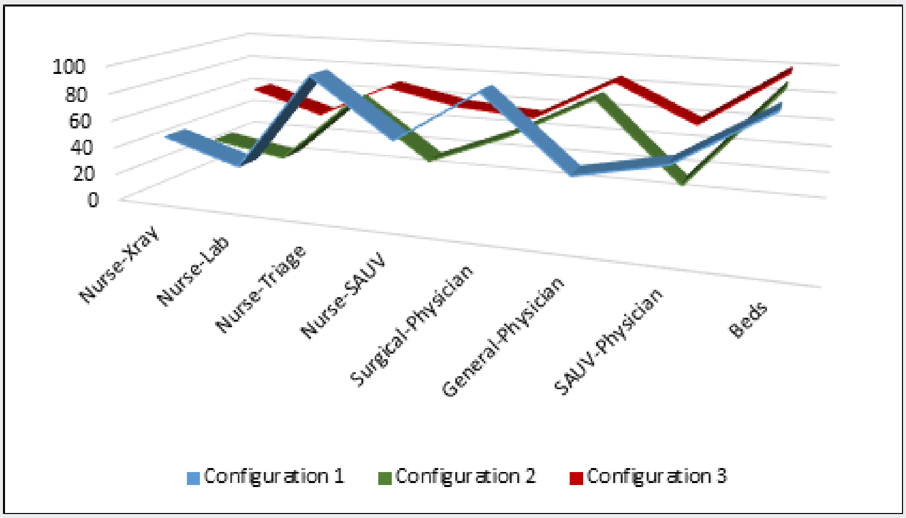

Figure 2. Comparison of the three configurations for key performance indicator "Resources utilization".

Scheduling rules evaluation

We consider now the configuration 3 and we evaluate three patients' scheduling rules

by considering two key performance indicators: resources utilization and the length of stay. The objective is to find the best patients management of schedule, by considering the required staffing resources and beds to be available found above (configuration 3).

• First scheduling rule ***FIFO***: patients are scheduled according to their arrival time (first in first out).

• Second scheduling rule ***Priority***: patients are scheduled given by severity level defined in triage activity. It is this rule, which was used in the previous results.

level (category 1) do not need to go to triage box because their health states require immediate intervention and cannot wait. They are immediately assigned to one of intensive care beds. The other categories are scheduled according to their severity level.

Figure 3 presents a comparison of these three patients' scheduling rules for resources utilization performance indicator.

We remark that the fast track rule outperforms the FIFO and Priority rules. It is clear that the resources utilization is better balanced with fast track scheduling rule, especially for SAUV nurse and SAUV physician. However, the decider can choose the suitable scheduling rule depending on different cases that can occur in the emergency department, the category of patients' arrival and the key performance indicators to consider; length of stay or resources utilization.

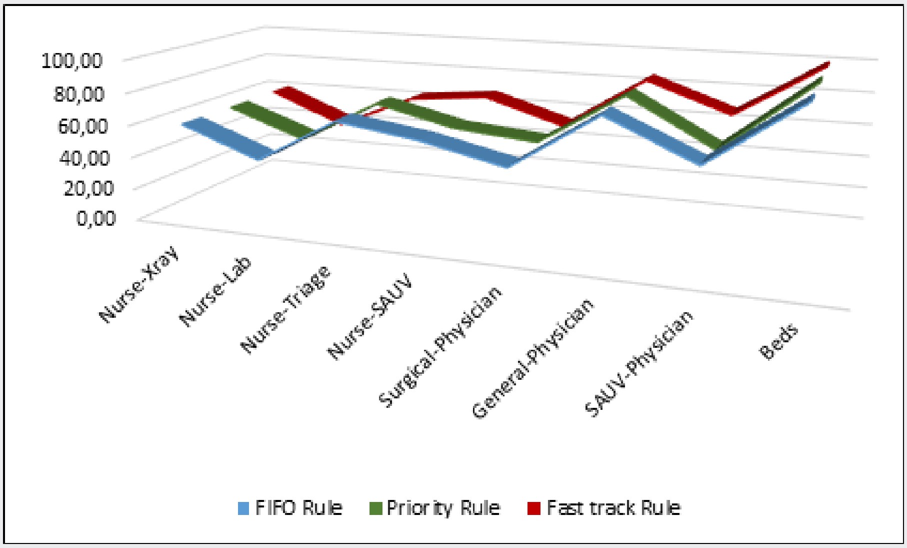

Figure 3. Comparison of resources utilization simulation results for each scheduling rule.

DISCUSSION

The goal of this study is to evaluate the impact of the proposed approach, which combining optimization with simulation, on improving the performance of an emergency department in terms of patients' length of stay and resources utilization balanced (physicians and nurses). This paper focuses on the allocation of medical capacity (physician, nurses and beds) and the patients' scheduling in the presence of multiple patients' categories. Indeed, when facing uncertain patient rate, resources management is a key factor to minimize patient waiting times, to improve resources' utilization, and to reduce the overcrowding system. Emergency department scheduling is more challenging than outpatient or operating room scheduling, as it involves emergency patients (1,3,15,16).

Contrary to the works of the literature dealing with the same problem (1,17–20), we consider the entire process of ED from the triage of patients to bed assignment. Moreover, we take into account the uncertainties related to patients' arrival, services time and patients' severity level that represent a major aspect in ED. By combining optimization with simulation, we evaluate the impact of simulation on optimal sizing by considering uncertainties and key performance indicators (length of stay and the rate of resources utilization). Based on our work, practical guidance for emergency management can be provided. Results demonstrate that the proposed approach helps decision-makers to improve the service quality of ED, by reducing the length of stay with an average of 44.55 % and balancing the rate of resources utilization while evaluating different scheduling rules, which is the case of La-Rabta hospital ED. Therefore, we propose a decision tool, which may help decision makers to select the most appropriate scheduling rule depending on characteristics of the emergency department. For example, in the case of natural disasters and epidemics, the arrival rate of patients in the ED increases, resulting in ED overcrowding. Thus, the ED has to be prepared to accommodate a large number of patients, especially categories 1 and 2. Therefore, it is better to emergency departments to put in place a fast track for very urgent patients, in order to minimize patients' length of stay and maximize consequently patients' satisfaction.

As a result, the combination of optimization and simulation is an effective tool for the emergency department of La-Rabta hospital. This tool gives the best resources' allocation to improve patients' flow, while minimizing patients' length of stay and balancing resources' utilization. Our approach is constructed based on the patient process of one ED, but we can easily evaluate our model to multiple EDs. This will be the subject of our research in the future.

CONCLUSION

The management of emergency department resources is challenging because of uncertain demand and severity level of patients. To minimize patient length of stay in the face of this uncertainty, we proposed an approach combining optimization with simulation to ED patient scheduling. Our results indicated that DES is an effective tool for studying the effects of proposed scenarios on ED capacity allocation by evaluating three scheduling rules, and help to optimize hospital resources' utilization. This study represents useful guidelines to hospital managers seeking to improve their ED.

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