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Modeling and optimization of resources in multi-emergency department settings with patient transfer

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ABSTRACT

The increasing number of non-emergency patients in emergency departments (EDs) and long wait times caused by their overcrowding are some of the main concerns in health systems research. If an ED reaches an overcrowding state, there may be a need to transfer patients to other hospitals, which may or not belong to the same hospital system. Therefore, this paper investigates the effect of transferring non-emergency patients to other hospitals in multi-hospital settings. The strategy of transferring patients between hospitals can be used to minimize patient wait times without increasing the number of required resources. In this research, hospital capacity allocation is modeled using capacitated network design models, wherein transferring patients between hospitals is allowed. To investigate the effect of various system parameters, a comprehensive set of experiments are conducted for the proposed integer programming model. The experimental results showed that transferring patients is an effective way to decrease the number of patients waiting, especially in cases when minimum overlap exists in peak demand times of hospitals or when there is high uncertainty in the rate of patient arrivals. The experiments proved that the proposed patient transfer strategy can reduce the number of patients waiting by up to 35%. It was also shown that transferring patients between hospitals can decrease the resource requirements in each hospital by about 10%.

1. Introduction

In more recent decades, overcrowding has become a primary concern for emergency departments (EDs) [1–4]. The ED, which is designed to deliver urgent care to high acuity patients, is one of the critical departments of hospitals. Overcrowding usually occurs when the rate of patient arrivals exceed ED's available capacity, thereby leading to long wait times for patients to receive their required treatment. This issue is more problematic for high acuity patients who require immediate treatments; wherein delays could potentially impact patient outcomes (e.g., increase their mortality rates). ED overcrowding is a widespread phenomenon in the world, especially in the United States (US), where it has been reported as one of the most emergent threats for patient safety [5].

Although negative effects of overcrowding vary in different hospitals, an increase in the length of stay (LOS), ambulance diversions, mortality rates, medical staff frustration, and decrease in patient satisfaction are common in most EDs [6]. It is also proved that overcrowding can jeopardize physician productivity and the quality of care in some cases [5]. An imbalance in the supply and demand of emergency care has been recognized as a main cause of overcrowding in recent years. The main leading factor in causing this problem is a reduction in the number of EDs since 1992 in the US specifically [7]. Based on the statistics that are provided by the national hospital ambulatory medical care survey, from 1995 to 2005, there was 20% increase in the number of ED visits while the number of hospitals decreased by nearly 10% [8]. The increasing trend in ED visits decreased to 14% between 2005 and 2010; however, existing capacities are not sufficient enough to meet all arising needs [9]. It is also proved that lack of effective patient flow leads to overcrowding problem in emergency departments [10].

Another possible cause of overcrowding is an inefficient resource allocation in hospitals, which causes long wait times to receive services and treatments. It is proved that efficient management of limited resources in EDs can decrease patient wait times considerably [11]. Transferring patients between hospitals is also recognized as another possible solution to reduce wait times of patients. Based on this strategy, in the case of exceeding ED capacity, some non-emergency patients are transferred to other nearby hospitals with available capacity. Although some researchers discussed the advantages of transferring patients in

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terms of decreasing patient LOS and associated costs for hospitals, there are still some doubts about the efficiency of this method in special cases [12,13]. It should be noted that inappropriate patient transfer is recognized as an important reason for undesirable referrals rate increase [14].

The main objective of the current research is to model the transfer of patients between hospitals and associated capacity expansion costs in order to investigate the effects of multiple transfer strategy in multi-hospital settings. To the best of the authors' knowledge, this is the first time that this issue is studied in a systematic way by proposing the mathematical model to capture the impact on patient wait times. It should be noted that some studies investigated patient transfers based on real data available for hospitals in Hong Kong [15], Saudi Arabia [16], and the US [17]. However, no unique model has been presented to formulate these relations between hospitals thus far. The objective of the proposed model is to determine optimal resource levels of multiple EDs while considering patient transfer between hospitals. This work differs from the work by [18] in its optimization approach, and considers the possibility of patient transfer and incorporating the influencing factors of selecting a destination hospital.

The remainder of this paper is organized as follows. In the next section, previous works are reviewed to provide a summary of the relevant research. The resource allocation model is explained in detail in Section 3. Experimental results, including sensitivity analysis to validate the model, are presented in Section 4. The conclusion and ideas for future research are presented in Section 5.

2. Literature review

In the literature, various solutions were proposed to mitigate the ED overcrowding problem. As mentioned in the previous section, optimizing the number of available resources in the ED is a critical factor for reducing patients' waiting time and solving the overcrowding problem. Various simulation models were developed to model the capacity requirement of EDs [19–21]. Besides wait times, the effect of resources on predefined key performance indicators (KPIs) was investigated by [22]. Their studies proved that an appropriate nurse and physician allocation can reduce wait times in the ED by up to 20%. Resource allocation also has direct influence on system's throughput and rate of patient admissions [23]. Increasing the ED's throughput is one of the main objectives of system optimization from the hospital standpoint, in which the rate of patients dismissed per unit time needs to be minimized under existing budget constraints [24].

The agent-based simulation was applied by [25] to find the best combinations of doctors, nurses, and admission personnel in the ED. One of the common concerns in most of the research related to ED resource optimizations is to handle the high level of uncertainty in demand [26]. Fuzzy sets concept is one of the helpful tools to incorporate uncertain variables. For example, [27] integrated a fuzzy expert system with discrete event simulation to determine optimal configuration and levels of resources. To search for the best resource level in a more efficient way than the scenario testing approach, various meta-heuristic, such as genetic algorithm, can be applied [28]. In a different study, integer linear programming was applied to optimize staffing in an emergency room using a simulation-based optimization approach to incorporate the effects of stochastic variables on the final solution [29].

One of the main solutions for overcrowding is to select the best patient admission strategy. Bekker and Koeleman [30] determined the optimal number of admitted ED elective cases by applying queuing theory combined with a quadratic programming model. To prepare the best admission strategy, some other factors, such as differences in patient acuity mix, arrival patterns, and volumes, and efficiencies of processes, need to be considered [31]. It may be more appropriate also to consider different patient types that share the same resource in the ED [32,33]. Although simulation is known as one of the best methods for capturing the effects of uncertainty at the system level, other methods, such as queuing theory and integer programming, gained a lot of attention for solving similar cases in a more systematic way [34]. Zhu et al. [35] presented a multi-stage queuing system model for optimizing the number of nurses in outpatient departments, including registration, diagnosis, chemical examination, payment, and medicine-taking sections. They applied simulation and neighborhood search, combined with the simulated annealing (NS-SA) method to find the best planning strategy that minimizes nurse idle times as well as the patient wait times. Similar to resource allocation problems, the admission strategy selection involves uncertainties in arrival rates, which it handles by integrating fuzzy sets with queuing theory efficiently [36].

In order to overcome the associated problems, transferring patients between hospitals was accepted as another effective way to reduce the length of stay of patients [37]. Applying patient transfer strategy, hospitals that are overcrowded in a certain time period can transfer a limited portion of patients in their ED to other hospitals with available (unutilized) resources in order to minimize patient waiting times in system [38]. It should be noted that this approach is different from ambulance dispatching problems, in which the main concern is the decision about the destination hospitals for ambulances based on characteristics of patients and hospitals [39]. Depending upon the decision of each hospital, transferring patients can be applied to any group of low, medium or high-acuity patients. One of the main concerns about this strategy is long travel time between hospitals and associated risks for emergency patients, which causes doubt about the effectiveness of this method for emergency cases [40]. A summary of the key articles discussed in the literature review is provided in Table 1.

3. Optimization framework

The current research mainly deals with modeling the patient transfer between hospitals and investigating its effect on patient wait times and its associated costs. In multi-hospital setting, it might be more appropriate to transfer the non-emergency patients to other hospitals with available resources instead of tolerating unmet demand or long wait times. As a result, finding the appropriate level of resources, given the assumption that patient transfer will reduce the overcrowding problem in hospitals considerably. In this section, the optimization model, which is adopted from capacitated network design concept [41] by adding time dimension to the formulations, is presented. Both costs related to the resource allocation and potential costs of system operation, including the penalty costs, are considered in the optimization model. The following notations for sets, indices, and parameters are used in the proposed mathematical model:

i, j Hospital and demand area indices
t Time indices
k Patient type indices (1: emergency patients, 2: non-emergency patients)
H Total number of hospitals
T Optimization period
T' Period in/during which accepting patients will require overtime
K Patient type variations
α_i Cost of increasing one unit capacity in hospital i
β_i Cost or income of accepted patients in hospital i
ϑ_i Cost of overtime in hospital i