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RESOURCE MANAGEMENT AND PROCESS CHANGE IN A SIMPLIFIED MODEL OF THE EMERGENCY DEPARTMENT

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ABSTRACT

Using a simplified model of an emergency department (ED), we illustrate a 2-step methodology for determining the optimal mix of resources (beds, clerks, triage nurses, registered nurses, and physicians) for different arrival rates. These arrival rates cover the range of annual visit volumes typically observed in EDs in the United States. We also use the model to test a widely recommended process change in EDs: bedside registration. Rather than perform registration immediately after triage, registration is now performed only after the patient is placed in an ED bed and assessed by a nurse and physician. Our results show that bedside registration is efficient only when sufficient beds are available; when an ED is crowded and bed availability is low it actually leads to an increased length of stay. We view our model as a first step in the development of a more elaborate, multiple-acuity ED model.

1 INTRODUCTION

Emergency Departments (ED) in the United States (US) are in crisis (IOM, 2006). In 2004 between 40 and 50% of US hospitals experienced crowded conditions in their EDs and almost two thirds of metropolitan EDs experienced crowding (Burt and McCaig 2006). Crowding occurs when there are inadequate resources to meet patient demands leading to a reduction in the quality of care (Pines 2007). The effects of crowding in EDs are increased waiting times, patients who leave without being seen, ambulance diversions, and delays in care which in turn result in increased patient mortality and morbidity (Bernstein 2009). Increased waiting times and delays in care result in increased patient length of stays and decreased ability of EDs to see new patients.

The most important reasons for crowding in EDs in the US are the increasing number of patients who are sick and require hospitalization but there are inadequate hospital beds to meet the demand, so patients stay in the ED after admission waiting for inpatient beds. Between 1996 and 2006, the annual number of ED visits in the US increased from 90 million to 119 million (32% increase) and the overall population based ED utilization rate increased by 18%, from 34.2 to 40.5 visits per 100 persons. During the same 10 year period, the number of hospital EDs decreased from 4019 to 3833 (10% decrease) and the number of hospital inpatient beds decreased by 134,000 (Pitts et al. 2008, AHA 2008). There is also a shortage of registered nurses and emergency physicians in the US further compounding the resource issues faced by EDs and hospitals (Ginde, Sullivan and Camargo 2009).

Emergency departments are not only seeing more patients, they are seeing sicker, older patients. Between 1990 and 2006 the number of people in the US aged 65 or greater has increased from 31 million to 37 million; by 2020 there will be approximately 71 million people in the US 65 years and older (Health US, 2008). In 2006, a higher proportion of ED visits by patients who are 65 years and older were designated at triage (the initial ED assessment step) as emergent or requiring immediate care in comparison to other age groups (Pitts et al. 2008). Furthermore persons aged 75 years or older have the second highest per capita ED visit rate of 60 visits per 100 (Pitts et al. 2008).

As the number of patients coming to EDs has gone up in the past decade, so has the incidence of crowding. As crowding gets worse in EDs so does the quality of care. Optimally managing the present resources in EDs and finding ways to reduce patient length of stay is critical to improving patient care in our EDs. In this paper, we demonstrate the use of discrete event simulation for resource management and process changes in a simplified model of an ED (henceforth Simple ED). The Simple ED model is a first step to the development of more complex models, which will be the focus of our future work.

2 LITERATURE REVIEW

2.1 General Statistics on ED Crowding

Data on EDs in the United States is primarily based on the National Hospital Ambulatory Medical Care Survey (NHAMCS), annually issued by the U.S. Department of Health and Human Services. The reports of McCaig and Nawar (2006) and Pitts et al. (2008) summarize the NHAMCS of 2004 respectively 2006 by presenting statistical data. The most relevant numbers for our research are visit volumes, waiting times, lengths of stay and patient criteria (e.g. sickness and origin). The reports also provide data about the development of these key measures over time. Based on the NHAMCS of 2004 Burt and McCaig (2006) state in their report that ED crowding results both from an increased demand for emergency care and a shortage of clinicians. They also report the number of operational EDs and their visit volumes. Based on the NHAMCS of 2001, Sullivan et al. (2006) create a classification system for all US EDs. The key characteristics were annual patient volume and its distribution among EDs.

According to Pines et al. (2007) "an ED is crowded when inadequate resources to meet patient demands leads to a reduction in the quality of care". Hoot and Aronsky (2008) conduct a systematic review of past research investigating causes, effects and solutions of ED crowding. They classify the causes for ED crowding into input, throughput and output factors. Input factors related to the inflow of patients; throughput factors to bottlenecks within the ED; and output factors to downstream bottlenecks in other parts of the health system. Non-urgent visits and the influenza season were identified as input factors. Inadequate staffing was identified as a throughput factor whereas the principal output factor was inpatient boarding, i.e. the inability of an ED patient to get admitted in the hospital due to the unavailability of a hospital bed. The effects of ED crowding were adverse outcomes, reduced quality, impaired access (i.e. people left without being seen and ambulance diversion), as well as provider losses. Hoot and Aronsky (2008) identify increased resources, demand management and operation research as commonly studied solutions to ED crowding.

Moskop et al. (2009) single out inpatient *boarding* as the most important cause for ED crowding. Boarding happens when an ED patient needs to be admitted to a hospital inpatient bed but is unable to do so because of the unavailability of an inpatient bed. Schull, Kiss and Szalai (2007) investigate, using statistical analysis, the impact of low-complexity patients (i.e. patients with low-acuity levels) on ED length of stay. They concluded that a reduction of "the number of low-complexity patients is unlikely to reduce waiting times for other patients or lessen crowding".

2.2 Discrete Event Simulation (DES) approaches

One of the earliest DES studies was conducted by Saunders, Mahens and Leblanc (1989). They developed a basic computer simulation model to investigate the impact of resources on patient flow in EDs. Their results provide basic insights on resource management and their impact on the average length of stay (Avg. LOS). The most important results are that both the number of primary nurses and physician as well as triage levels have an impact on the Avg. LOS and waiting times. They additionally show that resource availability varies inversely with resource utilization. Takakuwa and Shiozahi (2004) state that both the Avg. LOS and waiting time for patients in an ED increase when more patients are serviced using the same number of resources. They develop a stepwise operations planning approach to minimize the Avg. LOS. They increased the resources corresponding to the highest waiting times. In their model highest waiting times occurred for getting into a bed and seeing a physician.

Wiinamaki and Dronzek (2003) used DES to project bed requirements for extension of an existing ED. Based on the predicted increase in demand for emergency care at the Sarasota Memorial Hospital, Florida, they estimated the number of beds based on the results of their DES of patient flow. They considered in their study especially the growth of patients aged 45 years or more. Baesler, Jahnsen and DaCosta (2001) used DES to estimate the maximum demand an existing ED can handle and also investigated the impact of resources in order to minimize Avg. LOS. In their study, the maximum level of demand was 130% of the base case value while the most significant reduction of Avg. LOS was directly related to an increase in the number of beds and physicians. In contrast to this study Samaha, Starks and Armel (2003) investigated the impact of additional beds and space on patient flow in an ED but observed that they had no real impact on the Avg. LOS. They therefore concluded that additional beds and space are not profitable. Furthermore Duguay and Chetouane (2007) stated based on their simulation study of patient flow in a Canadian ED that additional examination rooms have no impact on the Avg. LOS. However they observed that additional staff significantly reduced the Avg. LOS. The study of Khare et al. (2009) shows that an increased number of beds results in an increased Avg. LOS. Khare et al. (2009) also investigated the impact of admitted patient boarding times and concluded that an improvement of the rate that admitted patients depart the ED will reduce the Avg. LOS. They suggest improving the boarding process rather than adding additional beds in order to reduce Avg. LOS. Storrow et al. (2008) investigated the impact of lab turnaround times on patient flow in EDs. According to their simulation model the decrease in lab turnaround time results both in a decrease of Avg. LOS and increase of patient throughput. In summary, an increase of the resource beds most often has no impact on the Avg. LOS whereas additional staff as well as reduced boarding and lab turnaround times seem to decrease Avg. LOS.

2.3 Process Changes

The literature on process changes particularly deals with the introduction of fast-track areas within EDs and the rearrangement of an existing process order. Fast-track areas are used for patients with lower acuities requiring less tests, treatments, and resources in the process of care. These patients often have a shorter LOS and can be moved quickly through the process of care and discharged. Garcia et al. (1995) investigated in their simulation study the impact of the introduction of a fast-track lane on patient flow in an ED. Their study revealed that the introduction of a fast-track lane reduced the Avg. LOS for low complexity patients by almost 25 %. Additionally the Avg. LOS of other patients was not negatively affected by this change. The study of Samaha, Starks and Armel (2003) also shows a reduction of the Avg. LOS for low complexity patients by introducing a fast track-area. They also state that the introduction of a fast-track area in their simulation model reduces the Avg. LOS among all patients. Additionally McGuire (1994) showed based on his simulation model that the extension of the operating hours of a fast-track area also reduced the Avg. LOS among all patients.

Samaha, Starks and Armel (2003) investigated the impact of bed side registration on the Avg. LOS. Based on the results their suggestion is to avoid bed side registration because it decreases the Avg. LOS only marginally while raising the expenses significantly. Medeiros, Swenson and deFlitch (2008) investigated the impact of adding a doctor to the triage process on patient flow in an ED. With such a change, low complexity patients can be immediately treated and don't have to enter the main ED as well. Furthermore, lab tests can be ordered before the patient is taken inside the ED. Based on a simulation study, Medeiros, Swenson and deFlitch (2008) suggest that this change in process has the potential to improve emergency care. Furthermore, they conducted a pilot study which showed a reduction of the Avg. LOS among all patients by 23 %.

3 METHODOLOGY

3.1 The Simple ED

We now discuss the processes, patient flow and resource needs of the Simple ED, which can also be considered as a "Single Acuity ED". The patient goes through twelve sequential steps in the following serial order (see also figure 1 below):

Arrive - Triage – Register – Bed Placement – RN Assessment – MD Assessment – Tests - RN Procedure – MD Procedure – MD Discharge – RN Discharge – Discharge or Admit.

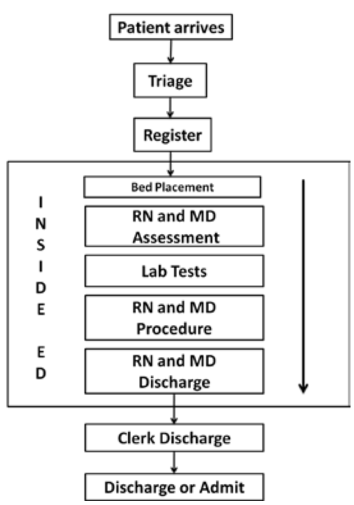

Figure 1: The emergency care process in the Simple ED

The emergency care process starts with patients arriving at the Emergency Department. The model allows only one type of patient arrival at the ED and therefore does not distinguish between patients walking in versus and those arriving in an ambulance. After a patient enters the ED, s/he is first seen by a triage nurse (t-RN). The triage care process consists of taking vital signs, doing a simple assessment, and estimating the acuity of illness. The Simple ED contains only one patient acuity level and all triage process steps are condensed into a single triage process.

After Triage, the patient goes through Registration where a clerk gathers the patient's demographic information and assigns the patient a medical record number. As soon as a bed becomes available the patient is taken inside the ED and placed in a bed (i.e. bed placement) and now is ready to be seen by the nurse (RN) and the doctor (MD) and have tests and treatment performed. The model accounts the possibility that the patient may have to wait before triaging, registering or bed placement. Such waiting occurs in a waiting room outside the ED treatment area. Once placed in a bed inside the ED, the patient receives an assessment by a primary nurse (p-RN) and by a physician (MD). After the MD assessment, the physician orders tests and treatments. In the Simple ED, several tests such as blood or X-ray tests are combined into one general test. Once the results of the test are available, the bedside procedures are performed. This consists of a RN procedure followed by a MD procedure.

Next the physician decides whether the patient is to be discharged (leave the ED for home) or admitted to the hospital. In the Simple ED, the term "discharged" includes leaving the ED or being admitted to the hospital. Before a patient can leave the ED, the primary nurse must complete the required paperwork. Upon discharge, the bed becomes available for a new patient to start the process of care within the ED.

Each patient can go through each of the process steps only if the required resources are available. The patient has to wait before the corresponding process step until the required resource becomes available. There are five different types of resources: beds, triage nurses (t-RN), clerks, primary nurses (p-RN) and physicians (MD). In between two process steps there is always a delay of one minute which reflects the fact that in reality a process step cannot immediately be followed by another one due to some natural delay, e.g. patient has to be taken to the X-ray area. The entire process of care without delays caused by waiting takes a minimum of 140 minutes; arrival to bed placement takes 18 minutes while bed placement to RN discharge takes 122 minutes. These numbers are reflective of the average time (averaged over different types of patients) it takes to see a patient in an ED in the United States when there is no wait time. Also, the default setting in the Simple ED is that every task performed by staff has the same priority among all staff groups as well as within a certain staff group.

3.2 Resource Management in the Simple ED

In order to investigate the impact of optimal resource management on patient flow in an ED we developed the following two-step method.

Step 1

First, we determine the optimal number of beds for each arrival rate (the method of defining the range of arrival rates will be discussed later). We do this by assuming that there are unlimited nurses, clerks, and doctors and calculating the number of beds such that the average LOS is 147 minutes or less (which is the minimum length of stay plus five percent). The number of beds obtained is a rough upper limit on the maximum number of beds needed in the ED for that arrival rate.

Step 2

Given the number of beds obtained in Step 1, we now optimize the mix of doctors, nurses and clerks needed so that the LOS is less than 169 minutes (minimum length of stay plus 20 percent. i.e. an average wait time of around 30 minutes). This is an arbitrary maximum length of stay but seemed clinically reasonable to the ED physician part of this research and allows for some delays in care (i.e. not a perfect system). With this constraining value for LOS, we will then optimize the resource mix that maximizes the ED's profit for a fixed number of patients. The simulation-optimization can be formulated as follows:

Maximize Profit
Subject to: Avg. LOS $\leq$ 169 min

We define profit as net revenue minus costs. The total net revenue for a given simulation consists of the sum of the net revenue for each patient. Net revenue per patient is obtained when a patient has completed the Simple ED process (i.e. a patient in our model only can be billed if he gets discharged or is admitted to the hospital). We assume in this Simple ED model that the revenue per patient is constant and that all arriving patients complete the Simple ED process. Costs are calculated based on the hourly staff salaries plus benefits times the duration of the Simple ED process, i.e. the time to treat all patients arriving at the ED.

3.3 Process Change: Bedside Registration

We use the Simple ED to test a commonly adopted process called *bedside registration*. Instead of the current Triage – Registration – Bed Placement – RN Assessment – MD Assessment sequence, we will change the order of processes to Triage – Bed Placement – RN Assessment – MD Assessment – Registration, with the remaining steps occurring in the same sequence as outlined in Section 3. Bedside registration is a process change that is widely recommended (GAO Report, 2009) to improve patient flow in an ED. The basic idea is: rather than do registration early right after triage, it can be delayed and done once the patient is in the bed. That way, the nurses and doctors can do patient assessments earlier.

We test bedside registration under three scenarios: 1) the "optimal" resource mix scenario; 2) crowded ED scenario; and 3) Open bed scenario. The optimal resource mix scenario is essentially the setting obtained using our 2-step methodology (the results of which are described in the previous section). The average LOS in this setting is not more than 169 minutes (waiting time per patient is not more than 35 minutes on average). We create a crowded ED scenario by decreasing the number of resources such that the length of stay is 60 percent of the minimum possible LOS. The third setting, the open bed scenario, is to reflect the situation that there is always an open bed once a patient is triaged. To model an open bed scenario while bedside registration takes place we use the optimal resource mix for each arrival rate and increase the number of beds to obtain zero waiting times for getting placed into bed.

3.4 Simulation Parameters

We test the model for arrival rates ranging from one to 20 patient arrivals per hour. These values are based on the fact that the smallest volume EDs may have a patient arrival rate of one or less patient per hour and the largest volume EDs in the US may have an arrival rate as high as 20 patients per hour. According to AHA (2008) EDs have a fivefold variation in the patient arrival rate during a 24 hour period. Baystate Medical Center in Springfield, Massachusetts, which is the source for many of inputs for this model, that has an annual volume of over 100,000 patients and an average patient arrival rate that ranges from 3 patients an hour to 16 patients an hour.

We assume inter-arrival times are exponentially distributed. For service times within the ED (i.e. for the activities shown in Figure 1, we use triangular distributions (based the opinion of an ED physician) in absence of detailed data. In all our simulations, we run 100 patients through the system and use 100 replications which give us 95% confidence estimates within 3% of the mean.

4 RESULTS

4.1 Resource Management

Table 1 shows the results of the resource mix obtained by our two step methodology. To quantify the effect of variability, we show the case were both arrivals are services are constant as well as the case where there is variability in both arrivals and services. As expected, variability increases staff requirements. We also observe from the table that the optimal resource mix consists of the same number of nurses and doctors and. This is contrary to reality where the ratio of nurses and physicians is about 3:1 (ED of Baystate Hospital, Springfield, FY 07). This is because our model does not accurately reflect the full workload of nurses yet. Furthermore, each patient requires the same number of treatments by nurses and physicians and the sum of treatment times per patient for both nurses and physicians is equal. Therefore we expect the need for the same number of nurses and physicians in the Simple ED. Additionally, the slightly higher number of physicians in the optimal resource mixes for all cases of variability is because in our model of patient flow each patient is assigned to one doctor who does not change during the care process whereas a patient can be treated by multiple nurses.

Figure 2 shows this increase in the total costs with an increase in variability in the Simple ED. Furthermore we observe that in the interval of arrival rates ranging from 2 patients per hour to 20 patients per hour. Costs are lowest for arrival rates ranging from 2 up to 20 patients per hour. In case of arrival rate 1 patient per hour it is still profitable in our scenario to run the Simple ED but in contrast to the other arrival rates by far less profitable. This matches with reality because an arrival rate of one patient per hour is most likely to happen in an ED at night, and EDs do operate at a financial loss during night shifts.

Table 1: Examples of optimal resource mix for 1) case of no variability in arrivals and services (constant case) and 2) case of variability in arrivals and services

Arrival Rate (patient per hour)	Optimal Resource Mix (Beds | Clerks | Triage Nurses | Nurses | Physicians)	
	Constant Case	Variability in Arrivals and Services
1	(3 | 1 | 1 | 1 | 1)	(4 | 1 | 1 | 2 | 2)
2	(5 | 1 | 1 | 2 | 2)	(7 | 1 | 1 | 3 | 2)
4	(9 | 1 | 1 | 3 | 3)	(11 | 2 | 1 | 3 | 4)
8	(16 | 2 | 1 | 6 | 6)	(20 | 2 | 2 | 5 | 7)
16	(31 | 3 | 2 | 9 | 9)	(33 | 4 | 3 | 10 | 11)

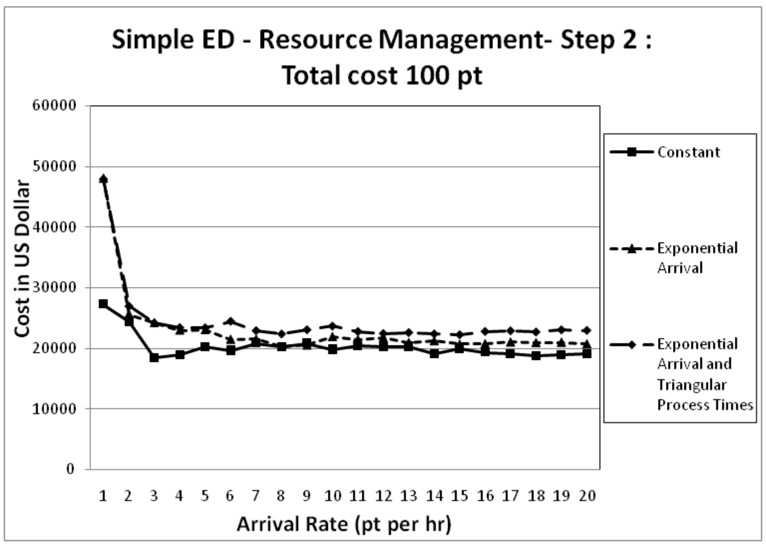

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Figure 2: Costs for seeing 100 patients for the different arrival rates

4.2 Bedside Registration

Figures 3, 4 and 5 show the impact of bedside registration in the three scenarios. Based on the results, we conclude that bedside registration has the potential to improve length of stay only in an open bed scenario – that is when an ED bed is always available to a patient after triage. In the optimal flow and crowded settings, bedside registration may actually worsen the length of stay. This is because the each patient occupies a bed longer, resulting in a scarcity of beds, which in turn pushes up the queue of patients waiting to obtain a bed. Our results correspond to those based on current literature. The GAO Report (2009) and the study by Takakuwa, Shofer and Abbuhl (2007) suggest to use bedside registration only during times when emergency department beds are available. This points to a state-dependent policy in EDs, where bedside registration could be performed when the ED has many unoccupied beds and avoided when an ED is crowded and bed occupancy is close to maximum.

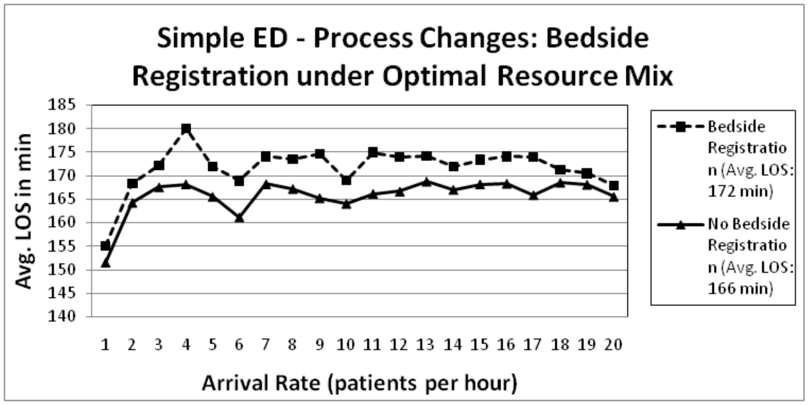

Figure 3: Bedside Registration under Optimal Resource Mix in the Simple ED for treament of 100 patients of single acuity and case of variability in arrivals and service times with arrival rates 1 to 20 patients per hour.

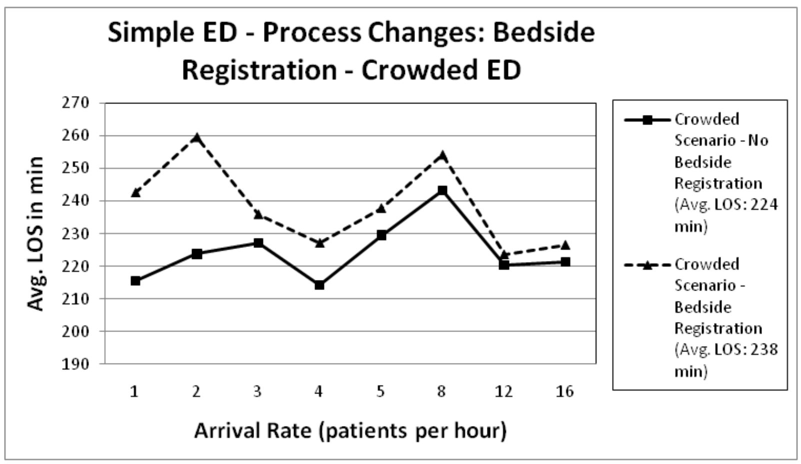

Figure 4: Bedside Registration under an Crowded ED scenario in Simple ED for treatment of 100 patients with single acuity and for case of variability in arrivals and services with arrival rates of 1 to 20 patients per hour.

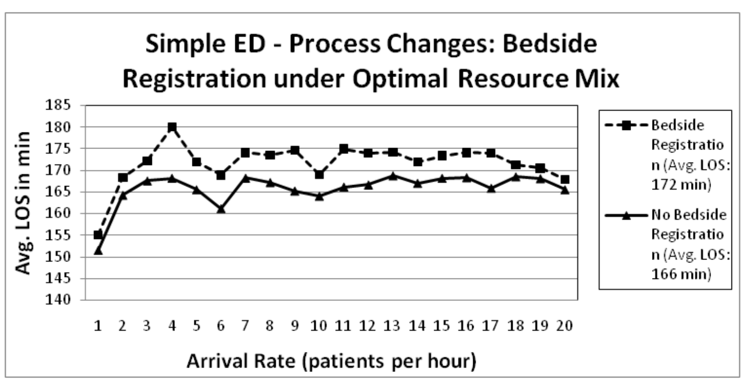

Figure 5: Bedside Registration under Optimal Resource Mix in the Simple ED for treament of 100 patients of single acuity and case of variability in arrivals and service times with arrival rates 1 to 20 patients per hour.

5 CONCLUSIONS AND FUTURE WORK

In summary we have outlined resource management and evaluated a process change in a simplified model of an emergency department. Our results provide staffing levels to be followed for various arrival rates such that a predetermined average length of stay is not exceeded and costs remain as low as possible. We also tested bedside registration, a widely recommended process change. Our results show the bedside registration may reduce length of stay only when an ED has beds available immediately after triage. While our model is a simplification of an actual ED, it allows us to generate preliminary findings which can then be further validated in a more realistic model.

A key feature of such a model is the presence of multiple acuities, since each patient is different. We will use five different acuities, which encompass patients with minor ailments to more critical patients whose process of care involves more steps (both in sequence and in parallel), requires more resources and time. We call this model, EDWA (ED With Acuities). In addition to resource management and evaluating process changes in EDWA, we also plan study the feasibility of a separate fast-track section in an ED. Fast-track sections are used for patients with lower acuities requiring less tests, treatments, and resources in the process of care; these patients often have a shorter LOS and can be moved quickly through the process of care and discharged. Many smaller EDs do not have a separate fast-track section; all patients are seen in the same beds by the same staff. An ED that is large enough may consider opening a separate fast-track section with dedicated beds and staff to expedite these patients through the ED process of care. We propose to study the impact of the introduction of such a fast-track area in the EDWA model on the Avg. LOS of all acuity levels as well as the operating costs. We will also identify when it is most "beneficial" to introduce a fast-track area given the arrival rates of the different acuities.

We will also use the EDWA model to study the effect of boarding on length of stay. Boarding is considered one of the main reasons for overcrowding and happens when an ED patient needs to be admitted to a hospital inpatient bed but is unable to do so because of the unavailability of an inpatient bed. The patient continues to occupy a bed in the ED, which delays other patients.

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