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# An alternative scheduling approach for improving patient-flow in emergency departments

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ABSTRACT

Overcrowding in hospitals, along with long lengths of stay, high arrival rates, budget constraints, and increasing demand for high service quality, create challenges for the work-flow and patient flow of hospital emergency departments (EDs). This paper proposes an algorithmic approach that seeks to enable ED decision makers (specifically, in the triage) to optimally schedule evaluations for patients who are waiting for treatment in the ED. The algorithm is an expansion of Karp's job sequencing with deadlines problem Karp (1972) and is embedded in a simulation model. From a managerial perspective, overcrowding can cause substantial profit–loss to the ED and the other departments. We assume that, in order to prevent this profit–loss, the hospital management determines a maximal (fixed or dynamic) value for patients' length of stay and for crowding levels in various departments, and that patients who cannot be evaluated in the ED in a timely fashion are redirected for treatment in other hospital departments. The latter approach (referred to as the "floating patient" method) is practiced, for example, in Israel. To build the algorithm, we solve this problem gradually; first we solve a scenario in which the triage decision maker has full information on patients' conditions and on how long their ED-treatments are expected to take. We then extend this problem in order to incorporate uncertainty as in real life scenarios: The triage decision maker (physician) needs to carry out initial examinations to obtain information on patient attributes and, at each point in time, decides whether to continue to examine patients or to stop the process (halting rule) and "float" the remaining patients to other departments. Next, the physician determines the optimal schedule for the full ED evaluations of the examined patients. We embed the algorithm into a simulation procedure and run simulations using empirical data from a hospital in Israel. Implementation of the "floating patient" method is shown to reduce patients' length of stay, queues for beds in departments and the ED, and cumulative treatment time in the ED. These improvements reflect a better balance of work-rate and crowding between the ED and the other departments.



## 1. Introduction

Emergency rooms were first established in the 20th century, in order to address the growing need for medical diagnosis and treatment in critical situations [1]. Nowadays, hospital emergency departments (EDs) in Israel and around the world provide primary health care to patients whose illnesses or symptoms require immediate attention and in some cases may be life threatening. Israeli EDs function similarly to EDs in the US and in Europe. Specifically, when a patient arrives at the ED, he or she undergoes an initial triage examination, in which a nurse checks the vital signs, runs tests as necessary and classifies the patient according to his or her condition. The classification process may vary slightly across hospitals — in particular, it may differ between private and public institutions — but in most cases, it is similar to the ESI (Emergency Severity Index) decision method, in which patients are sorted and prioritized on the basis of the urgency of treatment and the quantity of resources that treatment is expected to require. In recent years, many significant improvements to the ESI have been proposed (e.g. Utility Theory Based Patient Sorting [2,3], Multi-Attribute Utility Theory MAUT [4,5] and the Dynamic Grouping and Prioritization DGP [6]). In this paper, we will refer to a general classification method resembling the ESI, in which the order in which patients are received and treated is determined by the degree of urgency and severity of their respective medical problems and not necessarily by order of arrival. Patients who require urgent treatment are prioritized over patients with less severe symptoms. After initial examination and emergency treatment if needed, patients are either transferred to one of the

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areas within the ED, hospitalized in a department of the hospital, transferred to another hospital for various reasons, or discharged.

In recent years, as the population has grown faster than facilities or budgets (in most cases), overcrowding in EDs has become a serious problem in health care systems around the world and in Israel in particular. A common solution for handling overcrowding is to turn away arriving patients and ambulances (by referring them to other EDs in the area) and to reject non-urgent patients. Such "turn-aways" and rejections cause long waiting times, thereby increasing patients' pain and their likelihood of contracting disease or experiencing complications (causing a great deal of inconvenience to patients), and result in direct loss of income for the hospital and the ED. In addition, overcrowding in EDs has a negative influence on the quality of medical care as well as on hospital profits (see [7] for a study of the impact of crowding on hospital and ED expenses). Finally, rejection of patients takes a "social toll", causing damage to the public image of the hospital and of the health care system in general. ED overcrowding and patient length of stay (LOS) have therefore been attractive subjects for operations and health care researchers for many years, and numerous approaches have been developed to improve ED work flow. Most studies have focused on forecasting patient volume, scheduling physicians' and nurses' shifts, medical process chains and planning resource utilization.

Many operations research studies addressing ED work flow use scheduling methods and computer simulations in order to identify means of increasing the efficiency of health care and reducing patient LOS in the ED process chain. Su and Shih [8], for example, used computer simulations to model an emergency medical services system, focusing on pre-hospital care. Sinreich and Marmor [9] built a simulation model, based on empirical data from five EDs in Israel, with the aim of identifying means of reducing turnaround time and improving ED service quality. Sinreich and Marmor [9] showed that a "fast-track" processing method, whereby "easier" patients are treated separately from others, obtained better results than the common method in use at the time. They further showed that the model could be used to predict patient flow, LOS, and crowding rate in the ED. Today, many hospitals use the fast-track model.

One of the most frequently-cited articles on simulation models for ED operations is that of Connelly and Bair [10], which discusses the use of discrete-event simulation methods for advanced system-level investigation of ED operations. Similarly to Marmor [11], Connelly and Bair used simulation models to evaluate the fast-track approach, showing that it decreased patients' LOS in the ED by tens of percentage points. Duguay and Chetouane [12] also discussed discrete-event simulation approaches. Other papers analyzing patient LOS are those of Rossille et al. [13] and Harrison and Escobar [14]. These authors formulated multistage models describing the LOS distribution for diverse patient groups, distinguished according to various factors such as diagnosis, severity of illness, age, or hospital. They noted that information systems fail to capture certain types of information, and that there is a need to supplement the missing data.

In addition to the simulation approach, many studies in the literature use algorithmic approaches to derive recommendations for improving the quality of care provided by EDs. Most of the papers in this stream address the problem of increasing the accuracy of triage examination. Berman et al. [15] demonstrated the effectiveness of computerized nurse triage algorithms in correctly evaluating patients. Ballard et al. [16] validated a similar algorithm for categorizing the severity of patients' conditions in the New York University ED. Lowe and Fu [17], 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, it is less useful than other methods in predicting differences in patients' access to care (LOS).

Another method that is commonly addressed in the literature is the bed management approach, which improves patient flow by designating a "bed manager" who manages patients' assignments to the departments after their ED treatment. The bed manager is typically a member of the medical staff (nurse or shift manager), and his or her function may be particularly stressful and managerially complex. Nathan et al. [18] developed a training program for bed managers that improved participants' knowledge, skills and subsequent behaviors. In a recent paper, Landa et al. [19] built a discrete-event simulation that constituted a decision support framework to assist in determining how different bed management rules directly or indirectly affect system performance, thus enabling managers to improve the patient flow between the ED and the departments.

In recent years, hospital administrations have begun to implement a new method in which physicians are placed in triage, on the basis of the rationale that physicians may be able to perform more accurate assessments and handle more complex medical questions compared with triage nurses. This so-called physician-in-triage (PIT) model has been proposed as a process improvement that can increase the efficiency of ED work-flow. Indeed, He et al. [20] compared four methods of managing ED work-flow (first-in-first-out with priority, fast track, PIT and an extension of PIT called team triage) and showed that the PIT and team triage methods yield better performance. Imperato et al. [21] also showed that PIT can improve patient flow metrics, waiting time for treatment (and therefore LOS) and the quality of treatment itself. The PIT model may also provide the added benefit of enhancing patient satisfaction about the quality of service and their overall ratings of ED care.

In this paper, we suggest a dynamic programming approach and a corresponding approximation method with a simulation model that demonstrates and justifies the use of PIT, coupled with the use of the "floating patient" method, as described in guidelines issued by the CEO of the Israel Ministry of Health in January 2014. These guidelines, which promote partial implementation of the "floating patient" method, state that patients whose symptoms suggest that they should be hospitalized in internal departments, and who have been waiting for several hours in the ED, should be moved (floated) to internal medicine departments as "floating patients". Generally, the triage nurses — or the triage physician in the case of PIT — are those who decide, based on their professional judgment, which patients will "float" to other departments. A "floating patient" policy can take pressure off ED physicians and lower the work rate in the ED, balancing it with work rates in other departments. This can reduce delays for examinations and treatments, thereby reducing patients' LOS and their uncertainty about their conditions, and improving service quality overall. In addition, this method can feasibly be implemented in the Israeli system, in which all data from a patient's triage evaluation are entered into his or her file and can easily be accessed and processed.

In order to build the simulation model, we develop a dynamic programming (DP) algorithm (based on a job-sequencing algorithm and an FPTAS scheme) to schedule patients' examinations and treatment in the ED while taking into account the hospital's budget. This algorithm is used to simulate the PIT decision method with the goal of achieving proper application of the "floating patient" method.

## 2. Problem description

The problem we address in this paper is a rather complex scenario of a decision-making triage physician in the ED, who