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Omar M. Ashour, *The Pennsylvania State University*
Gül E. Kremer, *Iowa State University*
Deborah J. Medeiros

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Discrete Event Simulation Analysis to Compare Emergency Severity Index and FAHP-MAUT Triage Algorithms

Omar M. Ashour[1], Gül E. Okudan Kremer[2,1], and Deborah J. Medeiros[1]
[1]Department of Industrial and Manufacturing Engineering
[2]School of Engineering Design
The Pennsylvania State University
University Park, PA, 16802, USA

Abstract

Emergency Department (ED) crowding is a major problem in the U.S. like in many other countries world-wide. This problem is adversely affecting the safety of the patients who rely on timely emergency treatment. As a part of solving this problem, EDs utilize a triage process. Triage is a pre-hospital process by which patients are sorted according to the severity of their illnesses or injuries. Any improvement to this process would affect the patient flow positively, and in turn would enhance patient satisfaction and quality of care. In a previous study, we developed a new triage algorithm that uses Fuzzy Analytic Hierarchy Process (FAHP) and Multi-Attribute Utility Theory (MAUT) to rank the patients according to their characteristics: chief complaint, age, gender, pain level, and vital signs. The main purpose of this study is to compare two triage systems using Discrete Event Simulation (DES); one system uses the Emergency Severity Index (ESI), and the other uses the FAHP and MAUT algorithm. Based on the results, there was no strong statistical evidence that any system would do better than the other for all the performance measures when the average is taken across all ESI levels. On the other hand, the collected simulated data by each ESI level showed that the FAHP-MAUT algorithm tends to balance the time-to-bed (TTB) and length of stay (LOS) for ESI levels 2 to 5. This conclusion needs more study and should be interpreted carefully.

Keywords
Discrete Event Simulation (DES), Emergency Department (ED), Emergency Severity Index (ESI), Fuzzy Analytic Hierarchy Process (FAHP), Multi-attribute Utility Theory (MAUT)

1. Introduction
Emergency Department (ED) is a healthcare facility that provides medical treatments for patients with usually acute injuries or illnesses who come to the department without prior appointment, by either themselves or by ambulance. ED setting is unique in that patients arrive to ED without planned appointment, with various injuries or illnesses, with various health insurance plans or even without insurance. Some of these patients come with life-threatening status, and thus need immediate treatment, while others come with non-urgent status and can wait. In U.S., EDs are considered as vital components of the nation's health care safety net [1], which are responsible for 45%-65% of hospital admissions [2].

Emergency rooms are extremely complex. Complexity in health care settings, such as Operating Room (OR), Intensive Care Unit (ICU), and Emergency Room (ER), is obvious not only in the patient and treatment protocols, but also due to the high level of automation and instrumentation, huge volume of information, and interdisciplinary coordination that is necessary [3]. EDs in most hospitals operate 24/7. In 2006, there were 119.2 million visits to EDs [4]. Many U.S. EDs are exceedingly busy; in other words, they are crowded. Thus, they are characterized with increased production pressures, which prompt researchers to study the complexity and inefficiency factors of the ED system and the ED-hospital interfaces [5].

Every minute in the ED can make a big difference for patients. EDs usually implement a triage algorithm to assign a priority level for the coming patients. Triage is a pre-hospital process by which the triage nurse sorts the patients according to the severity of their illness or injury. The purpose of the triage interview is to place the patient in one of several queues, each having an associated maximum time until the patient sees a physician [6].

The aim of the paper is to compare two ED systems. One uses the Emergency Severity Index (ESI) algorithm to triage patients and the other uses the Fuzzy Analytic Hierarchy Process (FAHP) and Multi-attribute Utility Theory (MAUT) algorithm. The comparison is based on system performance measures, i.e., time-to-bed (TTB), length of stay (LOS), throughput, and time in ER.

The paper is organized as follows: section 2 describes key research papers that are relevant to the proposed work. Section 3 presents the problem and the methodology that was followed to draw our conclusions. Section 4 shows the experimental design and the results. Section 5 summaries the findings and future work.

2. Literature Review

One of the most commonly used triage systems in U.S., the five-level Emergency Severity Index (ESI), sorts the patients into five clinically distinct groups. These five levels are different with respect to resource and operational needs [7]. The most acutely ill patient gets ESI level 1 (the highest acuity level), or 2. The ESI levels 3, 4, and 5 (the lower acuity levels) are assigned based on the number of needed resources [7]. For example, a patient with ESI level 1 or 2 could be taken immediately to the treatment area, while patients with ESI levels 3, 4, or 5 can wait [7]. During triage process, the nurse records the patient's vital signs and then takes all the information about his/her current illness, past medical history, and any other needed information such as allergies and immunization status. Then, the nurse decides whether the patient needs immediate evaluation and treatment or he/she can wait [8].

Several attempts have been made to improve the ED care services. For example, minimizing waiting time intervals and improving patient satisfaction [9], developing a reliable decision support system in order to improve the patient waiting times and service quality problems [2], developing expert systems to aid the triage nurse in assigning patient's category [10], etc. The challenge in triage for nurses is to prioritize and rank non-urgent patients [8] in order to recognize who is most in need of care. Some hospitals in the U.S. use a three-level triage, which sorts the patients based on the question: "How long can this patient wait to be seen?" [2]. On the other hand, the five-level triage instrument has been developed and validated, which is based on not only on "Who should be seen first?" but also: "What will this patient need?" [11]. Despite the fact that this system sorts the patients and prioritize them based on severity of the illness and/or injury [11], the patients' waiting period or the order of treating them, especially, the patients with the same acuity level is rarely investigated [8]. Tanabe et al. [12] stated that the physician and nurses face a serious limitation of the ESI version 3; that is they could not determine how acutely ill these level 2 patients in the waiting room are, when they deal with the scenario of "there are six level 2 patients in the waiting room". Moreover, two levels of the ESI level 2 patients have been identified in the clinical experience; those who can safely wait for physician evaluation for at least 10 minutes without clinical deterioration, and those who cannot wait [12].

The prioritization of time-to-be-seen is essential to the patient and is related to his safety, especially, when the ED crowding delays evaluation [13]. Recent research utilized the utility theory to prioritize the patients with the same acuity level in EDs [8]. In this study, the authors demonstrated the use of utility theory in patient prioritization with a hypothetical example. They explained the choice of utility theory due to the inherent uncertainty in ED settings, and that the utility theory accounts for uncertainty. Ashour and Okudan [14] also present a solution to the problem of patient prioritization in EDs using utility theory. A major difference from prior work is that in this study patients are ranked with different acuity level, using patient age, gender, pain level, and the assigned ESI. For example, while vital signs (temperature, pulse, respiration rate and blood pressure) were considered for patient ranking in the Claudio and Okudan [8] study, patient age, gender and pain level information were neglected. Further, these variables were not considered in the ESI algorithm either.

In the work by Ashour and Okudan [15], the goal is to help triage nurses make the decisions more efficiently and easier taking into account their intuitive judgment and preferences but still minimizing potential bias. Their approach aggregates patient's chief complaint, age, gender and pain level along with the vital signs to create a clear ranking among waiting ED patients. The proposed decision algorithm starts by identifying the patient status as one would in the current ESI algorithm [7]. Then, if the patient requires any immediate intervention, he is considered to be in "Critical State". After this stage, the procedure progresses as follows: 1) Is the patient in need of immediate intervention? If the response is affirmative, he is a "Critical State" patient. If no, he goes to Step 2. 2) The triage nurse asks the patient about his complaint, pain level, age, and gender, and takes his/her vital signs. 3) The complaint and the vital signs data are treated using the FAHP as explained above to yield what we referred to as "pre-treated" data. 4) The data from Steps 2 and 3 are processed by the overall utility function to give the utility value for each patient. 5) Patients with high utility values go to the treatment area first, and the others with the lower values can wait in the waiting room. They are treated in descending order of priority based on the overall utility values.

In previous work, although it was shown that FAHP and MAUT based triage algorithm performs well, its comparison in a dynamic scenario has not been done; this paper fills this gap.

3. Problem and Methodology

3.1 Problem Definition

As discussed above, in EDs the triage nurse receives patients with different illnesses and/or injuries, and then based on several factors (i.e., vital signs, complaints, and pain level, etc.) he/she assigns the ESI level. Then, the nurse decides which patient will be treated first. The most widely used five-level ESI algorithm takes into account most vital signs in assessment of the acuity level (e.g., respiration rate, oxygen saturation and blood pressure, etc.). Only about 3% of the patients get the highest acuity level, and thus receive immediate service, however; the rest of patients would have to wait. Among the waiting patients, patients with lower ESI levels (which show a higher acuity level) will precede the others in receiving care. However, for conditions where several patients wait with the same ESI level, there are no clear differentiators to establish a prioritization. Clinical observations attest to the difficulty of this situation (e.g., [12]). Due to the dynamic and uncertain nature of the overall triage process in addition to the differentiation difficulty, methods are needed to help the triage nurse to be efficient (without increasing potential bias) in making prioritization among the patients with the same acuity classification.

Ashour and Okudan [15] have built FAHP and MAUT algorithm to help the triage nurses in making triage decisions. There is a need to investigate the effect of using this algorithm on system performance, such as, waiting times, resource utilization, etc. Simulation is an appropriate tool to compare two systems; one that uses the current triage algorithm, i.e., ESI, and the other uses the FAHP and MAUT algorithm.

The paper aims to investigate the effect of using the FAHP and MAUT algorithm on the system performance measures and to compare the performance measures of two systems; one that uses the current ESI triage algorithm and the other that uses the FAHP and MAUT triage algorithm. Table 1 shows the independent and dependent variables.

Table 1: Independent and Dependent Variables

Independent Variables	Dependent Variables (Performance Measures)
Current Triage Algorithm (ESI)	- Time-to-bed (TTB) - Length of Stay (LOS) - Time in ED - Throughput
FAHP and MAUT Algorithm	

3.2 Conceptual Model and Process Flow

In previous literature, Peck [16] has utilized Discrete Event Simulation (DES) to analyze patient flow in the Emergency Department (ED) to study the effect of operational changes of the Fast Track (FT) on the patient flow. His simulation model was built and validated based on his observations at the Newton-Wellesley Hospital (NWH), and thus reflects a realistic scenario. His conceptual model of the observed ED will be adopted for this study. We refer the reader to [16] for more information about the hospital but provide significant information below.

The ED has three Emergency Rooms (ERs). The main ER has two sides; one side has 12 beds and is open 24 hours, while the other side has 12 beds and is open from 10am to 2am. The pediatric ER has 8 beds and is open from 10am to 2am. The Fast Track (FT) ER has 4 beds and is open from 3pm to 11pm. The ED has 3 triage rooms, two of them are open 24 hours and the third one is open 10am to 2am. The incoming patients firstly approach the greeter desk and provide basic information and their chief complaint. Greeters pass the information to a triage nurse who works on a First Come First Served (FCFS) basis unless the severity of the patient injury/illness requires immediate attention. Then, the triage nurse does a preliminary examination for the patient, assign the ESI level, and send the patient to the waiting room. Patients under 18 years are sent to the pediatric ER, otherwise they are sent to the main ER. In any ER room, patients undergo a nurse examination, nurse treatment, doctor examination, doctor treatment, testing, and consultation. Patients experience one or more of these processes based on their needs. The patient then is either discharged to home or hospital, to another hospital, or to some other location. Figure 1 describes the process flow diagram of the ED at hand.

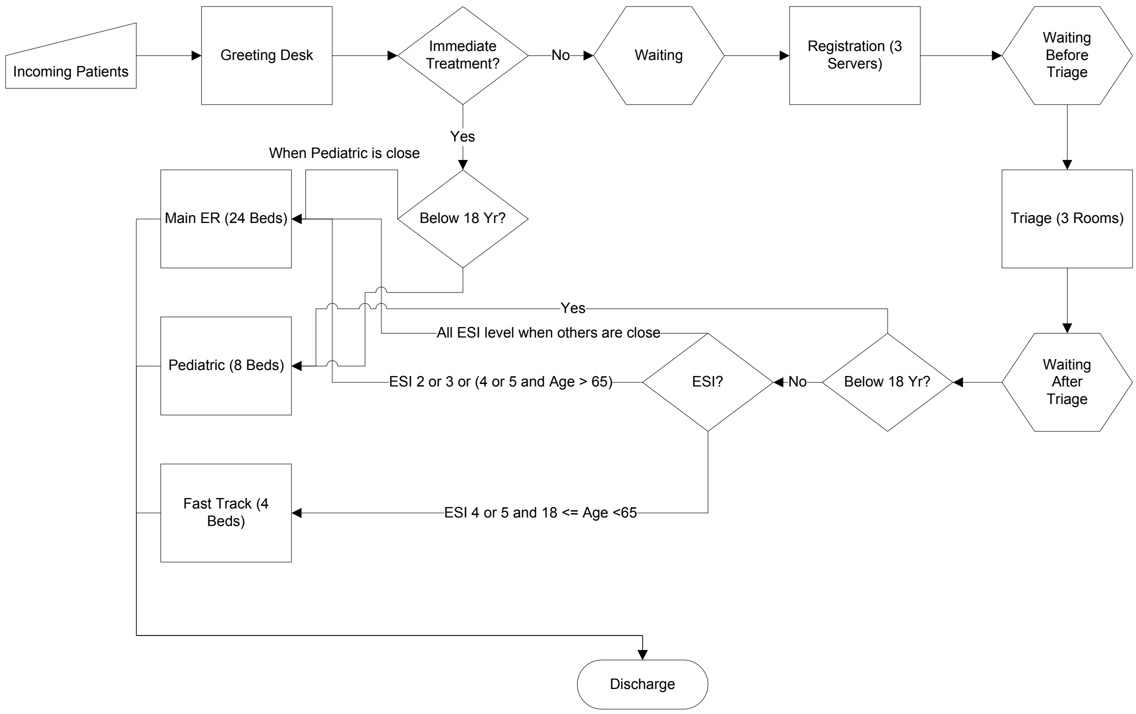

Figure 1: ED Process Flow

3.3 Model Assumptions and Simplifications

To design the experiment, the following assumptions and simplifications were made:

ED input/output assumptions:

1) Walk-in and ambulance-in arrivals are combined in patients' arrival.
2) Patients leave the ED by discharging them from the ED; the inpatient unit delays (boarding times are not considered), death, and transfer to any other location are not considered.
3) No scheduled appointments are allowed.

ED capacity assumptions:

1) The ED has three main departments; Main, Fast Track and Pediatric.
2) The total number of beds in ED is n_b, and $n_b^i$is the number of beds in department *i*, where *i* ϵ *{Main, Fast Track, Pediatric}*.
3) The number of doctors, nurses and equipment in ED are not considered in the model.
4) The greeting and registration desks have an infinite waiting capacity.
5) There is no limit for waiting times.

Operations assumptions:

1) The beds processing times are exponentially distributed and varied based on patient's ESI level.
2) The greeter desk has an exponentially distributed service time.
3) The patients' arrival process is a non-stationary Poisson process.

Although these assumptions may cause a deviation from the real life numbers, since the model logic is reflects a realistic case, we believe that the trends would still be useful.

3.4 Input/Output

The system variables used in the simulation model include inter-arrival times, treatment times, delay times (greeting). In order to count for variability, the input variables are modeled as random variables with appropriate probability distribution functions. System input variables are shown in Figure 2 and Table 2. In order to generate the arrival rates, we adopted an example of hourly patient arrival rates from [17] and the number of ED visits. The percentages based on ESI level and age categories were estimated using a two-week real dataset from Williamsport

Regional Medical Center, Williamsport, Pennsylvania. Patient treatment times in the ER were estimated based on Figure 3 from [16]. Since time in ER includes treatment time, testing, waiting, etc. the treatment times were estimated to be one third of the time in ER [16]. Table 2 presents the treatment times by ESI level.

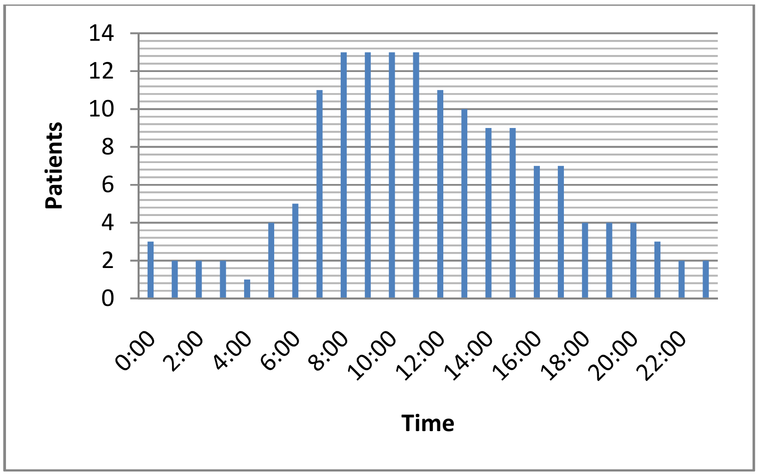

Figure 2: Patient Arrival

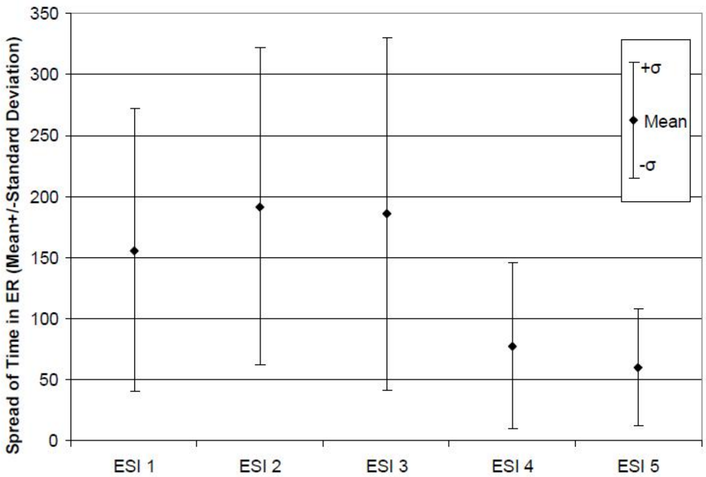

Figure 3: Time in ER by ESI Level [16]

Table 2: Processing Times by ESI Level

ESI Level	Greeting Time (Minutes)	Registration Time (Minutes)	Triage Time (Minutes)	Treatment Time (Minutes)
1	Random.Uniform(1,3)	0	0	Random.Exponential(55)
2	Random.Uniform(2,5)	Random.Uniform(5,10)	Random.Uniform(15,20)	Random.Exponential(65)
3	Random.Uniform(2,5)	Random.Uniform(5,10)	Random.Uniform(15,20)	Random.Exponential(60)
4	Random.Uniform(2,5)	Random.Uniform(5,10)	Random.Uniform(15,20)	Random.Exponential(25)
5	Random.Uniform(2,5)	Random.Uniform(5,10)	Random.Uniform(15,20)	Random.Exponential(20)

The FT accepts patients with the following criteria:

1) Younger than 65 years but not pediatric.
2) ESI 4 or 5.
3) Entered the ED during the FT hours.

The main ER would accept all ESI levels during the off-shift time of the FT and pediatric ERs. ESI level 1 patients go directly to the main ER or the pediatric ER (if they are under 18 and it is open).

The simulation outputs are: 1) ***Average Length Of Stay*** (LOS) is the length of time from the moment a patient steps into the ED after being greeted to when he is discharged from the ED system; 2) ***Average throughput*** is the number of patients who are discharged from the ED per hour; 3) ***Average time in ER*** is the length of time from the moment a patient steps into the bed up to when he is discharged from the ED system; 4) ***Average Time-To-Bed (TTB)*** is the length of from the moment a patient leaves the triage station up to when his treatment starts in an ER bed. Figure 4 defines the time metrics that describe patient flow.

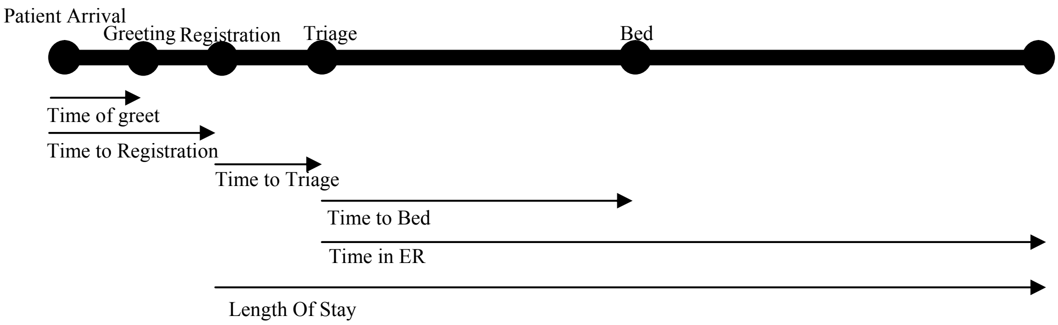

Figure 4: Time Metrics Used to describe Patient Flow

4. Experimentation and Results

Two alternatives are considered: 1) ED system that utilizes ESI algorithm, and 2) ED system that utilizes FAHP and MAUT algorithm. The alternatives were simulated for 74 days including 18 days as a warm up period, and the runs were replicated 20 times.

4.1 Results

This section presents the comparisons between the alternatives based on four performance measures: average TTB, average LOS, average throughput, and average time in ER. The alternatives have been compared using confidence intervals of differences in performance measures. The following equations have been used to calculate confidence intervals:

$$\left(\overline{Y}_1 - \overline{Y}_2\right) \pm t_{\alpha/2,\upsilon} * s.e.\left(\overline{Y}_1 - \overline{Y}_2\right) \tag{2}$$

$$s.e.(\overline{Y}_1 - \overline{Y}_2) = \sqrt{\frac{s_1^2}{R_1} + \frac{s_2^2}{R_2}} \tag{3}$$

$$\upsilon = \frac{\left(\frac{s_1^2}{R_1} + \frac{s_2^2}{R_2}\right)^2}{\frac{\left(\frac{s_1^2}{R_1}\right)^2}{R_1 - 1} + \frac{\left(\frac{s_2^2}{R_2}\right)^2}{R_2 - 1}} \tag{4}$$

Where; R_1 and R_2 are number of replications for system one and two, respectively; *s.e.* is the standard error; s_1 and s_2 are the standard deviations for system one and two, respectively; and v is the degrees of freedom.

The following table shows the resultant confidence intervals for each performance measure.

Table 3: Confidence Intervals of System Differences

Performance Measure	ESI System vs. FAHP-MAUT
Avg. LOS	(-1.46, 4.33) minutes
Throughput	(-36.23, 84.03) patients
Time in ER	(-0.34, 0.36) minutes
Avg. TTB	(-1.57, 4.35) minutes

According to Table 3, all the confidence intervals have zero; therefore, there is no strong statistical evidence that one system would do better than the other in terms of these performance measures. Therefore, we collected simulated data by ESI level for the average LOS and the average TTB performance measures. We noticed that these times are distributed almost uniformly across the ESI levels 2 to 5 in the case of FAHP-MAUT system. On the other hand, ESI level 5 experiences a very high average LOS and average TTB compared to the other ESI levels (2 to 4) in the case of ESI system.

The calculated confidence interval of average TTB for ESI 5 was calculated to be: (8.31, 207.19) minutes. This interval does not have a zero; thus, we have a strong statistical difference between the two systems. FAHP-MAUT system provides shorter TTB for patients with ESI level 5. This conclusion should be interpreted carefully, because this balance in TTB across patients with ESI levels 2 to 5 might adversely affect the patients with ESI level 2, who might be under high risk if they waited for long time. In addition, we set an upper limit for the TTB according to the Canadian Triage and Acuity Scale (CTAS) [18]: 1) Level I patients should have continuous nursing care; 2) Level II every15 minutes; 3) Level III every 30 minutes; 4) Level IV every 60 minutes; and 5) Level V every 120 minutes. Thus, patients with TTB less than these limits are assigned 1, otherwise 0. Then, the proportions of these patients are calculated by ESI level. Table 4 presents these proportions.

It should be noticed that for ESI level 2 patients, the TTB for all patients was not less than 15 minutes for both systems. Therefore, a new limit was set to be 30 minutes. According to the table, the FAHP-MAUT system outperforms the ESI system for ESI levels 4 and 5. Moreover, they were almost performing equally for ESI level 1. While ESI system slightly outperforms FAHP-MAUT system for ESI levels 2 and 3.

Table 4: Percentages of Patients with TTB less than a Specified Waiting Times

Percentage of Patients who Serviced	ESI 1 (ESI/FAHP-MAUT)	ESI 2 (ESI/FAHP-MAUT)	ESI 3 (ESI/FAHP-MAUT)	ESI 4 (ESI/FAHP-MAUT)	ESI 5 (ESI/FAHP-MAUT)
< 0.5 min	75/74	--	--	--	--
< 15 min	--	0/0	--	--	--
< 30 min	--	44/34	36/33	--	--
< 60 min	--	--	--	39/66	--
< 120 min	--	--	--	--	30/75

One solution for ESI level 2 patients is to exclude them from our algorithm and treat them as ESI level 1 patients or use another ranking rule which is a multiplication of the FAHP-MAUT score and ESI level then study the results.

5. Summary and Conclusions

DES has been used as a tool to compare two ED systems: one system uses the current ESI as a ranking rule while the other system uses FAHP and MAUT as a ranking rule. Despite the fact that the new system would lower the cognitive stress and load on the triage nurse, and would aid nurses to make better decisions, i.e. accurate and repeatable decisions for the same scenarios that they might face, we investigated the effect of using this algorithm on other system performance measures and compare it with the current system in terms of these measures.

The performance measures that were used are: TTB, LOS, throughput, and time in ER. These measures were averaged across all ESI levels. The results showed that there is no strong statistical evidence that one system would do better than the other in terms of these performance measures. The simulated data was collected by each ESI level, we found that the new algorithm tends to balance the length of stay and the time-to-bed for ESI levels 2 to 5. While the previous algorithm showed there is a huge difference in terms of these measures, for example, between ESI level 4 and Level 5. One case was tested, for ESI level 5 and the time-to-bed as a performance measure, the conclusion is the two systems are statistically different from each other, and the new algorithm outperforms the previous one.

Waiting time limits were established based on CTAS to measure the proportions of patients whose TTB times are less than these limits. FAHP-MAUT system outperforms the ESI system for ESI levels 4 and 5. Both systems almost perform equally for ESI level 1. On the other hand, ESI system slightly outperforms FAHP-MAUT system for ESI levels 2 and 3.

These conclusions should be interpreted carefully. Because of balancing, for example, TTB for all ESI levels except ESI level 1, ESI level 2 patients would experience longer waiting time which in turn might adversely affect their safety. Further studies are recommended to investigate all performance measures by ESI level.

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