Computers & Industrial Engineering 110 (2017) 289–296

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Using the "Floating Patients" method to balance crowding between the hospital emergency department and other departments

Guy Wachtel *, Amir Elalouf

Bar - Ilan University, Ramat-Gan, Israel

ARTICLE INFO

Article history:
Received 4 December 2016
Received in revised form 4 June 2017
Accepted 13 June 2017
Available online 15 June 2017

Keywords:
Floating Patients
Overcrowding
Emergency department
Scheduling
Approximation algorithm
FPTAS

ABSTRACT

This paper proposes a model and a corresponding scheduling algorithmic approach to reduce crowding in an emergency department (ED), and to provide patients with faster and better service. This approach relies on the "Floating Patients" (FP) method, in which the ED triage can send some patients directly to hospitalization departments instead of providing them with full examinations in the ED. In contrast to previous work in this vein, our technique takes a holistic approach, considering crowding not only in the ED but also in other departments in the hospital. It also considers the extent to which information has been made available about the patient's condition (e.g., through referring physicians), in addition to other factors such as the severity of the patient's condition and the effect of crowding on treatment time. A key benefit of this method is that it enables triage staff (the decision maker) to control and balance the crowding in the ED with crowding in other hospitalization departments. We define the model and propose an efficient Fully Polynomial Time Approximation Scheme (FPTAS) to solve it. In addition, we present a numerical example to validate our approach.

1. Introduction

Overcrowding in hospital emergency departments (EDs) - where incoming patients receive initial diagnosis and treatment and are referred for subsequent treatment elsewhere (either inside or outside the hospital) - is a serious concern in health-care systems worldwide. ED overcrowding has a negative influence on the quality of medical care that patients receive, as well as on hospital profits (Kim, Carey, & Burgess, 2009). Yet hospitals continue to struggle to find ways to mitigate ED overcrowding; in fact, it is still common for EDs to turn patients away (i.e., refer them to other EDs in the area or reject them altogether) once occupancy exceeds a predetermined threshold. Accordingly, operations and health-care researchers have been attempting for years to address the problem of ED overcrowding and patient length-of-stay (LOS), and, more generally, to propose approaches to improve the quality of care provided by EDs. Research in this domain has focused on forecasting patient volume, scheduling physicians' and nurses' shifts, streamlining medical process chains, and planning resource utilization.

When addressing the problem of overcrowding in EDs, many papers use simulations (see Gul & Guneri, 2015) in order to deal with the complexity of the ED environment and to validate their models. One of the key simulation models was developed by González, González, and Ríos (1997), who proposed a simulation and a total quality management method in order to improve the quality of service inside the ED. Their method and recommendations have since served as the basis for many subsequent simulation tools.

Some studies in this stream rely on algorithmic approaches, most commonly with the goal of increasing the accuracy of triage examination. Ballard et al. (2010) used data from the New York University ED to validate an algorithm for categorizing the severity of patients' conditions. Lowe and Fu (2008), from another angle, tested the ability of ED algorithms to detect changes in ED use: They found that even if an algorithm can efficiently identify the severity of different patients' conditions and various patient characteristics, reliance on such data is less useful than other methods in predicting differences in patients' LOS and their access to care. An algorithm-based study by Yeh and shan Lin (2007) departs from the focus on triage examination, proposing a genetic algorithm that seeks to improve nurses' shift scheduling for the purpose of enhancing ED care quality. The genetic algorithm approach is useful for planning and determining the allocation of resources in the ED within the constraints of the hospital's budget. Yeh and Lin's

* Corresponding author.
E-mail addresses: Guy.Wachtel@biu.ac.il (G. Wachtel), Amir.Elalouf@biu.ac.il (A. Elalouf).

http://dx.doi.org/10.1016/j.cie.2017.06.023
0360-8352/

results (Yeh & shan Lin, 2007) imply that it is possible to improve quality of care merely by adjusting nurses' schedules, even without increasing the number of nurses in the system.

Another stream of studies regarding algorithmic scheduling in health-care focuses on the management of operating rooms; these studies include the heuristic algorithms developed by Molina-Pariente, Fernandez-Viagas, and Framinan (2015) and Latorre-Núñez et al. (2016). The latter study addressed the resources needed for scheduling, taking into account the availability of anesthesia beds and the need to accommodate unscheduled emergency surgeries. The authors designed an integer linear algorithm model and metaheuristic model to deal with all the problem's factors at the same time.

In the current paper we develop an algorithm whose goal is to address ED crowding, and illustrate it with a numerical example. Notably, our approach is compatible with other methods that have been proposed over the years for improving ED work flow and quality of care. These methods include bed management (Landa, Sonnessa, Tànfani, & Testi, 2014; Proudlove, Boaden, & Jorgensen, 2007); methods of prioritizing and sorting patients (Ashour & Okudan, 2010; Ashour & Kremer, 2016); and the physician in triage (PIT) method (Imperato, Morris, Sanchez, & Setnik, 2013). The latter method serves as the basis for the algorithm we propose.

We assume that the ED determines a maximal (fixed or dynamic) value for patients' LOS, and that patients who cannot be evaluated in the ED in a timely fashion are redirected for treatment into the hospitalization department that is capable of serving their needs. This approach, referred to as the "Floating Patients" (FP) method, is practiced in Israel, for example. In a recent study, (Elalouf & Wachtel, 2016) developed an algorithm for implementing this method under a basic set of assumptions, and simulated it using data from an actual ED. The simulations presented in that study indicated that the FP method can indeed reduce ED crowding and patient LOS, without diminishing the quality of care (as compared with subjecting all patients to full evaluations in the ED). In our present work, we expand the problem discussed in Elalouf and Wachtel (2016) to deal not only with patients who have actually arrived at the hospital but also with patients who are on their way to the hospital. We assume that data about the latter patients are obtained from sources such as regional clinics and nurse hotlines that refer patients to the ED (see Fig. 1). In addition, herein we adopt a holistic view, considering the rate of crowding not only in the ED but also in other hospital departments. Our algorithm seeks to balance the crowding rates across these different departments, with the goal of contributing to the improvement of the work flow of the entire hospital system.

The problem we address is clearly NP-hard. Because of this, and taking into account the need to make decisions rapidly in the ED, we base our algorithm on a fully polynomial time approximation scheme (FPTAS). We build on an FPTAS that Levner and Elalouf (2014) developed for the minimization version of the job sequencing problem with deadlines. Levner et al.'s algorithm is an adaptation of a technique proposed by Ergun, Sinha, and Zhang (2002) to improve the complexity of the original solution method for the

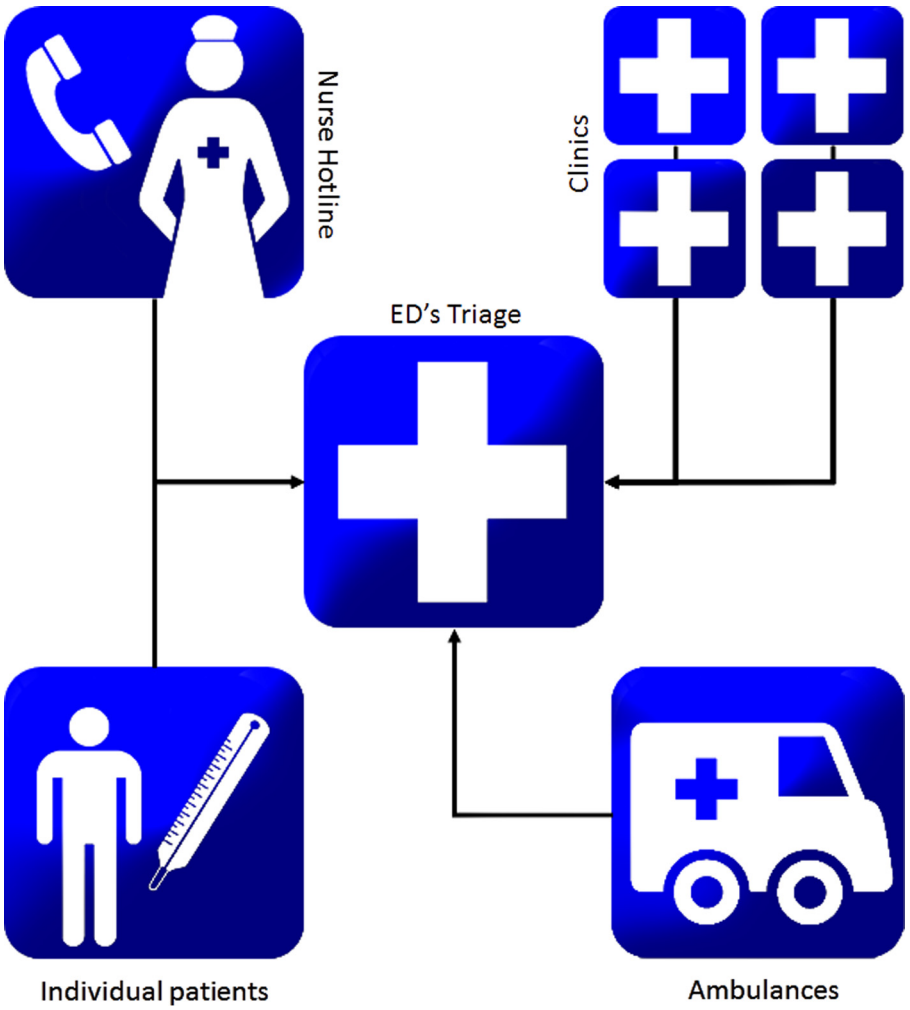

Fig. 1. Ways of arrival and data flow to the ED.