# USING SIMULATION TO EXAMINE OPERATIONAL EFFICIENCY ENHANCEMENT IN A HOSPITAL EMERGENCY ROOM THROUGH ADOPTION OF A FAST SERVICE TRACK

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**Abstract.** Overcrowding in hospital emergency departments has been reported in regions around the globe, and in many cases the situation is worsening. In order to alleviate overcrowding, hospital administrators have been studying and implementing different solutions for the enhancement of system efficiency. This work adopts a simulation approach to examine the implications of a fast service track on the efficiency of service provision. Our simulation experiments help examine possible tradeoffs between the waiting times of different types of patients when the fast track is adopted. We also found that the adoption of a fast-track system can be more beneficial, in terms of the reduction in overall patient waiting time, to emergency departments which have a higher proportion of urgent patients.

**Keywords.** Emergency department, Patient flow, Simulation, Fast Track

## 1. INTRODUCTION

Overcrowding in emergency departments (EDs) is a challenging and critical global issue (e.g., Cowan and Trzeciak, 2005; Derlet et al., 2001; Horwitz et al., 2010; Miró et al., 1999; Shih et al., 1999). While the problem has drawn great attention from the hospital's management and the public for years, the overcrowding situation is still observed to be worsening (Herring et al., 2009; Wilper et al., 2008). EDs have the mission of providing immediate and effective medical treatments to patients who have medical emergencies. However, the many challenges for EDs, such as increased complexity and acuity of patients, overall increase in patient attendances, managed care problems and lack of beds for patients admitted to hospitals (Derlet and Richards, 2000), have further complicated the overcrowding problem. As a result, the hospital's management has a very difficult task to promise the prompt provision of the necessary medical treatments to patients. The postponement of the delivery of the required medical treatements to patients has significant negative effects on the effectiveness of treatments provided to patients and may even cause unnecessary deaths of patients with life-threatening conditions. Although there has already been massive work on improving ED performance, the overcrowding problem remains unsolved in many hospitals because most potential solutions require large investments, e.g., expanding hospital capacities and increasing medical resources. Most hospitals, in particular government hospitals, have only limited financial budgets and are not able to afford. Therefore, hospital administrators have been seeking effective ways to enhance the ED operational efficiency. In this work, we study the effectiveness of a fast-track system on the enhancement of the ED performance with a simulation approach. We conduct computational experiments with the simulation model that we have previously developed for an ED to evaluate the impacts of the fast track.

This paper is organized as follows. In the next section, we provide a literature review on the applications of simulation for analyzing and improving ED operations. In section 3, we present our simulation model. In section 4, we conduct a computational study and examine the effectiveness of a fast-track system. Section 5 concludes our work.

## 2. LITERATURE REVIEW

Simulation has been adopted for aiding decision-making problems in healthcare delivery systems for more than half of a century (e.g., Fetter and Thompson, 1965) and the academic literature on its applications for healthcare management is vast. For an overview, we refer the reader to Jun et al. (1999), Fone et al. (2003), Günal and Pidd (2010), Katsaliaki and Mustafee (2011), Paul et al. (2010), and Gul and Guneri (2015).

There have been various successful applications of simulation for aiding decisions in EDs over the world. Rossetti et al. (1999) developed a simulation model of an ED in Charlottesville, Virginia and used the model to assess the impacts of different doctor work schedules on patient throughput and resource utilization. Yeh and Lin (2007) applied simulation with genetic algorithms to optimize the nurse roster and reduce patient waiting time for an ED in Central Taiwan. Ahmed and Alkhamis (2009) combined simulation and optimization to determine the staffing levels of different types

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of medical staff (e.g., physicians and nurses) in an ED in Kuwait. Their goal was to optimize, with limited financial budgets, both patient throughput and patient total time in the ED. Wang et al. (2009) applied a simulation approach to identify bottlenecks in the system of an ED in Lyon and examine resource allocation decisions. Abo-Hamad and Arisha (2013) developed a decision support system with the use of simulation to optimize the ED operations in an adult teaching hospital in North Dublin. They used the tool to determine the number of staff and the physical capacity for improving patient experience. They also examined, with their simulation model, the "zero-tolerance" policy regarding exceeding the national 6-hour boarding time and found that this policy has a great impact on reducing the average length of stay of patients. Kuo et al. (2016b) tackled the challenge of incomplete data for modeling service times and developed a simulation model of an ED in Hong Kong. They applied the simulation model to examine the effects of physician heterogeneity (Kuo et al., 2015) and missing patients (Kuo et al., 2016a) on the ED performance.

There have also been applications of simulation for analyzing effects of fast-track systems on ED performance. García et al. (1995) conducted a simulation study of the ED of Mercy Hospital in Florida and found that a fast track lane can reduce the total time in system for patients with low priority in the ED by almost 25% without negatively affecting other patients with higher priority. Connelly and Bair (2004) used a simulation model of an ED in Davis, California, to assess the effectivnesses of a fast-track triage approach and their proposed acuity ratio triage (ART) approach. They reported that their proposed ART approach could reduce the average treatment times for high-acuity patients; however, the tradeoff was the increase in the average service time for low-acuity patients. Kausha et al. (2015) developed an agent-based simulation model to evaluate a fast-track treatment strategy in an ED in Canada. They found that the strategy can reduce the patient waiting time without affecting the overall ED performance.

The above applications show that simulation is an appropriate and powerful tool for evaluating the effectiveness of a fast-track system in an ED. In this paper, we adopt a simulation model that we previously developed to examine the effects of a fast-track system on ED operational efficiency. We also conduct a sensitivity analysis and study possible tradeoffs between waiting times of urgent and non-urgent patients when the fast track is adopted.

## 3. CASE STUDY

In this section, we present the ED system of our case study and our simulation model. This ED provides provide 24-hour accident and emergency services. Between 07:00 and 23:00, mobile patients and non-mobile patients (i.e., those on a trolley or wheel chair) are treated respectively in two different divisions (referred to Walking and Non-walking Divisions). Between 23:00 and 07:00, the two types of patients are merged to receive medical treatments in the same division for better utilization of the reduced workforce commensurate with the low patient demand overnight. The ED has classified patients into five triage categories according to their level of urgency: 1 (critical), 2 (emergency), 3 (urgent), 4 (standard) and 5 (non-urgent). In this ED, categories 3 and 4 patients are the majority, consisting of more than 95% of the total patient attendances. Assuming that the numbers of category 1, 2, and 5 patients are negligible, the proportions of category 3 and category 4 patients are 30% and 70% respectively. The triage category gives the priority of receiving medical treatments. The more urgent, the higher priority the patient has. Within the same category, patients are treated on a first-come, first-served basis. Categories 1 and 2 patients are the critically-ill patients who need immediate medical treatments and will be rushed to resuscitation rooms promptly after they are admitted to the ED. For other patients, they first register upon arrival and then are examined by a triage nurse for assigning a triage category. After triage, they wait until being seen by a physician. After consultation, some may need to undergo certain diagnostic tests (e.g., X-ray and blood tests) and revisit the physician for a follow-up consultation. After all the required tasks are performed, they either leave the hospital or are required to stay in an in-patient ward for further examinations and treatments.

Based on the patient flow, ED layout and actual data collected, we developed a simulation model of the ED using simulation software ARENA. The main logic of our simulation model to represent the patient flow is depicted in Figure 1. For more details about the development of our simulation model, parameters estimation procedure, and model verification and validation, we refer the reader to Kuo et al. (2016b).

## 4. SIMULATION EXPERIMENTS: EXAMINING THE EFFECTIVENESS OF THE FAST-TRACK SYSTEM

For many EDs, patients are placed in a single queue for consultation, coded in terms of their levels of urgency (i.e., their triage categories). The more urgent patients will be given a higher priority to see a physician. However, these urgent patients are more complex and more likely to spend longer time for physician consultation. As a consequence, those patients with low priority may need to wait for many hours to be seen by a physician. Thus, this leads to the overcrowding problem in the ED (i.e., a large number of patients staying in the ED) and prolonged patient time waiting time. Both result in poor patient experience in the ED. More importantly, the overcrowding environment can also prevent the medical staff from providing effective and efficient services to patients.

The establishments of fast-track systems in EDs aim to facilitate care of the non-urgent cases in a more rapid fashion. A fast-track system first streams less complicated patients with low-acuity concerns and then treats them via a dedicated queue, which is different from the regular ones treating more urgent patients with a higher complexity. Fast-track systems have been demonstrated to be practically effective in many EDs (e.g., Considine et al., 2008; Kwa and Blake, 2008; Ieraci et al., 2008) and do not deteriorate the quality of care provided to patients (Sanchez et al. 2006). Although these real applications are shown to be successful, the effect of a fast-track system can vary from one environment to another. The hospital's management may wish to explore its potential benefits and impact on the ED performance before they start to actually implement the system. A simulation approach provides the hospital's management with a powerful way to examine the effect of a fast-track system on the ED operations without jeopardizing the patients.

In this section, we conduct simulation experiments to examine the effectiveness of a fast-track system in the ED that we study. Given real-world constraints such as limited financial budgets, EDs may not be able to hire an additional physician for this fast-track system. In our experiments, the physician dedicated to this fast track is relocated from the existing staffing resources. This setting enables us to compare the efficiencies of the different systems subject to the same level of resources. We adopt a similar fast-track system used in García et al. (1995), Meislin et al. (1988), and Hampers et al. (1999): a physician is dedicated to the non-urgent patients (i.e., category 4 patients in our example), but these patients can proceed to the regular physicians when the fast track doctor is occupied and the regular ones are free. In the simulation model, this fast track is established in the consultation module in Figure 1. After a patient is examined by the triage nurse, he/she will be diverted to the regular queue or the fast-track queue according to his/her triage category.

## 4.1. Computational instances

For the baseline simulation model in our computational study, we use the actual patient arrival rates to the ED, service-time distributions estimated in our previous work, staff work schedule as the model input. In order to conduct a more comprehensive study, we also consider other scenarios where the settings in the simulation model vary slightly from the baseline. This aims to conduct a sensitivity analysis to ensure that the enhancement of the fast track is robust with respect to the ED environment and to extract insights into the adoption of a fast-tack system in general EDs. Table 1 lists the scenarios that we examine in this simulation study.

Scenario S0 is the baseline case, which adopts the current actual settings of the ED. Scenarios S1 and S2 are to examine the effectiveness of the fast track with different proportions of formation of the major patient categories. Scenarios S3 and S4 consider the cases that the number of patient visits to the ED slightly changes by five percent. The fluctuation in the number of patient visits is common for EDs due to the increasing population, epidemics, and seasonal factors. Scenarios S5 to S8 are to examine the effectiveness of the fast-track system under different scenarios that the required attention paid to patients changes. As there has been reported that ED patients are becoming more complex, the level of required attention and the consultation time spent by physicians to patients also vary. For each scenario, we run two simulation experiments, with and without the fast-track system adopted, to examine the effectiveness of the adoption of the fast-track system.

## 4.2. Computational results

For each problem setting, we ran 100 replications of simulation runs of 34 days, each starting from an empty system. The first three days of each replication was a warm-up period and excluded for our reported statistics. This can be interpreted as simulating patient flows of 100 independent months. In each problem setting, more than one million patients are examined and included in our reported statistics. We recorded ED key performance indicators (KPIs) such as the average number of patients in the ED, i.e., work in process (WIP), net time between registration and consultation, i.e., patient waiting time (to first consultation), and doctor utilization. From the simulations, we computed the averages of these KPIs among the 100 replications, as reported in Table 2. We also report the absolute changes and percentage changes in these KPIs when the fast-track system is adopted.

**Table 1** Scenarios in our computational study.

| Scenario | Description |
|---|---|
| S0 | The simulation model adopts the original settings. |
| S1 | The proportions of category 3 and category 4 patients are 20% and 80% respectively (assuming the numbers of category 1 and 2 patients are negligible). |
| S2 | The proportions of category 3 and category 4 patients are 40% and 60% respectively (assuming the numbers of category 1 and 2 patients are negligible). |
| S3 | All the patient arrival rates decrease by 5%. |
| S4 | All the patient arrival rates increase by 5%. |
| S5 | The average of the consultation time for category 3 patients decreases by 5%. |
| S6 | The average of the consultation time for category 3 patients increases by 5%. |
| S7 | The average of the consultation time for category 4 patients decreases by 5%. |
| S8 | The average of the consultation time for category 4 patients increases by 5%. |

In all the scenarios, the adoption of the fast-track system could alleviate the ED overcrowding situation. The average number of patients in the ED and the overall patient waiting time were reduced after the fast track was adopted. However, as expected, there is a tradeoff between the waiting times of category 3 and category 4 patients; after the fast-track system was implemented, on average, category 4 patients could be seen by a physician earlier but category 3 patients had to wait for a longer time for consultation because one of the regular physicians was reallocated to the fast track. As the majority

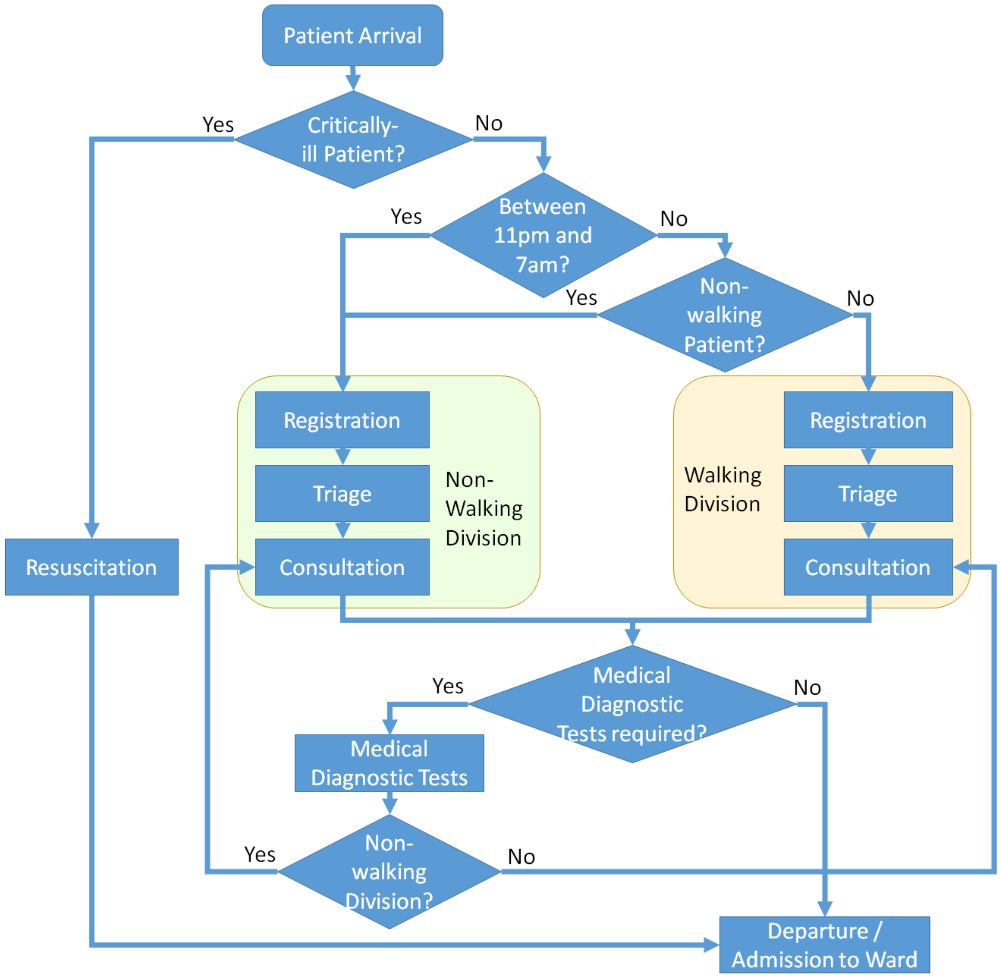


**Fig. 1** Main logic of our simulation model of the ED patient flow.

of patients in the ED are in category 4 and their absolute reductions in waiting time are significantly higher than those of category 3 patients, the overall waiting time could thus be reduced. The hospital administrators will have to determine whether this increase in waiting time of category 3 patients is acceptable. For example, in the current environment of the ED (i.e., scenario S0), although the adoption of the fast track increased the waiting time of category 3 patients by a large percentage (18.17%), the absolute increase was only around 4 minutes. In this is acceptable, the hospital administrators may consider the adoption of a fast track because the majority of patients (category 4 patients) can benefit from the fast-track system but at the same time the waiting time of category 3 patients is still within the acceptable range.

From the simulation results, we have the following observations.

1. The waiting time of category 4 patients is quite sensitive to the number of attendances and the consultation durations. A small change (5%) in the arrival rates or the average of the consultation time can lead to a big increase in the waiting time of category 4 patients. (Please compare S3 to S8 with S0.) This implies that the current ED environment is overloaded.
2. There is no significant change in doctor utilization due to the adoption of the fast-track system under all scenarios. This indicates that the fast-track system does not increase or reduce the physician workloads.
3. The reduction in the overall patient waiting time due to the adoption of the fast-track system is larger when there are more category 3 patients (a reduction of -8.82% in overall patient waiting time in S3, which is the largest among all scenarios). The reason is that when there are more category 3 patients, category 4 patients are expected to wait for a longer time. The fast track allows category 4 patients to bypass this large group of category 3 patients and, therefore, reduces their waiting time more significantly. This suggests that the adoption of a fast track can be more beneficial to EDs that have more patients of higher levels of medical urgency. However, when a fast-track system is adopted, the hospital's management needs to examine if the increase in the waiting time of the urgent patients is acceptable and to ensure that the care provided to those urgent patients is adequate.

**Table 2** Key performance metrics resulting from the ED systems with and without fast track adopted under difference the scenarios.

| Scenario | Is fast track adopted? | WIP | Waiting time (minutes) | | | Doctor utilization |
|---|---|---|---|---|---|---|
| | | | Category 3 | Category 4 | Overall | |
| S0 | No | 68.2 | 23.08 | 192.99 | 142.02 | 0.87 |
| | Yes | 64.74 | 27.28 | 177.05 | 132.12 | 0.8707 |
| Absolute difference | N/A | -3.46 | 4.19 | -15.93 | -9.89 | -0.0013 |
| % change | N/A | -5.08% | 18.17% | -8.26% | -6.97% | -0.15% |
| S1 | No | 73.03 | 24.33 | 193.58 | 159.73 | 0.8681 |
| | Yes | 69.37 | 27.7 | 178.75 | 148.54 | 0.8688 |
| Absolute difference | N/A | -3.65 | 3.37 | -14.82 | -11.18 | 0.0006 |
| % change | N/A | -5.01% | 13.88% | -7.66% | -7% | 0.07% |
| S2 | No | 65 | 22.62 | 199.06 | 128.48 | 0.8748 |
| | Yes | 64.74 | 27.28 | 177.05 | 117.14 | 0.8707 |
| Absolute difference | N/A | -0.26 | 4.65 | -22 | -11.33 | -0.0041 |
| % change | N/A | -0.41% | 20.6% | -11.05% | -8.82% | -0.47% |
| S3 | No | 55.69 | 19.75 | 134.81 | 100.29 | 0.8285 |
| | Yes | 51.07 | 23.38 | 126.69 | 95.7 | 0.8301 |
| Absolute difference | N/A | -4.62 | 3.62 | -8.11 | -4.59 | 0.0016 |
| % change | N/A | -8.3% | 18.35% | -6.02% | -4.58% | 0.19% |
| S4 | No | 100.18 | 27.7 | 318.82 | 231.49 | 0.9177 |
| | Yes | 94.82 | 32.36 | 295.47 | 216.54 | 0.9163 |
| Absolute difference | N/A | -5.35 | 4.66 | -23.35 | -14.94 | -0.0014 |
| % change | N/A | -5.35% | 16.82% | -7.32% | -6.46% | -0.16% |
| S5 | No | 64.62 | 23.35 | 176.44 | 130.51 | 0.8613 |
| | Yes | 62.42 | 27.15 | 166.26 | 124.53 | 0.8647 |
| Absolute difference | N/A | -2.19 | 3.79 | -10.17 | -5.98 | 0.0034 |
| % change | N/A | -3.4% | 16.26% | -5.77% | -4.58% | 0.39% |
| S6 | No | 74.47 | 23.5 | 212.63 | 155.89 | 0.8744 |
| | Yes | 70.08 | 27.67 | 201.52 | 149.37 | 0.882 |
| Absolute difference | N/A | -4.39 | 4.17 | -11.1 | -6.52 | 0.0076 |
| % change | N/A | -5.9% | 17.77% | -5.22% | -4.18% | 0.87% |
| S7 | No | 60.05 | 23.13 | 154.81 | 115.31 | 0.8489 |
| | Yes | 57.75 | 27.07 | 144.74 | 109.44 | 0.8486 |
| Absolute difference | N/A | -2.3 | 3.94 | -10.07 | -5.87 | -0.0003 |
| % change | N/A | -3.83% | 17.04% | -6.51% | -5.09% | -0.04% |
| S8 | No | 79.79 | 23.46 | 247.61 | 180.36 | 0.8937 |
| | Yes | 76.09 | 28 | 229.79 | 169.26 | 0.8945 |
| Absolute difference | N/A | -3.7 | 4.54 | -17.81 | -11.1 | 0.0008 |
| % change | N/A | -4.64% | 19.37% | -7.19% | -6.16% | 0.09% |

## 5. CONCLUSIONS

Overcrowding in EDs is one of the most challenging issues for hospital's management. Practitioners and researchers have been trying different ideas to tackle this challenge for many years but this problem remains unsolved in many EDs. In this paper, we adopt a simulation approach and conduct computational experiments to examine potential effect of a fast-track system on the ED performance. This fast-track is dedicated to non-urgent patients, who are the patients suffering from the prolonged waiting time for physician consultation. We found that the adoption of the fast-track system may alleviate the ED overcrowding situation by reducing the number of patients in the ED and the overall patient waiting time. We also observed that there is a tradeoff between the waiting times of urgent patients and non-urgent patients when a fast-track system is adopted. The hospital administrators will have to determine if the increased waiting time of the urgent patients is acceptable in return for the reduction in the waiting time of the non-urgent patients. A simulation model enables the policy maker to foresee the benefit from the adoption of a fast-track system and its detriment. From the computational experiments, we also found that a fast-track system can achieve a larger reduction in the overall patient waiting time for EDs which have more patients of higher levels of medical urgency.


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