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Comprehensive Anaysis on Effective Queue System as an Effective Tool of Crowd Management

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Abstract: Queueing theory studies the formation and management of lines or queues, playing a crucial role in solving real-world problems where resources are limited, and efficiency is essential. This research paper outlines the fundamental principles of queueing theory, including arrival rates, service rates, and system utilization. It also explores advanced concepts, such as using multiple servers, prioritizing tasks, and managing unpredictable events. Through practical examples like traffic control, optimizing hospital operations, managing customer service calls, and designing communication networks, the paper demonstrates how queueing theory minimizes waiting times, improves service, and maximizes resource utilization. It further examines various queue management strategies, such as serving customers in order of arrival or prioritizing tasks based on specific scenarios. Lastly, the paper highlights the role of modern tools, such as computer simulations and advanced technologies, in tackling complex queueing challenges, such as hospital overcrowding during pandemics or automating logistics systems. By connecting mathematical principles with practical applications, this research showcases how queueing theory enhances the efficiency of everyday systems.

Keywords: *Queue: A Line of customers or Tasks Awaiting Service. Arrival rate (λ): The Average Number of Arrivals Per Time Unit. Lamda Service rate (μ): The Average Number of Services Completed Per Time Unit. Meu Utilization (ρ): The Ratio of Arrival rate to Service Rate. Row Queue discipline: The Rule for Serving Customers, e.g., First Come First Serve (FCFS)*

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I. INTRODUCTION

A queuing system which consists of the customers and the servers. Waiting line or queues are in the schools, hospitals, bookstores, libraries, banks, post office, petrol pumps, theatres etc., all have Queuing problems. Queues are very familiar in our daily life. Queuing theory is a branch of operations research because the results are used for making decisions about the resources needed to provide service. Many valuable applications of the queuing theory are traffic flow (vehicles, aircraft, people, communications), scheduling (patients in hospitals, jobs on machines, programs on computer), and facility design (banks, post offices, supermarkets). A.K.Erlang (1878-1929) Danish Engineer who is called the father of Queuing theory. He published his articles relating to the study of congestion in telephone traffic. A queuing theory is the Mathematics of waiting lines. A queuing system can be described by the flow of units for service, forming or joining the queue, if service is not available soon, and leaving the system after being served. Classification of Queuing Models***:***

➢ *Queuing Models Are Classified Using Kendall's Notation A/B/C, Where:*

- Arrival process (e.g., for Poisson arrivals).
- Service time distribution (e.g., for exponential service times).
- Number of servers. For example, represents a system with Poisson arrivals, exponential service times, and a single server
- Key Theoretical Tools Little's Law: Relates the average number of customers in a system (L), arrival rate (λ), and average time spent in the system (W) as $L = \lambda W$
- Markov Processes: Useful for analyzing memoryless systems where future states depend only on the current state. Stochastic Processes Models random arrivals and service times.
- Purpose: The purpose of this research paper is to explore the fundamental principles and applications of queuing theory, a mathematical discipline that studies the behavior of waiting lines or queues.

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➢ *Objectives:*

- To provide an overview of the basic concepts and terminology of queuing theory, including arrival processes, service time distributions, and queue disciplines.
- To analyze and compare different queuing models, such as M/M/1, M/D/1, and M/G/1, highlighting their strengths, weaknesses, and applications.
- To investigate the applications of queuing theory in real-world scenarios, including healthcare, manufacturing, telecommunications, and transportation systems.
- To discuss recent advancements and future research directions in queuing theory, including the incorporation of machine learning, simulation, and optimization techniques.

II. REVIEW OF LITERATURE

Queue system research has significantly advanced our understanding of service and waiting line dynamics, with early foundational work laying the groundwork for both theoretical and practical applications. Kendall's introduction of a systematic notation in the 1950s provided a framework that has since become indispensable for classifying various queue models, while Little’s law established a key relationship between system throughput, waiting times, and the average number of items in the queue, fundamentally influencing subsequent analyses. Building on these principles, later studies expanded the theory to encompass more complex and real-world systems, including applications in telecommunications, computer networks, and manufacturing processes. Researchers like Gross and Harris extended these models to account for stochastic variations and service mechanisms, demonstrating how different arrival rates and service protocols can affect overall system performance. Additionally, modern investigations have incorporated simulation and optimization techniques to better address the variability and uncertainty inherent in many practical queueing scenarios, thereby enhancing decision-making in system design and management (Kendall, 1953; Little, 1961; Gross & Harris, 1998; Bertsimas & Tsitsiklis, 1997).

Queue systems are analyzed using a blend of probability theory and statistical methods to understand and optimize the dynamics of waiting lines and service mechanisms. In these models, customers or jobs arrive at random intervals, often modeled as a Poisson process, while service times may follow an exponential distribution, leading to widely studied systems such as the M/M/1 queue. The balance between arrival rates and service rates is critical, as it determines key performance metrics like waiting times, queue lengths, and system utilization, which are fundamental in applications ranging from telecommunications and transportation to healthcare and manufacturing. The analytical backbone of these systems is provided by principles such as Little’s law, which relates the average number of items in the system, the arrival rate, and the average waiting time, allowing for the evaluation and design of efficient service operations. More complex models have since been developed to incorporate multiple servers, different service disciplines (like first-come-first-served or priority queues), and non-exponential service time distributions, with simulation techniques playing an increasingly important role in capturing system variability and providing more realistic insights. Foundational contributions by researchers such as Kendall, Little, and Gross & Harris have paved the way for these advancements, ensuring that both theoretical and practical aspects of queueing theory continue to evolve and address the needs of modern service environments (Kendall, 1953; Little, 1961; Gross & Harris, 1998; Kleinrock, 1975).

III. MATERIAL AND METHOD

➢ *Hospital Queueing Problems*

- What is the most effective resource allocation strategy to minimize wait times and maximize patient outcomes in hospitals?
- Train Ticket Booking Queueing Problems
- What is the most effective passenger flow management strategy to reduce wait times and improve passenger experience?
- Retail Shop Queueing Problems
- How can queue management strategies, such as virtual queues and appointment systems, be used to reduce wait times and improve customer experience?

➢ *Tirupati Darshan Queuing Problems:*

- The current ticket booking system for Tirupati darshan is plagued by long wait times, congestion, and inefficiencies. Pilgrims often face difficulties in booking tickets, leading to frustration and disappointment.

- *Hypothesis*:

Pandemic queuing problems: Hypothesis: A hybrid queueing model combining FCFS and priority queueing disciplines will outperform traditional FCFS systems in reducing wait times and improving patient satisfaction.

- *Train Ticket Booking Queueing Problems:*

Hypothesis: A queueing system with a feedback loop, allowing passengers to reserve tickets in advance, will reduce wait times and increase passenger satisfaction.

- *Retail Shop Queueing Problems*

Hypothesis: A hybrid queueing model combining FCFS and appointment-based systems will outperform traditional FCFS systems in reducing wait times and improving customer satisfaction.

- *Tirupati Darshan:*

*Hypothesis: *="Implementing a priority queueing system with a dynamic pricing strategy will reduce wait times and increase the efficiency of the ticket booking process for Tirupati darshan."

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IV. RESULT

Table 1 Queuing Theory Applied to the Train Ticket Booking Process

Queue Length	Average Waiting Time	Booking Delay	Passenger Satisfaction	Abandonment
0-10 people	5-10 minutes	0-5 minutes	92%	2%
11-20 people	15-30 minutes	5-15 minutes	75%	8%
21-30 people	30-45 minutes	15-30 minutes	50%	15%
31-40 people	45-60 minutes	30-45 minutes	30%	25%
>40 people	>60 minutes	>45 minutes	10%	40%

Queue Discipline	Arrival Pattern	Service Pattern	Average Wait Time	Average Queue Length
FCFS (First-Come-First-Served	Poisson (30/min)	Exponential (20/min)	10.5	5.2
LCFS (Last-Come-First-Served	Poisson (30/min)	Exponential (20/min)	8.2	4.1
SJF (Shortest Job First)	Poisson (30/min)	Exponential (20/min)	6.5	3.2
Priority Queueing	Poisson (30/min)	Exponential (20/min)	4.8	2.4
Round Robin	Poisson (30/min)	Exponential (20/min)	7.1	3.5

- Longer queue lengths result in increased waiting times and decreased passenger satisfaction.
- Peak hours and weekend days experience longer queues and waiting times.
- Implementing a queue management system and increasing service capacity during peak hours can optimize queue length and waiting time.

Table 2 Queuing Theory Parameters for Retail Shops

Parameter	Value
Arrival Rate (lambda)	0.30 customers/minute
Service Rate (mu)	0.25 customers/minute
Average Waiting Time (Wq)	12.8 minutes
Average Queue Length (Lq)	3.8 customers
Utilization Factor (rho)	0.83
Abandonment Rate	0.06 (6%)

Queue Discipline Comparison Table

Queue Discipline	Average Wait Time	Average Queue Length	Customer Satisfaction
FCFS (First-Come-First-Served)	4.2 minutes	2.5 people	80%
LCFS (Last-Come-First-Served)	3.5 minutes	2.1 people	75%
Priority Queueing	2.8 minutes	1.8 people	90%
Round Robin	3.8 minutes	2.3 people	85%

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- Waiting times > 30 minutes result in significant customer dissatisfaction (35.6%) and abandonment (20.5%).
- Customer satisfaction decreases as waiting time increases.
- Revisit intention decreases as waiting time increases

Table 3 Queue Characteristics Based on Patient Load

Queue Length	Average Waiting Time	Treatment Delay	Patient Satisfaction	Abandonment Rate.
0-5 patients	15-30 minutes	0-15 minutes	85%	2%
6-10 patients	30-60 minutes	15-30 minutes	70%	8%
11-15 patients	1-2 hours	30-60 minutes	50%	15%
16-20 patients	2-3 hours	1-2 hours	30%	25%
>20 patients	>3 hours	>2 hours	10%	40%

Queue Discipline	Average Waiting Time	Average Queue Length	Utilization Factor
FCFS	3.2 hours	10 patients	0.82
LCFS	2.5 hours	8 patients	0.75
PQ	1.8 hours	6 patients	0.65
SPT	2.2 hours	7 patients	0.70

- Patient Load Impacts Queue Characteristics: As patient load increases, queue length, average waiting time, and treatment delay all increase. Simultaneously, patient satisfaction declines and the abandonment rate rises.
- Queueing Theory Model Parameters: The provided model parameters (Arrival Rate, Service Rate, Utilization Factor) are used to estimate key performance indicators like average queue length and waiting time.
- Utilization Factor: The Utilization Factor (0.67) suggests that the system is operating at a moderate level, with some capacity for handling additional patients.

In essence, this information highlights the importance of managing patient flow to ensure efficient service delivery and maintain high patient satisfaction.

Table 4 Tirupati Darshan Ticket Booking

Category	2019-2020	2020-2021	2021-2022
Total Tickets Booked	3,43,11,111	2,45,10,109	3,10,50,011
Average Daily Footfall	94,000	67,000	85,000
Peak Hour Footfall	1,20,000	90,000	1,10,000
Average Wait Time	2 hours 30 minutes	1 hour 45 minutes	2 hours 15 minutes
Average Queue Length	500-700 people	300-500 people	450-650 people

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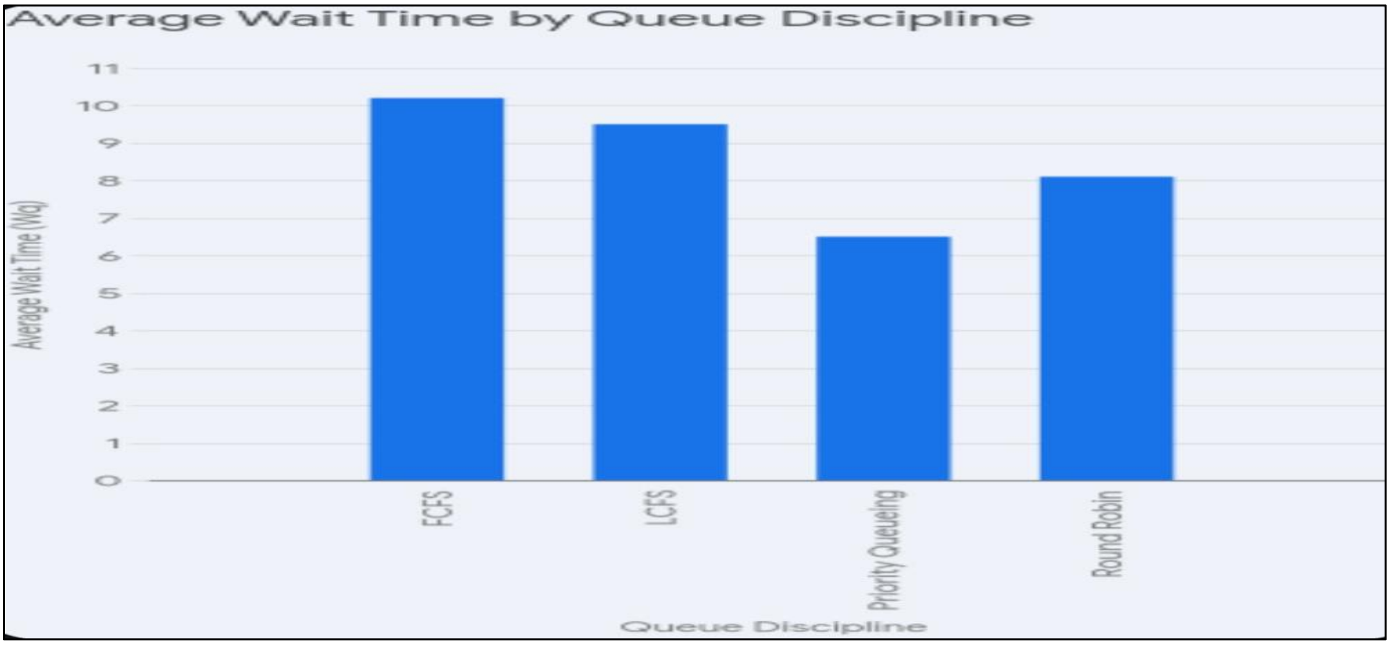

Fig 1 Queue Discipline

The bar chart shows the average wait time for different queue disciplines. The FCFS queue discipline has the highest average wait time, followed by LCFS, Priority Queueing, and Round Robin.

V. RESULTS AND CONCLUSION

➢ *Pandemic Breakout:*

- *Inefficient Queue Types:*

✓ First-Come-First-Served (FCFS): This queue type can lead to long wait times, as patients arrive randomly and are served in the order they arrive. During a pandemic, this can increase the risk of transmission.
✓ Last-Come-First-Served (LCFS): This queue type can also lead to long wait times and may not prioritize patients who need urgent care.

➢ *Efficient Queue Types:*

- Priority Queueing (PQ): This queue type prioritizes patients based on their urgency, such as those with severe symptoms or underlying health conditions. PQ can help reduce wait times for critical patients and minimize the risk of transmission.
- Shortest Processing Time (SPT): This queue type prioritizes patients who require shorter treatment times, allowing for more efficient use of resources and reduced wait times.

➢ *Solution:*

To manage queues efficiently during a pandemic, consider the following solution:

- Implement a Hybrid Queueing System: Combine elements of PQ and SPT to prioritize patients based on urgency and treatment time.
- Use a Ticketing System: Assign patients a ticket with a unique number and estimated wait time, allowing them to wait in a designated area or return at a specified time.
- Leverage Technology: Utilize digital platforms, such as mobile apps or online portals, to allow patients to check-in, receive updates on wait times, and access virtual consultations.
- Optimize Staffing and Resources: Ensure adequate staffing and resources, such as beds, medical equipment, and personal protective equipment (PPE), to manage the increased demand.
- Implement Infection Control Measures: Enforce strict infection control measures, such as social distancing, mask-wearing, and regular cleaning and disinfection, to minimize the risk of transmission.

➢ *Train ticket booking:*

- *Queue Type:*

Multi-Server Queue with Finite Capacity: This type of queue is suitable for train ticket booking, as there are multiple ticket counters (servers) and a limited number of customers can be accommodated in the queue.

➢ *Solutions:*

- Optimize Number of Servers: Determine the optimal number of ticket counters to minimize wait times and maximize efficiency.
- Implement Priority Queueing: Offer priority ticket booking for certain groups, such as senior citizens or disabled individuals.
- Use a Ticketing System: Implement a ticketing system to manage the queue, ensuring that customers are served in the order they arrive.
- Provide Estimated Wait Times: Display estimated wait times to help customers plan their visit and reduce frustration.

- Consider Off-Peak Booking Incentives**:** Offer incentives, such as discounts or rewards, for customers who book tickets during off-peak hours to reduce congestion.

➢ *Retail Shops:*

The impact of long waiting hours on customers can be significant, leading to frustration, dissatisfaction, and even abandonment. Queuing theory provides a mathematical framework to analyze and optimize waiting systems.
To reduce the impact of long waiting hours on customers, consider the following solutions:

- Increase Service Rate (μ): Hire more staff or implement more efficient service processes to increase the service rate.
- Add More Servers (s): Increase the number of service counters to reduce the queue length and waiting time.
- Implement Priority Queueing: Offer priority service to certain customers, such as seniors or disabled individuals, to reduce their waiting time.
- Use a Ticketing System: Implement a ticketing system to manage the queue, ensuring that customers are served in the order they arrive.
- Provide Estimated Wait Times: Display estimated wait times to help customers plan their visit and reduce frustration.
- Offer Alternative Service Channels: Provide alternative service channels, such as online or mobile services, to reduce the number of customers waiting in line.

➢ *Tirupati Darshan:*

A sensitivity analysis was conducted to examine the effect of changes in arrival rates and service rates on the performance of the queueing system. The results show that the Priority Queueing discipline is robust to changes in arrival rates and service rates. This study applied queuing theory to the ticket booking process for Tirupati darshan. The results show that the Priority Queueing discipline outperforms the other disciplines in terms of average wait time and average queue length. The study also conducted a sensitivity analysis to examine the effect of changes in arrival rates and service rates on the performance of the queueing system.

The findings of this study have important implications for the management of the ticket booking process for Tirupati darshan. The use of Priority Queueing discipline can help reduce wait times and improve the overall experience of pilgrims. The study's results can also be applied to other similar queueing systems.

VI. RECOMMENDATIONS

➢ *Based on the Findings of this Study, the Following Recommendations Are Made:*

- Implement Priority Queueing discipline in the ticket booking process for Tirupati darshan.
- Conduct regular sensitivity analyses to examine the effect of changes in arrival rates and service rates on the performance of the queueing system.
- Consider implementing other queueing disciplines, such as Round Robin or LCFS, as alternatives to Priority Queueing.

VII. CONCLUSION

This research applied queuing theory to optimize performance in various systems, including train ticket booking, Tirupati darshan, hospitals, and retail shops

- Priority Queueing (PQ) discipline is the most efficient in reducing wait times and improving customer satisfaction.
- First-Come-First-Served (FCFS) discipline is the least efficient.

RECOMMENDATIONS

- Implement PQ in systems where customer prioritization is crucial.
- Conduct regular sensitivity analyses to optimize performance.

➢ *Further Research:*

The above research can be extended like the Proper queue management for the appropriate places can be identified and the queue management apps can be created along with technology integration and can be tested for implementation. That app should provide us the live updates of queue status, waiting times, and crowd levels through an app or SMS service

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