Optimal Strategy in Queueing Systems in Emergency Department

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ABSTRACT

The authors’ study a noncooperative game problem for queueing control in emergency department (ED). One of the challenges to emergency department (ED) is the control of the urgent patients and the non-urgent patients. The urgent patient which is the primary customer, can be considered as the service interruption in a queueing system. The service interruptions occur frequently and can incur significant delays for the non-urgent patients. Therefore, a non-urgent patient needs to decide whether to join the queue or leave. The scenario is modeled as an M/M/1 queueing game with server interruption where each patient wants to optimize his benefit. It is shown that the individually optimal strategy for joining the queue is characterized by a threshold of queue length. The socially optimal threshold of queue length is also obtained. To bridge the gap between the individually and socially optimal strategies, a pricing mechanism is proposed to toll the service of each non-urgent patient, thus equalizing the two optimal strategies.

KEYWORDS

Emergency Department (ED), Interruption, Patients, Queueing Theory

1. INTRODUCTION

The international crisis of emergency department (ED) crowding has received considerable attention, both in political (United States, 2003; Institute of Medicine, 2006) and lay (Barrero, 1989; Goldberg, 2000; Hoot & Aronsky, 2008) venues. J M. Pines (2015) considered the ED crowding problems facing hospitals in an Israeli ED, and pointed out that it is a prevalent and important issue facing hospitals in Israel and around the world, including North and South America, Europe, Australia, Asia and Africa (Pines & Bernstein, 2015). Three general themes existed among the causes of ED crowding: input factors, throughput factors, and output factors. Commonly causes of crowding included non-urgent visits, “frequent-flyer” patients, influenza season, inadequate staffing, inpatient boarding, and hospital bed shortages. And the effects of crowding included patient mortality, transport delays, treatment delays, ambulance diversion, patient elopement, and financial effect. Among them, the increased of non-urgent patients is an important cause of the crowding in ED.

The scenario is modeled as an M/M/1 queueing game with server interruption in ED, where each patient wants to optimize their benefit. Because the non-urgent patients cannot get exact queue length

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information immediately, we use the unobservable queue model, where non-urgent patients make a decision just based on the average delay measurement that takes into account the presence of the urgent patients. In this paper, the queue of the ED can be modeled by using the server-interruption queueing model. To understand the interruption, we can consider the ED, where non-urgent patients and urgent patients can be both served, as a server. When urgent patients emerge and occupy the non-urgent patient band, the server has a interruption, i.e. the service for non-urgent patients is stopped. We consider an arrival process of non-urgent patients, arriving at ED which is considered as the server. Each patient makes a decision whether to join or to leave the queue, i.e. leaving the ED. When a non-urgent patient makes a decision to join the queue, the waiting time in the queue will incur a cost. If the patient finishes his service then he will get a reward.

Fortunately (for academic study) or unfortunately (for practical systems), a new challenge, called service interruption, is identified for ED, as illustrated in Figure 1.

From Figure 1, we can consider the ED as a server and each non-urgent patient as a customer. When urgent patient emerges, the server service is interrupted due to the higher priority of the urgent patients. It is well known in queuing theory that such a service interruption can bring a substantial impact on various queuing metrics like average queue length and average waiting time (Doshi, 1986; Gaver Jr, 1962). Although interruptions have been shown in aviation and other work settings to result in error with serious and sometimes fatal consequences, little is known about interruptions in the emergency department (ED) (Chisholm et al., 2000). Many papers use queuing theory to derive and analyze different prioritization policies in ED services. But to the authors’ best knowledge, there few study on the queuing control subject to service interruptions for patients. In this paper, patients in ED will be divided into two types: non-urgent patients and urgent patients. We consider an M/M/1 queue with server interruption to study how to control the ED crowding.

In 1969, P. Naor found that, in a queuing system in which a customer decides to queue or not to queue, the individually optimal strategy, does not imply a socially optimum. Hence, P. Naor proposed a pricing mechanism to force the customers to change their strategies to the socially optimal one, which maximizes the total reward (Naor, 1969). Then, Edelson and Hildebrand (1975) shown that in unobserved queues the individual’s decision deviates from the socially preferred one. Therefore, a correct admission fee must be computed and administratively imposed. So, from the hospital’s point, we can impose an appropriate fee to control the number of non-urgent patients in ED.

To conclude, the main contributions of this paper are: we consider the interaction among non-urgent patients as a noncooperative game. Based on the queuing analysis for fixed non-urgent patients’ policies, we then analyze both individually optimal strategy and optimal social welfare strategy of non-urgent patients. A pricing agent, e.g., the ED, announces an admission fee for the queuing system such that the individually optimal decision of patients coincides with the socially optimal strategy that optimizes the total welfare of the society.

Figure 1. Illustration of queuing system with interruption
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