Hospital Emergency Department (ED) Simulation for Resource Management

1. Introduction

The Emergency Department (ED) is an integral part of hospitals. Admissions from the ED account for a significant proportion for a hospital's activity. Ensuring a timely and efficient flow of patients through the ED is crucial for optimizing patient care. In recent years, ED overcrowding and its impact on patient flow has become a major issue facing the health sector.

Simulation is rapidly becoming a tool of choice when examining hospital systems due to its capacity to involve numerous factors and interactions that impact the system. In this project, a simulation model is developed to investigate potential impacts of changing the following aspects of ED (number of beds; number and rate of patient arrivals; acuity of illness or injury of patients; hospital staffing arrangements; and access to inpatient beds). The project combines implementation of basic data structures (priority queues, lists, arrays) with the design and implementation of several interesting interacting classes. In addition, you learn analysis of simulation results to evaluate ED performance efficiency. The performance of ED can be measured by one or more of the following performance indicators: waiting time; bed utilization and access block.

2. Problem Description

Figure 1 shows the ED patient flow. Specific elements along the path that patients follow include some or all of the following stages: arrival; triage (triage is the assessment of a patient's urgency for medical treatment and is divided into 5 categories 1-5 in increasing order of seriousness.); record retrieval; physician assessment; imaging and laboratory studies; x-rays or MRI; treatment planning; nursing activity; procedures (e.g. suturing and casting); decision to discharge or admit; access to inpatient beds and physicians. These stages generally occur in a sequential manner.

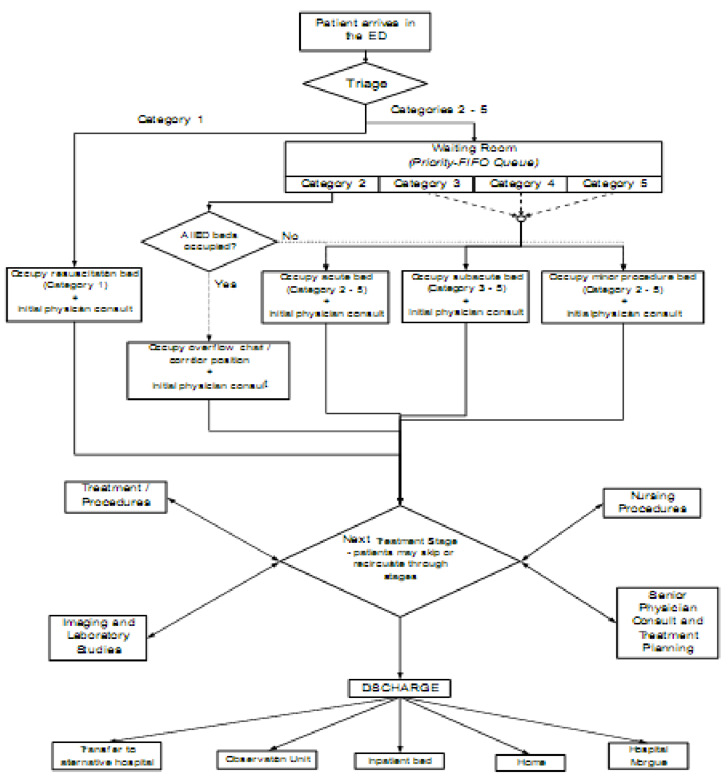


Figure 1. Patient flow through the ED.

Figure 1. Patient Flow through ED

Patients generally arrive according to some discrete probability distribution. The probability distribution is condition-dependent and recognizes: Multitrauma; Blood/Immune; Cardiac/Vascular; Diabetes/Endocrine; DNW Prior to Triage; Drug/Alcohol/Poisoning; ENT/Oral; Environmental/Temperature/MISC; Gastrointestinal; GP referred /Hosp transfer; Injury; Neurological; Eye; Nonemergent Review; Obstetrics/Gynaecology; Paediatric; Pain; Psychiatric/Behavioural; Regional Problems; Renal; Respiratory; and Urinary/Reproductive. As an example, patients with a gastrointestinal condition arrive with interarrival times according to a Weibull distribution with scale and shape parameters 180 and 0.914 respectively.

$$f(x)=\frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}e^{-\left(\frac{x}{\beta}\right)^{\alpha}}=\frac{0.914}{180}\left(\frac{x}{180}\right)^{-0.086}e^{-\left(\frac{x}{180}\right)^{0.914}}$$

Once a patient arrives, he/she is assigned a triage category and then assigned a treatment time and inpatient admission status dependent on the triage category. The final assignment is the post discharge decision time PDDT (only if the patient has a positive admission status), which follows a single probability distribution.
The percentages of each triage category for each condition are also studied; an example is shown in Figure 2.

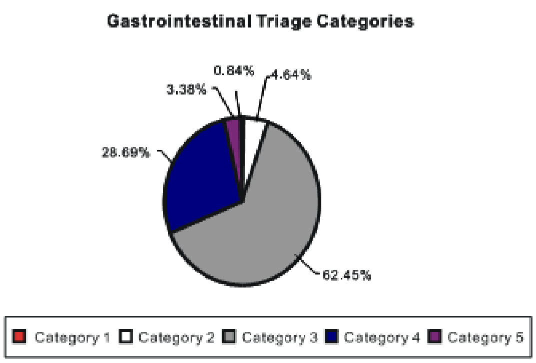


Figure 2. Category Distribution for Gastrointestinal Triage Categories

The treatment time and admission status is determined based on the category. The treatment times for Category 4 patients are based on a Pearson VI distribution with scale and two shape parameters 355, 1.64, and 5.72 with the following density function:

$$f(x)=\frac{\left(\frac{x}{\beta}\right)^{p-1}}{\beta\left[1+\left(\frac{x}{\beta}\right)\right]^{p+q}\mathrm{B}(p,q)}=\frac{\left(\frac{x}{355}\right)^{0.64}}{355\left[1+\left(\frac{x}{355}\right)\right]^{7.36}\mathrm{B}(1.64,5.72)}$$

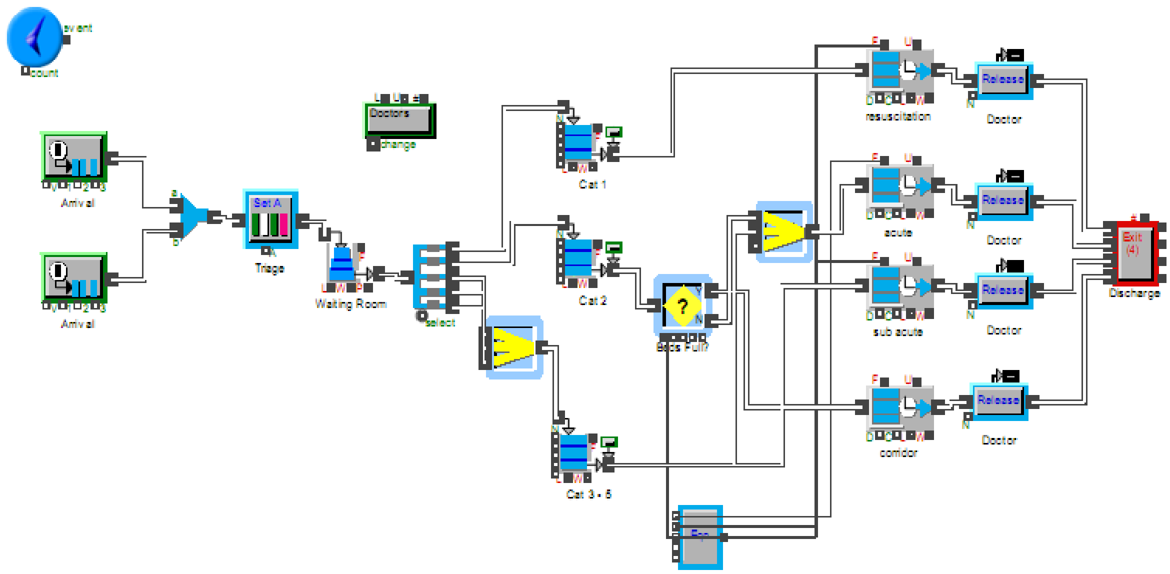
where B(p, q) is the beta function.

The patients, once being admitted to a treatment room, are then placed in other sub-queues as determined by their presenting condition. These sub-queues include staffing resources and diagnostic testing and imaging.
A patient may also be admitted as inpatient if required. The PDDT follows an exponential distribution with mean 156 and the following density function:

$$f(x)=\frac{1}{\mu}e^{-\frac{x}{\mu}}=\frac{1}{156}e^{-\frac{x}{156}}$$

Staffing resources queues are priority based allowing pre-emption, that is, patient treatment may be interrupted for treatment of a higher priority with the intent of returning to complete treatment.
Patients follow paths through the ED as shown in Figure 3. As can be seen paths are highly dependent on triage category.

Due to the possibility of the patient presenting with any condition or disease and being in any stage of that disease, patients have a variable time in the system. There are guidelines that dictate as to the expected length of time required for treatment of any presenting conditions by breaking up the patients into categories based on characteristics including condition, time of day, triage category, admission requirements, and productivity rates of the resources.



The assignment of the next arrival to enter the system is determined by a priority rule. Patients are triaged and seen according to priority. The College for Emergency Medicine gives the Triage Scale and the recommended maximum time between arrival in the ED queue and the commencement of treatment. The assumption is that if these patients are not seen within this time their condition will degenerate requiring further time in the system when they are finally treated. The categories that patients are sorted into are given in Table 1, along with the recommended and desired times for the patient to be assessed by a physician.

Table 1. Maximum Waiting Time for Various Categories

Category	Response	Description
1	Immediately	Immediately life threatening
2	10 minutes	Imminently life threatening
3	30 minutes	Potentially life threatening
4	60 minutes	Potentially serious
5	120 minutes	Less urgent

The resources in ED are both physicians and beds. Patients could only enter the ED system from the waiting room if both resources are available. Physicians possess multitasking patient treatment capabilities. Physicians in the ED include interns, junior residents, senior residents, registrars and consultants. The registrars and consultants supervise junior staff, consult patients as required and initiate and oversee the treatment of Category 1 and 2 patients. Interns are first year doctors who are able to treat Category 3-5 patients under supervision. Generally, interns can see 1-2 patients simultaneously. Junior and senior residents can treat Category 3-5 patients with supervision as required and form part of the team treating Category 1 and 2 patients. Junior and senior residents can see 2-3 and 2-4 patients simultaneously respectively.

The typical ED has 24 standard treatment areas ranging in equipment available for use. There are an additional 13 corridor positions for stretchers and 3 recliner chairs to be used as overflow treatment areas in cases of critical overcrowding. The ED consists of resuscitation beds (Category 1 only); acute beds (Category 2-5); subacute beds (Category 3-5); minor procedure rooms (Category 2-5).

3. Solution Design (Tentative, Incomplete)

3.1 Patient and Bed Classes

The member data of patient class represents the time of arrival, the assigned triage category, the time when the patient has been assigned a bed, and the time of discharge.

The bed object only needs to know whether a bed is available, or which patient is using the bed. A reference to a patient object can encode both pieces of information - a NULL reference indicates that the bed is available.

The bed that the patient can enter is dependent on their category and patients wait in the resource queue until a doctor is available to take them to the bed and perform an initial consultation. If all beds are full, Category 2 patients are routed to the corridor positions, otherwise they enter beds as normal. Once treatment is completed, the patients are discharged and doctors are released into the resource pool, available to see the next waiting patient.

3.2 Queue Classes

The simulation contains multiple queue types. All arrivals join a single queue in the waiting room. This queue is a priority-FIFO queue with patients being seen in order of priority (Category 1 through to Category 5) with the patients within a category group being seen in order of arrival. Lower category patients are bumped down the queue every time a higher priority patient enters the ED. When both a bed and a doctor are available the patient at the top of the queue enters an ED bed. The patient remains in the bed for the treatment time and, if the patient is to be admitted, the PDDT is generated. All patients are then discharged home; or to an inpatient bed.

3.3 Assumptions

- registrars and consultants are considered always available to initiate treatment on Category 1 and 2 patients and are sufficient to consult patients as required and supervise the junior staff;
- all patients are considered equal for inpatient bed placement-triage categories no longer dominate queue position but rather transfer to an inpatient bed depends on availability in the target ward and length of time waiting for bed;

3.4 Outputs

- utilization of the trainee doctors
- percentage of patients seen within recommended time
- utilization of the different bed types
- number of patients waiting

3.5 Collecting Statistics

There are several options for collecting the results of the simulation. The easiest is to save the results to a file. To make this file usable for further analysis, each line should represent the data for one discharged patient, with individual data items separated by tabs. This format is readable by most spreadsheet applications.

Another option is to create a dynamically growing array of patient discharge data objects. The STL vector class is well suited for this use. In any case, eventually, you should be able to see and plot the results for at least several different runs of the simulation.

3.5 Designing Experiments and Analyzing Data

You have to continue with designing a suite of simulation runs, where all decisions - the length of the run, the number of beds, and the discrete probability distributions are read from a file and several runs are done during one execution of the program.

At this point, you also work on designing the proper user interface, use input files in a meaningful setting, and work on the design of experiments.

You should be able to demonstrate what happens if more beds are available, measure the utilization of beds, model the busier times in the emergency room (e.g. Saturday night) when the number of patients and the severity of their problems increase, etc. You should also look at data and compare the behavior for the different sets of input parameters.

The user should be able to vary the discrete probability distributions of three events: patient arrivals, the triage of the patient's problem, and the estimated length of treatment in minutes. The user should also be allowed to choose the number of available beds and the length of the simulation run.