EEX5362 Performance Modelling

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GitHub Repository - https://github.com/SudaraDilshan/Performance-Modeling

1. High-Level Problem Statement

Emergency departments represent high-stakes environments that are the most critical to hospitals, with a complex, multistage service system configuration. Patients arrive unpredictably and vary in urgency, necessitating a series of services that range from triaging and registration to diagnosis, treatment, and discharge or admission. Bottlenecks often impede this flow, causing long patient waits and ED overcrowding, as well as staff burnout. Inefficiency in the process could therefore impact the quality of care and results in patient outcomes.

The core problem is to optimize the flow of patients through the ED to minimize the total time a patient spends in the system (Length of Stay) while efficiently using limited and expensive resources such as doctors, nurses, and diagnostic equipment. This requires deep understanding of the system's dynamics under varying loads, and the ability to test potential improvements in a risk-free environment.

2. System Description: The Multi-Stage ED Pipeline

The ED is modeled as a dynamic queueing network with the following key stages:

* Arrival: The arrivals are random. The rate of arrival is not constant and therefore often reaches its peak at specific times, like in the evenings or on weekends.
* Triage: A nurse assesses each patient to determine the severity level and categorizes accordingly (e.g., on a 5-level scale ranging from Level 1-resuscitation-to Level 5-nonurgent). This stage introduces a priority queue, whereby the more critical patients jump ahead in the line for the doctor.
* Registration: Administrative data collection. This process can proceed in parallel to other steps for non-critical patients.
* Treatment: This is the core service stage, where patients are seen by a doctor in a treatment bay. Service times here are highly variable.
* Diagnostics: A possible branch in patient flow where patients need auxiliary services such as X-rays, CT scans, or laboratory tests. These are typically shared resources and common bottlenecks.
* Disposition: The ultimate decision regarding the discharge or hospital admission of the patient.

With its feedback loops, priority interrupts, and sharing of resources, this system is one of the best candidates for performance modeling for analysis in terms of bottlenecks, throughput, and latency.

3. Performance Objectives

The primary aim is to minimize the average patient Length of Stay (LOS) in the Emergency Department. There is a positive correlation between reduced LOS and patient satisfaction, better clinical outcomes, and increased departmental capacity. This goal can be broken into the following specific, measurable performance objectives:

* Minimize Critical Latency ("Door-to-Doctor" Time): Time from patient arrival to first contact with a physician. Goal: Less than 30-minute median door-to-doctor time for high-acuity patients (Triage Levels 1-3).
* Maximize Patient Throughput: Increase the number of patients processed and discharged from the ED per 12-hour shift without sacrificing care quality.
* Identify and Quantify System Bottlenecks: Pinpoint the exact stage (for instance, triage, doctor availability, or waiting for a CT scan) or which resource is the limiting factor in overall system performance. The goal remains to assess line lengths and waiting times for every station.
* Optimize Resource Allocation: Analyze the utilization of key staff (doctors and nurses) along with physical resources-treatment bays-to suggest a data-driven staffing model by balancing the workload, hence reducing idle time, which ensures effective resource utilization. Evaluate
* System Scalability and Stability: Understand how the ED's performance, in particular, average LOS, degrades as the patient arrival rate increases - such as during a flu epidemic. This helps define the operational limits of the current system.

4. Data Set Description

For the purpose of this modeling exercise, a synthetic dataset will be generated that reflects realistic ED operations. The data will be structured to include the following entities and attributes:

Table: Patient\_Arrivals

| Column Name | Data Type | Description |
| --- | --- | --- |
| Patient\_ID | Integer | Unique identifier for each patient |
| Arrival\_Time | DateTime | Timestamp of patient arrival |
| Triage\_Level | Integer (1-5) | Severity level (1=most critical, 5=least) |

Table: Patient\_Flow\_Timestamps

| Column Name | Data Type | Description |
| --- | --- | --- |
| Patient\_ID | Integer | (Foreign Key) Links to Patient\_Arrivals |
| Triage\_Start | DateTime | Time triage assessment began |
| Triage\_End | DateTime | Time triage assessment ended |
| Doctor\_Seen | DateTime | Time first seen by a doctor |
| Labs\_Ordered | DateTime | Time lab tests were ordered (if applicable) |
| Imaging\_Ordered | DateTime | Time imaging was ordered (if applicable) |
| Disposition\_Time | DateTime | Time of decision to discharge/admit |
| Departure\_Time | DateTime | Time patient physically left the ED |

Table: Resource\_Availability

| Column Name | Data Type | Description |
| --- | --- | --- |
| Shift\_Start | DateTime | Start of a staffing shift |
| Shift\_End | DateTime | End of a staffing shift |
| Doctors\_On\_Duty | Integer | Number of doctors available |
| Nurses\_On\_Duty | Integer | Number of nurses available |
| Available\_Bays | Integer | Number of free treatment bays |