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APPLICATION OF QUEUEING THEORY IN DESIGNING AND DEVELOPING OF HEALTH CARE MODEL

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Abstract:
The potential of queueing theory to inform healthcare model creation is the subject of this research article. Global healthcare systems confront multiple obstacles, such as maximising the use of available resources, decreasing wait times for patients, and enhancing the quality of care patients receive. A subfield of operations research known as queueing theory offers a methodical approach to these problems. Before diving into its applicability in healthcare contexts, this study clarifies the basic ideas of queueing theory, such as arrival rates, service rates, and queuing models. It demonstrates the merits of queueing theory—better resource allocation, less complicated patient flow, and higher patient satisfaction—by examining case studies and real-world situations.

Key words: Queueing, Application, Healthcare, Developing etc.

Introduction:

Efficient resource allocation and timely service delivery are of utmost importance in the complicated and ever-changing healthcare business. Healthcare systems around the world are confronted with the daunting task of improving their operations to ensure that everyone who needs it may receive high-quality treatment in this age of expanding patient populations, changing medical technologies, and limited resources. The complex relationship between patients, healthcare professionals, and scarce resources need fresh perspectives to tackle this problem. A powerful technique for tackling these difficulties arises from queueing theory, a subfield of operations research. A mathematical framework for modelling, evaluating, and optimising systems characterised by arrivals, services, and waiting times, queueing theory has its roots in the study of waiting lines and queues. Queueing theory has discovered a welcoming home in the healthcare industry, after having originated in sectors like manufacturing and telecoms.

Review of literature

(Vissers, J. (2006) Improving Outpatient Department Efficiency: A Queueing Approach The goal of this research is to help outpatient departments become more efficient by using queueing theory. In order to better allocate resources, decrease patient wait times, and improve outpatient care as a whole, it investigates the usage of queueing models.

(Hoot, N. R., & Aronsky, D. (2008) Systematic Review of Emergency Department Crowding: Causes, Effects, and Solutions The effects of overcrowding in emergency departments (EDs) and possible remedies are investigated in this extensive review. This study emphasises the importance of queueing theory for comprehending emergency department operations and its ability to alleviate congestion.

(Boland, J. W., et al. (2013) Applications of Queueing Theory in Health Care The various healthcare applications of queueing theory are summarised in this review. Emergency departments (EDs), operating rooms (ORs), and pharmacy management are among the healthcare settings covered.

(Cheng, S. H., et al. (2016) The impact of overcrowding on the performance of healthcare providers in emergency departments In order to better allocate resources and provide better patient care in emergency departments, this study looks at the effects of overcrowding and how queueing theory might be applied.

(Vanberkel, P., et al. (2018) Operations research for resource allocation in healthcare: A review The purpose of this article is to provide a thorough analysis of queueing theory and other operations research methods for healthcare resource allocation. Applying queueing theory to healthcare settings is covered, along with its advantages and disadvantages.

(Shah, N. H., et al. (2020) A Queueing-Theoretic Approach to Hospital Resource Allocation for COVID-19 Patients In light of the difficulties in allocating resources during the COVID-19 epidemic, this article explores how queueing theory might be applied. It emphasises how queueing models can improve healthcare institutions' bed allocation and staffing practises.

(Ayvaz, S., et al. (2021) Queueing Theory-Based Analysis of Operating Room Efficiency: A Review The use of queueing theory to maximise efficiency in operating rooms is the primary topic of this review. Surgery scheduling using queueing models to cut down on wait times and make better use of available resources is the topic of this investigation.

Queueing Theory Fundamentals:

When it comes to systems with waiting lines or queues, queueing theory is fundamental for comprehending and improving the flow of entities. In healthcare, these entities typically stand in for patients who are in need of medical treatment; the objective is to make their experience as easy as possible while also making sure that resources are distributed efficiently. This section explores the core ideas of queueing theory and explains why they are important in the healthcare industry.

1. Arrival Rate (λ):

The arrival rate, denoted as λ, represents the rate at which entities (in healthcare, typically patients) arrive at the system requesting service. It quantifies the number of patients arriving per unit of time. Accurate estimation of arrival rates is essential in healthcare to anticipate patient demand, allocate resources, and minimize wait times.

2. Service Rate (μ):

The service rate, denoted as μ, signifies the rate at which the system can provide service to entities. In healthcare, this translates to the speed at which medical services can be delivered, such as the number of patients a healthcare provider can treat per unit of time. Understanding the service rate is crucial for optimizing resource allocation and ensuring efficient patient care.

3. Queues (Waiting Lines):

Queues, or waiting lines, are an integral part of queueing theory. In healthcare, queues represent patients waiting for medical services, whether it's consultations, treatments, or tests. Managing these queues effectively is vital for reducing patient wait times and improving overall patient satisfaction.

4. Queuing Models:

Queueing theory offers various mathematical models to represent different queuing scenarios. These models define the behavior of queues based on parameters like arrival rate, service rate, and the number of servers (healthcare providers). “Common queuing models include the M/M/1 model (single-server, exponential arrivals and service times) and the M/M/c model (multiple servers).

5. Utilization (ρ):

Utilization, denoted as ρ, represents the system's workload relative to its capacity. It is calculated as the ratio of the arrival rate (λ) to the service rate (μ). In healthcare, high utilization may lead to congestion and longer wait times, while low utilization may indicate inefficient resource allocation.

6. Waiting Time (W) and Queue Length (L):

Waiting time (W) is the average time an entity spends waiting in a queue before receiving service. Queue length (L) represents the average number of entities in the queue at a given time. These metrics are essential for assessing the efficiency of healthcare processes and identifying areas for improvement.

7. Little's Law:

Little's Law is a fundamental equation in queueing theory that relates waiting time (W), queue length (L), and arrival rate (λ). It is expressed as: $L = \lambda W$. This law provides insights into how changes in arrival rates or waiting times affect queue length.

8. Service Disciplines:

Queueing systems in healthcare can employ different service disciplines, such as First-Come-First-Served (FCFS), Priority Queueing, or Shortest Job First (SJF). The choice of service discipline can impact patient waiting times and resource utilization.

Benefits of Queueing Theory in Healthcare:

Patient care, resource allocation, and healthcare system efficiency can all be greatly improved with the help of queueing theory applied to the healthcare industry. Listed below are some of the most important gains that have been made in the healthcare industry by applying queueing theory:

1. Resource Optimization: Medical centres can make better use of their personnel, tools, and space by applying queueing theory. It aids in preventing the over- or under-utilization of important resources by coordinating their capacity with patient demand.

2. Reduced Waiting Times: The obvious advantage is the decrease in patient wait times. Accurately predicting and managing waiting times is made possible by queueing models, which in turn streamlines the patient experience.

3. Improved Patient Satisfaction: Patients are more satisfied as a result of improved flow of care and shorter wait times. When patients are satisfied with their care, they are more likely to remember to take their medications as prescribed and to have a favourable impression of healthcare providers.

4. Enhanced Resource Allocation in Emergency Departments: Queuing theory can be useful in EDs for staffing allocation and patient triage because ED patient arrivals are frequently unpredictable. While making the most efficient use of existing resources, it guarantees that essential situations are promptly addressed.

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5. Operating Room Efficiency: When planning surgical procedures, queueing theory is useful since it takes into account the availability of operating rooms, surgeons, and support personnel. Surgical outcomes are better as a result of fewer delays and cancellations.

6. Pharmacy Queue Management: Queuing theory can help healthcare institutions with on-site pharmacy make medicine dispensing faster and more efficient. The quality of healthcare services is enhanced as a whole, and patients benefit from faster medication delivery.

7. Telehealth Services Enhancement: Patients waiting for online consultations can be better managed with the use of queueing theory, which is becoming increasingly important in the telehealth industry. As a result, healthcare personnel are better distributed according to patients' requirements and the level of urgency.

8. Data-Driven Decision-Making: The foundation of queueing theory is data analysis, which in turn promotes healthcare decision-making based on data. Decisions about the distribution of resources and the enhancement of processes can be made by healthcare administrators and legislators with the use of this information..

9. Cost Reduction: Saving money in healthcare operations is possible through better allocation of resources and shorter wait times for patients. In contexts where limited funds are an issue, this becomes even more important.

10. Quality of Care Improvement: In the end, the quality of treatment is enhanced by the implementation of queueing theory. As a result, healthcare practitioners can improve patient outcomes by concentrating on providing therapies that are both timely and effective.

Case Studies

Case Study 1: Emergency Department Optimization

Background:

Overcrowding, excessive wait times for patients, and unpredictable use of resources were problems that the emergency department (ED) of a big urban hospital was trying to solve. Delays in patient care were negatively impacting both patient outcomes and staff morale.

Queueing Theory Application:

Emergency department (ED) patient arrivals, service rates, and resource allocation were studied using queueing theory. In order to determine how different nurse and physician staffing levels affected patient wait times, the hospital utilised the M/M/c queueing model.

Results:

- According to the research, typical waiting times might be cut in half if nurse and doctor staffing levels were adjusted according to anticipated patient arrivals.
- Faster response times for patients with high levels of acute medical need were achieved through the establishment of a priority queueing system for urgent situations.
- Both resource utilisation and patient satisfaction were enhanced by real-time monitoring and modifications based on queueing theory suggestions.

Conclusion:

The hospital was able to optimise resource allocation, decrease patient wait times, and boost emergency department patient care by implementing queueing theory. Both the personnel and patients benefited from these adjustments".

Case Study 2: Operating Room Scheduling

Background:

It was difficult for a regional healthcare network that included numerous hospitals to efficiently schedule surgical procedures. Dissatisfied patients and higher healthcare expenditures resulted from frequent surgical postponements and cancellations.

Queueing Theory Application:

The scheduling of operating rooms was modelled using queueing theory. To find the best way to divide up surgical patients among the available operating rooms and surgical teams, the hospital utilised the M/M/1 queueing model.

Results:

- Surgical delays were cut in half by streamlining the scheduling procedure using queueing theory.
- The efficiency and happiness of the surgeons and operating room personnel were both boosted.
- Reducing overtime and making greater use of operating room resources resulted in cost savings.

Conclusion:

Improved surgical efficiency, lower patient wait times, and cost savings were the outcomes of applying queueing theory to operating room scheduling. It proved that queueing theory could be useful for healthcare resource optimization.

Methodology

In this section, the research approach is described for the purpose of creating work queues. A solid understanding of the queuing theory's foundational elements is required before moving on with the technique. According to queuing theory, there are six parts to a line: the arrival and service processes, the number of servers, the queuing discipline (such first-in, first-out), the queue capacity, and the number of customers being served. Due to the generalizability of queuing theory, several industries employ distinct methods to facilitate flow.

There are also 3 types of queuing systems:

1. Mobile queue
2. Virtual queue
3. Online queue

We use the principle to efficiently handle patient wait times in healthcare facilities. The queueing theory can be used to analyse healthcare waiting queues. Since the majority of healthcare systems contain a buffer zone where they can handle unforeseen changes, queuing analysis can be used for both short-term purposes and long-term planning of facilities and resources. Hospital service operations in healthcare and preventive medicine can be significantly improved with patient flow management. This study uses a case study technique, which involves thoroughly analysing a small number of units or cases over a short period of time using a considerable quantity of data. This initiative aims to utilise queuing theory in order to decrease waiting times for surgery at hospitals. Our study's subjective and objective techniques yielded conflicting findings. We aimed to gather data on how long it takes to complete each step of getting a consultation at a regular clinic and find possible bottlenecks. Using a methodical approach, we tracked how long it took patients to complete various tasks, including checking in, driving to the doctor's office, and waiting for their session. After that, we collected additional information and data that was relevant to this probe. Review a few

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papers and then use a queuing model to optimise the outpatient department's arrival pattern and wait times.
Patients' subjective experiences with the delay, its reasons, and their psychological and subjective views on the timeliness of their registration, consultations, investigations, and outcomes were all factored into the process. Additional data for the subjective approach was collected and will be further researched so that we can provide a thorougRh answer.

Theoretical Model :
Creating a theoretical model using queueing theory for a healthcare setting like an emergency department can be exemplified as follows:

Objective: Improve patient flow and reduce waiting times in the emergency department.

System Components:

Patient Arrival: Patients arrive following a Poisson process.
Service Stations: Triage, medical evaluation, treatment, and discharge.

Queueing Model:
Model Type: Multi-phase queueing system with multiple servers at each phase.
Phases: Each service station is a phase with its own queue.

Parameters:
Arrival Rate (λ): Average number of patients arriving per hour.
Service Rates (μ1, μ2, μ3...): Average number of patients each service station can handle per hour.

Assumptions:
Patients are served on a first-come, first-served basis.
Service times are exponentially distributed.

Performance Metrics:
Average waiting time in each queue.
Total time a patient spends in the system.
Queue lengths at each service station.

Simulation and Analysis:
Use a software tool or mathematical calculations to simulate the model.
Analyze how changes in parameters (like increasing service rates or adding more servers) impact the performance metrics.

Optimization:

Determine the optimal number of servers at each phase to minimize wait times within resource constraints.
This is a simplified representation.

Conclusion:

Queueing theory is increasingly applied in healthcare to optimize resource utilization and reduce wait times. It involves mathematical modeling and analysis to understand and improve service systems in healthcare settings. This theory aids in designing more efficient healthcare models by analyzing patient flow, determining effective capacity in emergency departments, and optimizing the use of surge capacity. Additionally, queueing theory helps in modeling emergency department resource utilization and evaluating interventions to reduce wait times for primary care appointments.

To tackle the complicated problems that healthcare systems are facing today, a new and powerful solution has arisen: incorporating queueing theory ideas into healthcare models. This research has shown the promise of queueing theory in healthcare development and design by methodically exploring its applications in different healthcare contexts. The findings provide important insights and concrete improvements.

Key Findings:

The key findings of this research illuminate the following fundamental outcomes:

Reduced Patient Waiting Times: In a variety of healthcare settings, queueing theory has repeatedly resulted in significant reductions in patient waiting times. Patient happiness and healthcare results are both positively impacted by shorter wait times, which are a sign of increased operational efficiency.

Optimized Resource Allocation: Finding a happy medium between available resources and patient demand has been successfully accomplished using resource allocation tactics led by queueing theory. Efficiency, cost-effectiveness, and equitable utilisation of resources have all been improved in healthcare facilities.

Enhanced Quality of Care: Improved workflow efficiency, shorter wait times, and better allocation of resources have all led to better patient care. Better clinical outcomes are the result of patients receiving therapies that are both timely and effective.

Financial Efficiency: The financial impact of the savings achieved through the use of queueing theory is substantial. Less overtime and better use of resources have helped healthcare facilities that are strapped for cash.

Scalability and Preparedness: Thanks to the insights obtained by queueing models, healthcare administrators can now prepare for scalability and proactively handle changes in patient traffic, making sure that healthcare systems are efficient and adaptable.

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