Simulation of Emergency Department System Performance and Capacity Design

Introduction

Emergency Departments (ED) in hospitals play a critical role in providing immediate care to patients with various conditions, ranging from minor injuries to life-threatening emergencies. However, as patient volumes increase, EDs face significant challenges in managing patient flow, optimizing resource utilization, and reducing wait times. The complexity of these systems, especially in larger hospitals, makes it difficult to ensure efficient performance during periods of high demand.

This report explores how discrete-event simulation (DES) can be used to model and evaluate the performance of an ED system. In particular, we will focus on a hospital's Fast Track and Main ED areas, assessing system bottlenecks, identifying areas for improvement, and informing decisions about optimal capacity design. The simulation results will provide valuable insights for improving patient care and operational efficiency.

Process Flow of the Emergency Department System

A clear understanding of the process flow is critical in designing an effective simulation model. Below is the typical sequence of events in the ED system:

Patient Arrival: Patients arrive at the Emergency Department (ED) based on predefined arrival rates specific to both the Fast Track and Main ED areas.

Triage: Upon arrival, patients undergo triage to assess their condition and determine whether they should be directed to Fast Track or Main ED.

Treatment Process:

Fast Track: Patients in this area receive quick treatment, primarily for minor ailments, and are subsequently discharged.

Main ED: Patients requiring more extensive treatment may undergo laboratory tests and will either be discharged or admitted to the hospital for further care.

Room Management:

Once treatment is completed, rooms or treatment cubicles are cleaned and prepared for new patients. The availability of rooms is a key factor in ensuring smooth patient flow through the system.

Admission/Transfer Process:

Patients requiring admission remain in the ED until they are transferred to another department.

Simulation Model Algorithm

The simulation model focuses on patient flow through the Fast Track and Main ED areas. By modelling the ED as a discrete-event simulation, we can incorporate variability in patient arrivals, treatment times, and resource availability. The model will allow us to explore different scenarios and evaluate their effects on key metrics such as wait times and resource utilization.

Key Input Data:

Patient Arrival Rates: The rate at which patients arrive in both Fast Track and Main ED areas. This could be based on historical data.

Service Times: The time taken for a patient to be treated (e.g., average treatment time in Fast Track and Main ED).

Staffing Levels: The number of doctors, nurses, and other medical personnel available in each area.

Cubicle Availability: The number of treatment cubicles available in both Fast Track and Main ED areas.

Patient Characteristics: Information on the severity of patients (e.g., Fast Track patients vs. Main ED patients).

During the simulation, key metrics such as patient wait times, treatment durations, and resource utilization are simulated. This data is then analysed to assess system performance and inform resource allocation and capacity decisions.

Simulation Process:

Patient Arrival: Patients arrive based on predefined rates (e.g., hourly or daily).

Triage: Patients are assessed based on their condition, and triage times are simulated based on staff availability.

Treatment Process: Depending on triage, patients are routed to either Fast Track or Main ED, where they undergo various treatments and processes (e.g., lab tests, doctor consultation).

Resource Allocation: The model tracks the availability of key resources (doctors, nurses, cubicles) and assigns them to patients based on availability.

Metrics Tracking: The simulation records key performance metrics such as wait times, resource utilization, and throughput.

Simulation Outputs and Performance Evaluation

Wait Time Histogram:

Purpose: Displays the distribution of patient wait times (e.g., triage, doctor consultations, cubicle assignments).

Interpretation: Peaks in the histogram signal bottlenecks where delays occur. For example, a peak at high wait times in triage indicates insufficient triage staff, while peaks at the other stages suggest similar resource constraints.

Average Wait Time:

Purpose: Provides an overall measure of the average time patients wait at various stages.

Interpretation: High average wait times signal that resources are insufficient to meet patient demand. Lower average wait times suggest an optimized system with sufficient resources.

Utilization Rates:

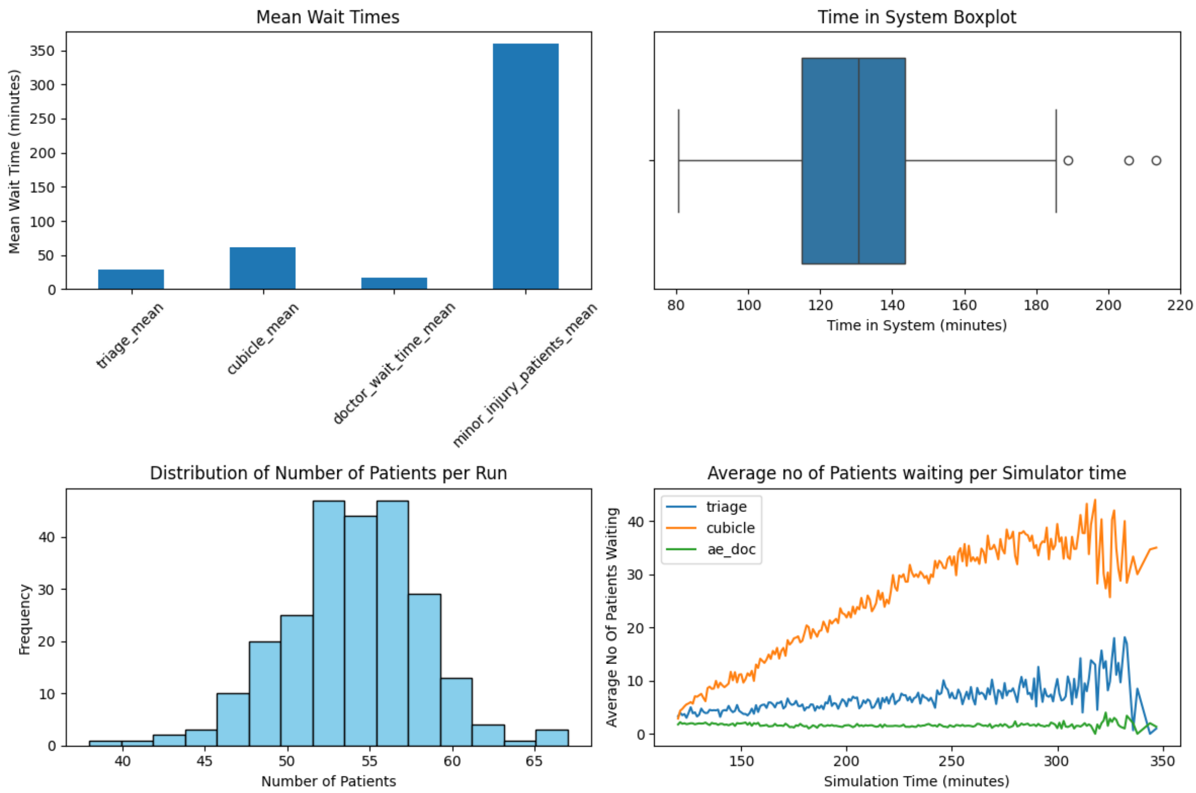
Purpose: Measures the percentage of time that resources (doctors, nurses, cubicles) are in use.

Interpretation: If utilization rates are too high (e.g., over 85-90%), it may indicate overburdening of resources. Conversely, very low utilization suggests inefficiency in resource allocation.

Throughput:

Purpose: Tracks the number of patients treated over a defined period.

Interpretation: Higher throughput indicates that the ED is efficiently processing patients. If throughput is low, the system may be overwhelmed by demand or inefficient in its patient management.



Detailed Metrics

Triage Mean: This represents the average wait time for patients to see a triage nurse, measuring the duration from arrival to initial assessment.

Cubicle Mean: This metric indicates the average wait time for patients awaiting placement in a cubicle after triage, reflecting delays before receiving further assessment or treatment.

Doc Mean: This average wait time quantifies how long patients wait to see a doctor after being placed in a cubicle, shedding light on potential inefficiencies in the treatment process.

Minor Injury Unit (MIU): The MIU handles less severe injuries, streamlining care for patients who do not require comprehensive ED services, thus optimizing overall patient management.

Actionable Insights

The simulation results allow hospital administrators to make informed decisions about staffing and resource allocation.

Staffing Recommendations:

Triage Staffing: Increasing the number of triage nurses can reduce wait times by allowing for more parallel assessments.

Doctor Staffing: Adding more doctors reduces wait times, particularly in the Main ED, although the effect diminishes beyond a certain point.

Resource Allocation:

Cubicle Management: Optimizing cubicle assignments is critical in minimizing delays, especially in the Main ED where complex cases may require extended treatment.

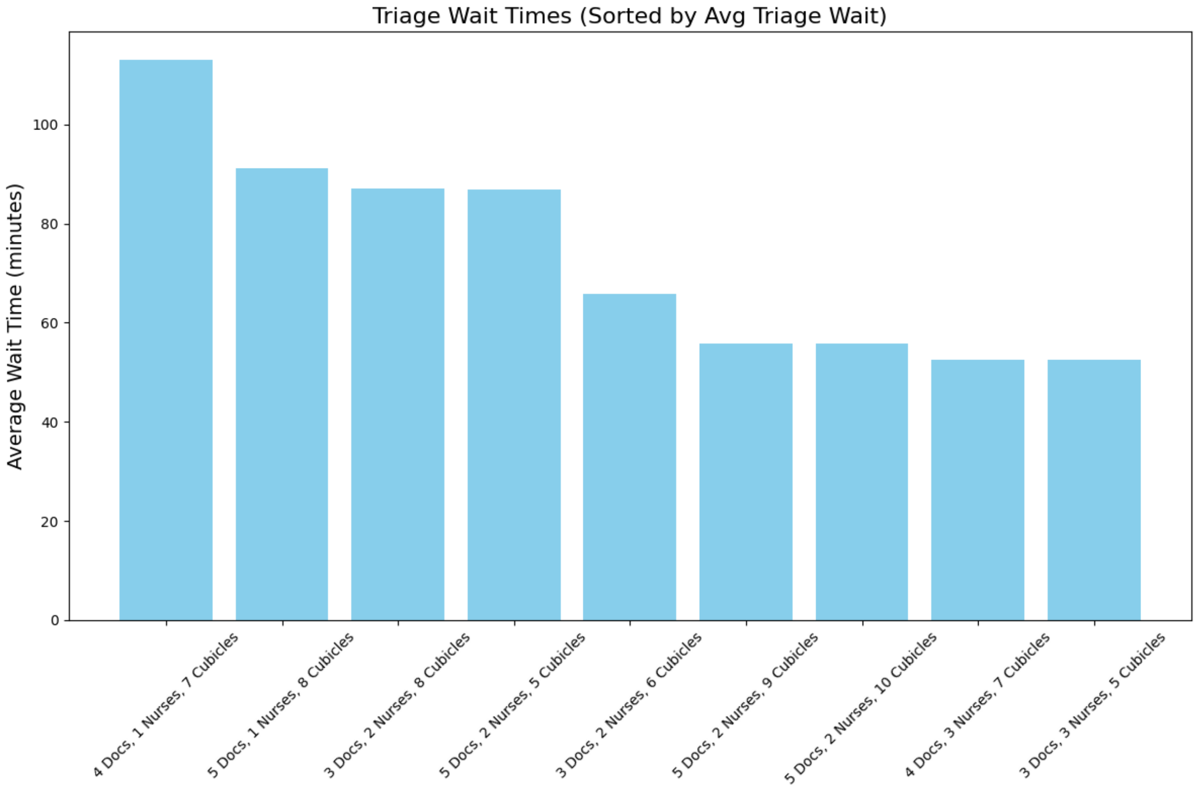
Fast Track Staffing: Increasing staffing levels in the Fast Track area improves throughput by reducing treatment times, particularly during periods of high volume.

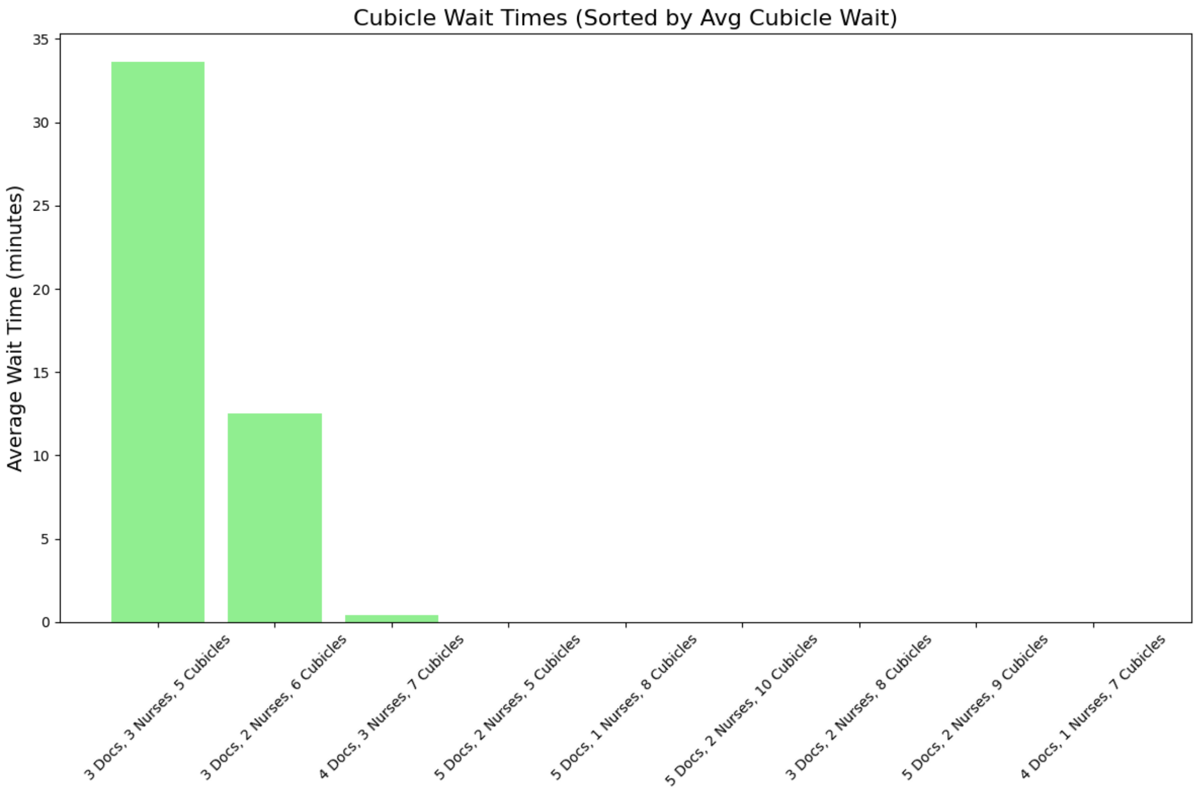
Scenario Analysis:

Simulating various staffing and patient arrival scenarios enables hospital administrators to test the effectiveness of different strategies, such as adding staff during peak times.

Effect of Resource Availability on Wait Times

From the simulation, we can draw insights about how varying the number of available resources (doctors, nurses, and cubicles) influences wait times at different stages of the emergency department process:


Triage Wait Times (Sorted by Avg Triage Wait)
Average Wait Time (minutes)
0
20
40
60
80
100
4 Docs, 1 Nurses, 7 Cubicles
5 Docs, 1 Nurses, 8 Cubicles
3 Docs, 2 Nurses, 8 Cubicles
5 Docs, 2 Nurses, 5 Cubicles
3 Docs, 2 Nurses, 6 Cubicles
5 Docs, 2 Nurses, 9 Cubicles
5 Docs, 2 Nurses, 10 Cubicles
4 Docs, 3 Nurses, 7 Cubicles
3 Docs, 3 Nurses, 5 Cubicles


Cubicle Wait Times (Sorted by Avg Cubicle Wait)
Average Wait Time (minutes)
0
5
10
15
20
25
30
35
3 Docs, 3 Nurses, 5 Cubicles
3 Docs, 2 Nurses, 6 Cubicles
4 Docs, 3 Nurses, 7 Cubicles
5 Docs, 2 Nurses, 5 Cubicles
5 Docs, 1 Nurses, 8 Cubicles
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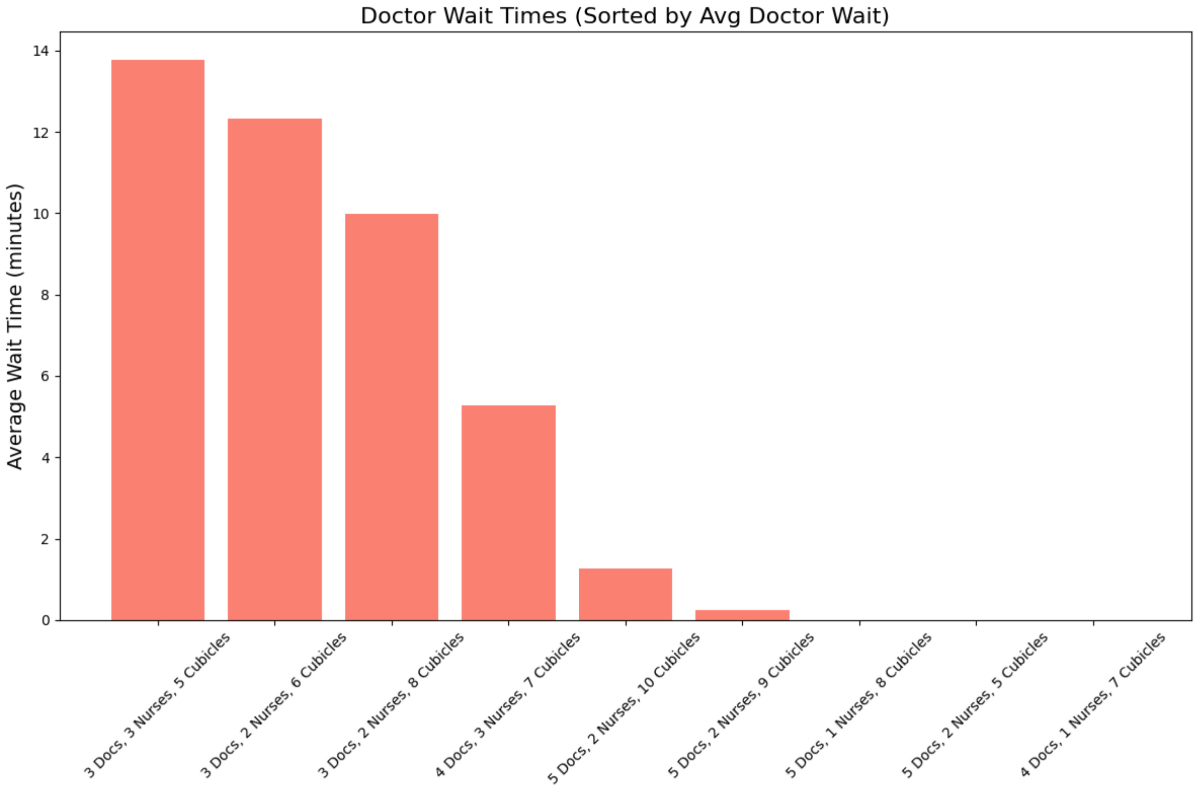
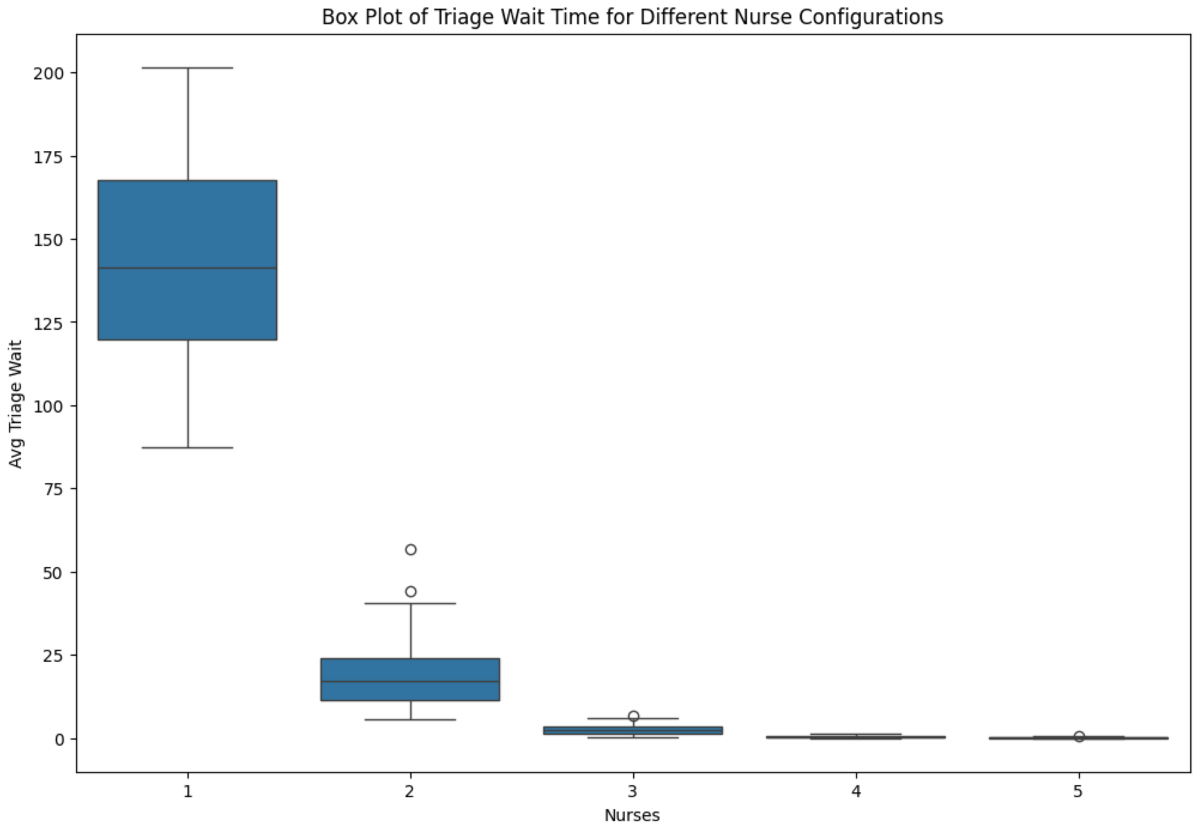
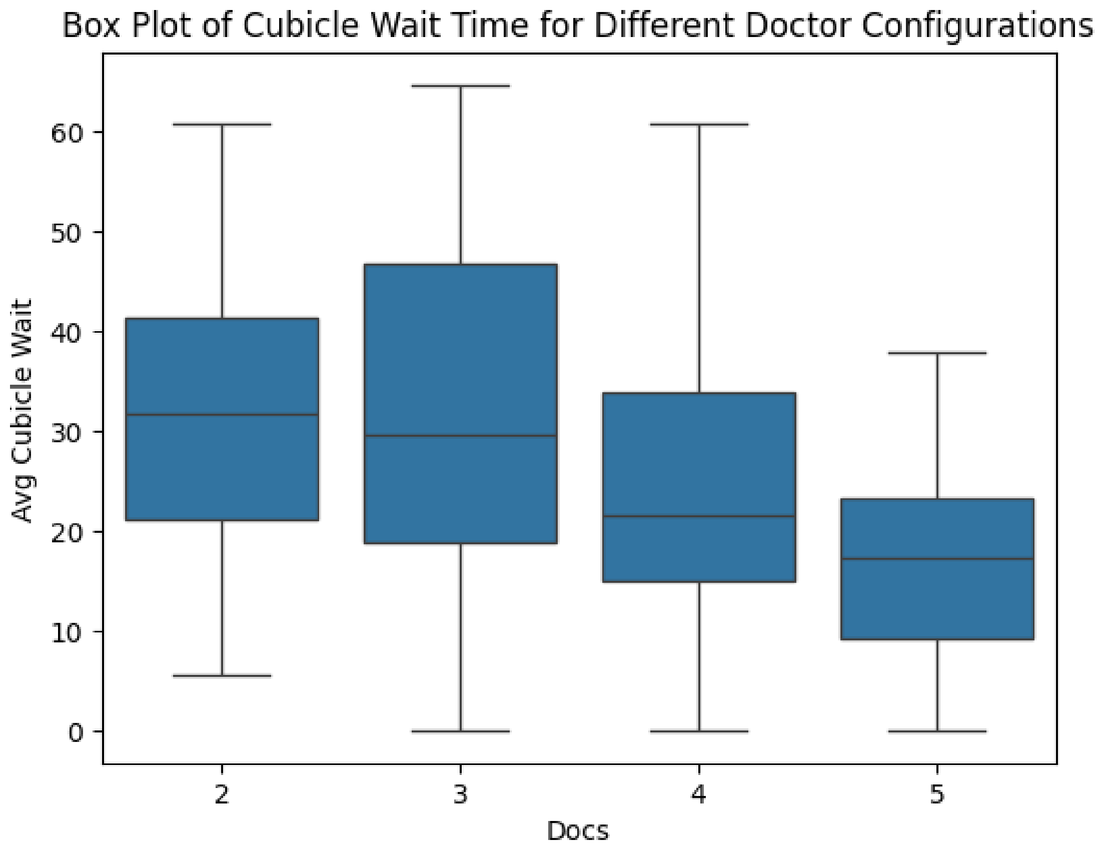
3 Docs, 2 Nurses, 8 Cubicles
5 Docs, 2 Nurses, 9 Cubicles
4 Docs, 1 Nurses, 7 Cubicles



Doctor Wait Times (Sorted by Avg Doctor Wait)
Average Wait Time (minutes)
14
12
10
8
6
4
2
0
3 Docs, 3 Nurses, 5 Cubicles
3 Docs, 2 Nurses, 6 Cubicles
3 Docs, 2 Nurses, 8 Cubicles
4 Docs, 3 Nurses, 7 Cubicles
5 Docs, 2 Nurses, 10 Cubicles
5 Docs, 2 Nurses, 9 Cubicles
5 Docs, 1 Nurses, 8 Cubicles
5 Docs, 2 Nurses, 5 Cubicles
4 Docs, 1 Nurses, 7 Cubicles



Box Plot of Triage Wait Time for Different Nurse Configurations
Avg Triage Wait
200
175
150
125
100
75
50
25
0
1
2
3
4
5
Nurses



Triage Wait Times:

As the number of nurses (p.number_nurses) increases, the triage wait times tend to decrease. This is because more nurses allow more patients to be triaged in parallel, reducing the time each patient spends waiting for initial assessment.

With fewer nurses, there is an increased burden on the existing resources, leading to longer wait times.

Doctor Wait Times:

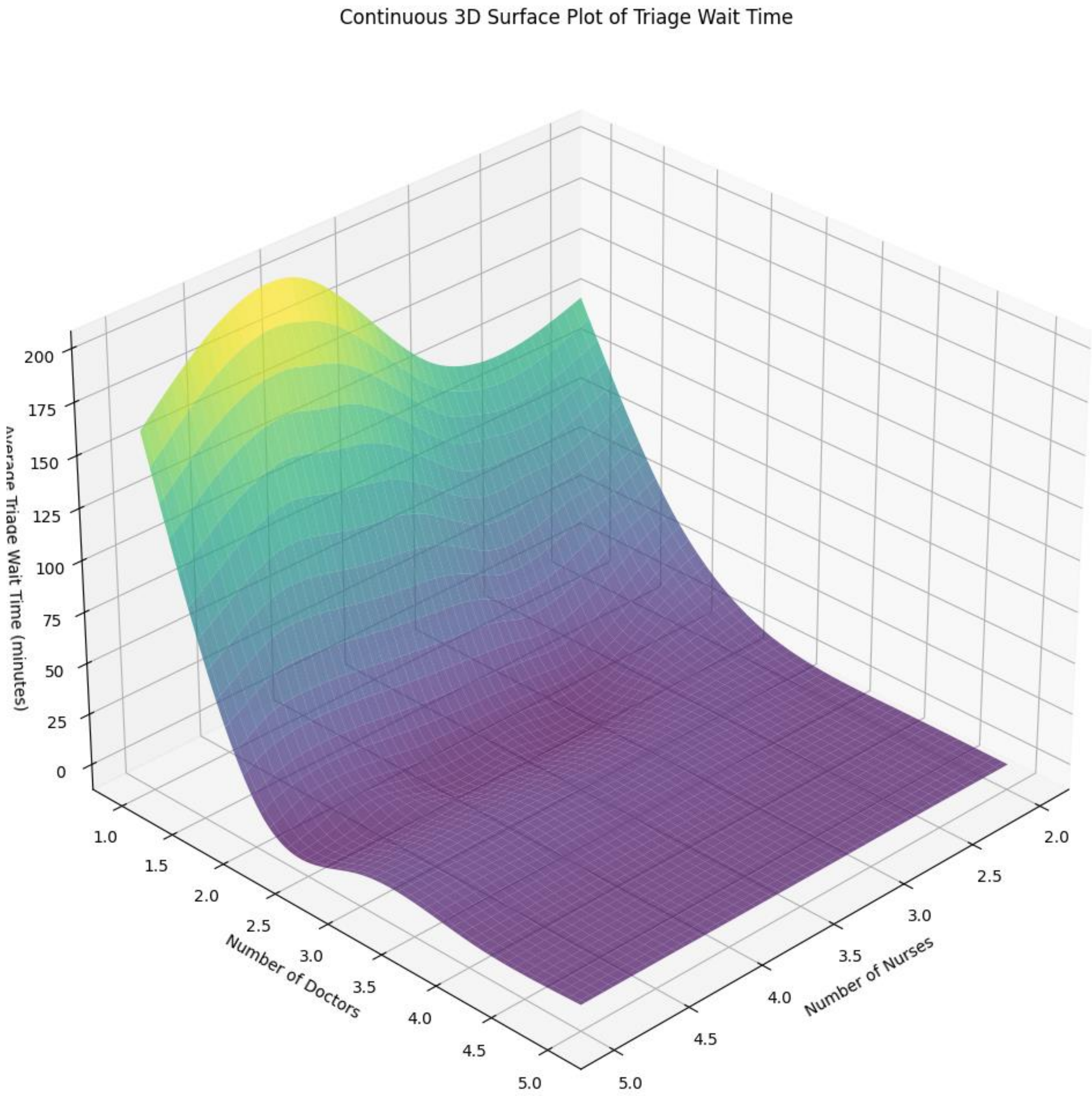
Similarly, the number of doctors (p.number_docs) plays a crucial role in determining how long patients wait to see a doctor after being assigned to a cubicle.

A higher number of doctors allows for quicker consultations and reduces patient wait times. However, increasing the number of doctors beyond a certain point may have diminishing returns if the other resources (nurses, cubicles) remain fixed.

3D Surface Plot of Triage Wait Time

The plot for **Triage Wait Time** represents the relationship between:

- **X-axis**: Number of doctors in the system.
- **Y-axis**: Number of nurses in the system.
- **Z-axis**: Average time patients wait to be triaged.



Key Insights:

- **Higher Staffing Levels Reduce Wait Times**: As the number of **doctors** and **nurses** increases, the average triage wait time decreases. This suggests that staffing is a key lever in improving triage efficiency.

Diminishing Returns: Beyond a certain point, adding more doctors or nurses does not significantly reduce the wait time, indicating there might be an optimal staffing level for triage. This insight is crucial for avoiding overspending on unnecessary staff.

Bottlenecks: If the **wait times** are high at lower staffing levels, it indicates a **resource bottleneck** where there aren't enough doctors or nurses to handle incoming patients efficiently.

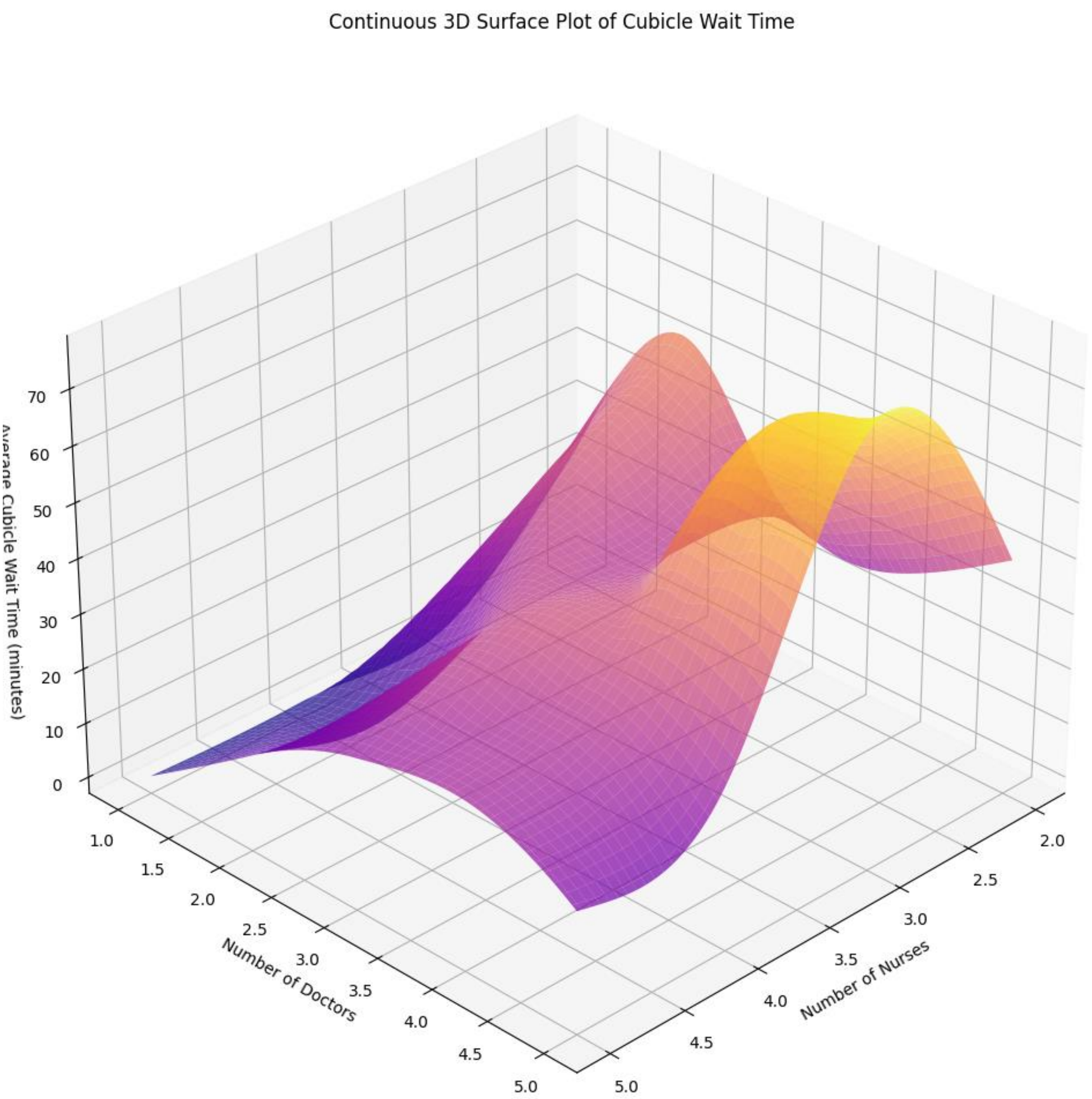
Relating to the ED System:

Fast Track: If the current number of doctors and nurses in the **Fast Track** area is insufficient, the **triage wait time** could be too high, leading to delays and longer queues. This model helps simulate how to balance staffing to reduce triage delays, especially in light of predicted patient volume increases.

Main ED: Since the **Main ED** involves more complex cases, having sufficient doctors and nurses can reduce wait times, prevent bottlenecks, and improve overall patient throughput.

3D Surface Plot of Cubicle Wait Time

This plot examines the **average cubicle wait time**, which measures how long a patient waits to be assigned to a treatment cubicle after triage.



Key Insights:

Impact of Staffing on Wait Time: Similar to triage wait time, cubicle wait times are lower when there are more doctors and nurses. A higher number of doctors and nurses likely ensures that treatment is initiated more quickly once patients have been triaged.

Resource Constraints: As cubicle wait times increase with fewer resources, there's a clear indication that the **cubicle assignment process** is a critical area that could cause delays. The availability of staff directly impacts how quickly patients are assigned and treated.

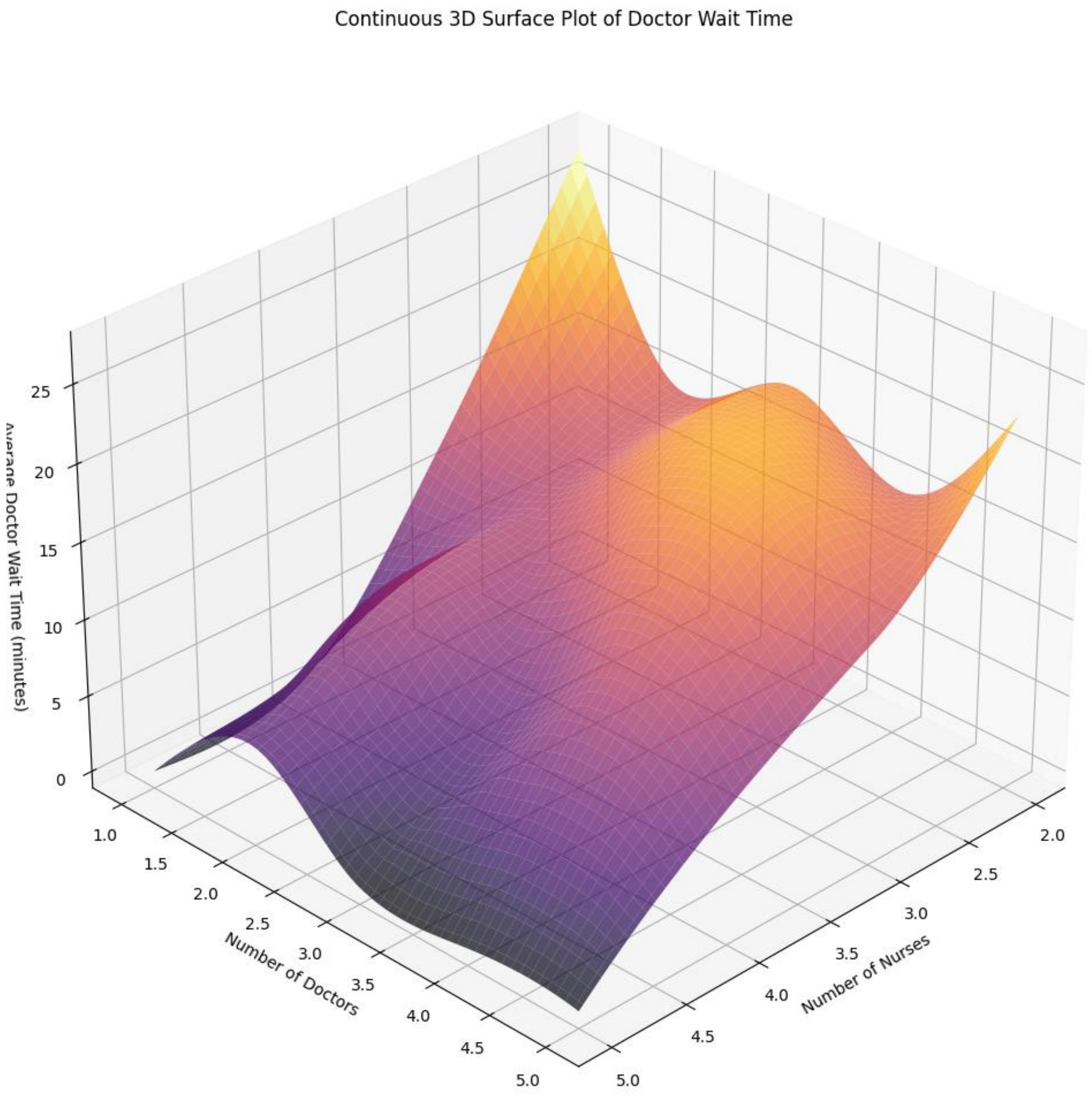
Relating to the ED System:

Main ED Bottlenecks: In the **Main ED**, a lack of available treatment cubicles (due to limited nurses, doctors, or beds) could significantly delay treatment, increasing wait times and affecting patient satisfaction. The plot highlights that improving staffing in the **Main ED** can help reduce delays in cubicle assignments, improving patient flow.

Fast Track Considerations: While the **Fast Track** area likely doesn't require cubicle wait time as a major issue (since patients are discharged quickly), the increased volume could still strain cubicle availability, necessitating optimization in how space is managed across both areas.

3D Surface Plot of Doctor Wait Time

This plot shows the **average doctor wait time**, or how long patients have to wait before seeing a doctor after being triaged or assigned to a cubicle.



Key Insights:

Doctor Availability: Doctor wait times decrease as the number of **doctors** increases. This suggests that **increasing the number of doctors** can reduce delays in care, which is particularly important in areas where more complex cases are handled (like the **Main ED**).

Impact of Nurse Numbers: The relationship between nurses and doctor wait times is somewhat less direct, but having more nurses may allow doctors to focus more on actual patient care, improving wait times.

Critical Staffing: For both **Fast Track** and **Main ED**, the model highlights the importance of staffing the system adequately to minimize doctor wait times, especially as patient volume increases.

Relating to the ED System:

Main ED: Longer doctor wait times in the **Main ED** are likely to result in delays in treatment, increasing patient dissatisfaction and possibly compromising patient outcomes. The simulation shows how **additional doctors** could reduce these delays, which is essential when anticipating higher patient volumes.

Fast Track Area: While doctor wait times may be lower in the **Fast Track** area due to fewer patients requiring intensive care, increasing staffing here can ensure a faster response time for the less severe patients, contributing to better overall throughput.

Overall Implications for System Design:

Increasing Staffing

Across all performance metrics (triage wait time, cubicle wait time, and doctor wait time), increasing staffing leads to shorter wait times. This underscores the importance of adequate staffing to handle higher patient volumes effectively.

Optimization of Staffing

The simulation shows diminishing returns when staffing exceeds a certain threshold. Hospitals should optimize staffing by distributing resources efficiently between Fast Track and Main ED, adjusting staffing levels according to patient severity and volume patterns.

Process Improvement

While staffing is a key factor, the simulation also highlights areas for process improvements, such as faster triage or expedited lab results, to further reduce delays.

Cost-Effective Solutions

Simulation results help determine the minimum staffing levels required to meet operational goals while maintaining cost-effectiveness. Hospitals can balance budget constraints with maintaining high-quality patient care.

Conclusion

The discrete-event simulation model of an Emergency Department can provide valuable insights into system performance, bottlenecks, and resource utilization. By exploring various staffing and resource allocation scenarios, the simulation helps hospitals improve patient flow, reduce wait times, and optimize the capacity design of both the Fast Track and Main ED areas. With actionable insights derived from the simulation, hospital administrators can make data-driven decisions to enhance patient care and operational efficiency.