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An Efficient Simulation-Based Optimization Approach for Improving Emergency Department Performance

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Abstract

In recent years, health care organizations, in particular emergency department (ED), have come under increasing pressure to provide quality care. In this context, human resources are a central aspect: a good utilization of health worker could improve quality of care. In this paper, a simulation model is proposed. The model represents an ED coupled with an optimization method to optimize the allocation of medical and para-medical human resources in the hospital center of Troyes. We aim to improve the quality of services offered to patients through the minimization of Average Waiting Time (AWT) and Average Inpatient Stay (AS). The proposed approach has proved to be effective to reduce AWT and AS by 12 minutes and 21 minutes respectively.

Keywords:

computer simulation, resource allocation, emergency departments

Introduction

In recent years, health care organizations, in particular emergency departments, have come under increasing pressure to provide quality care while overcoming increasing volume pressure. In the other side, simulation has become an effective decision-making tool to optimally allocate the often-limited resources in health care to improve patient flow while minimizing the costs of providing care and increasing patient satisfaction. In addition, combined optimization and simulation tools allow decision makers to efficiently find optimal emergency department configurations, even for complex integrated installations.

Over the last decade, there have been several studies in the literature dealing with the optimization of human and material resources in a health care through the technique of coupling simulation with optimization [1, 2, 3, 4].

In this paper, in order to improve the quality of services offered to patients in the ED of the hospital center of Troyes (CHT) (France), a simulation-based optimization approach is developed. This method uses a discrete-event simulation model, combined with a genetic approach. This tool allows the users to evaluate the Average Waiting Time (AWT; the time that the patient spends from their arrival to their first medical exam) and the Average Inpatient Stay (AS; the time the patient spends from the first exam to their exit) of patients for different organizations of the service. The expected value of patient arrivals is obtained through forecast models developed in a previous work, and that reached a very good performance (up to 91.24 % for the annual total flow forecast) and robustness to epidemic periods [5].

Methods

Simulation model

The developed simulation model requires three kinds of inputs: 1) patient arrival rates, 2) the frequency of each pathway, and 3) the processing times of services. These were obtained from data collected from the emergency database for the whole 2017 year. We modeled the considered probability distribution using the "fitdistrplus" package of R® software [6]. These data were used to determine the best probability distribution to represent each stage of the patient flow. The time of inter-arrival process (T_i) follows an exponential distribution with average of $Y_j * T_h$, i.e $T_i \sim e^{Y_j * T_h}$, where T_h is the average arrival rate observed for the hour h of the day, and Y_j the number of daily arrivals for the day j.

Optimization

The optimization problem considered in this work aims to minimize the AWT and the AS of patients. In order to reach the optimization goal, the problem was solved with a genetic algorithm coupled with the simulation model (as an objective function evaluator) in order to optimize emergency staff planning. Thus, the optimization problem can be represented as follow:

$$\text{Minimize } F(x)$$
$$\text{Subject to}$$
$$\sum_{j=1} X_{ij} = Ci \qquad \forall i = 1 \dots 4 \quad (1)$$
$$X_{ij} \in N \qquad \forall i = 1 \dots 4 \;\; \forall j = 1 \dots 4 \; (2)$$

Where X_{ij} is the decision variable that represents the number of available staff per slot time of 6h. $i(= 1 \dots 4)$ is the index of staff type: 1 for emergency physicians, 2 for resident physicians, 3 for nurses and 4 for caregivers, and j = 1...4 is the index of the slot time of 6h per day. The constraint (1) ensures that the same number of hours worked by each type of staff is fixed because the ED of CHT, as a first step, does not seek to increase or decrease its workforce.

Table 1 shows the availability of interchangeable staff per 6 hour time slot.

To define the best parameters of the genetic approach, the experimental design methodology proposed by [7] is used. Then, the parameters used for our GA are: population size = 100, probability of mutation = 0.9, number of maximal iterations = 500 and probability of crossover = 0.9. The time limit was set to 1h30

Table 1: Availability of staff per slots of 6 hours

	00h -6h	6h - 12h	12h - 18h	18h - 00h
Emergency physician	2	2	2	2
Resident physician	3	3	3	3
Nurse	3	3	3	3
Caregiver	3	3	3	3

Results

To assess the efficiency of the proposed simulation model, the performance indicators obtained from our simulation model were given to CHT's decision makers who compared them to daily indicators of the hospital. The assessed gap between real and simulated indicators is less than 9%. Based on this assessment, the model was considered reliable and able to support experiments.

The best solution of the emergency staff planning returned by the genetic approach is presented in table 2. In terms of performances, the solution reduces the AWT by 12 minutes and the AS by 21 minutes.

Table 2:Optimized solution of the annual planning

	00h - 6h	6h - 12h	12h - 18h	18h - 00h
Emergency physician	1	1	3	3
Resident physician	2	2	4	4
Nurse	2	2	5	3
Caregiver	1	2	4	3

Discussion and Conclusion

After improving the current staff planning by keeping the same number of staff, the effect of increasing the number of staff by 1 for each type is studied.

Results show that the nurse resource has the greatest impact on the system. Adding a nurse allows the hospital to reduce the AWT by 25 minutes and the AS by 32 minutes.

To conclude, a simulation-based optimization approach that aims to minimize the AWT and the AS for patients in the hospital center of Troyes, France is presented. The proposed solution provides a gain of 12 minutes in AWT of patient and a gain of 21 minutes in AS which represents a noticeable reduction in waiting times for patients.

This work can be extended to include the planning of human resources, in which the assignment of resources can further reduce waiting time by effectively assigning resources on overloaded shifts.

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