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ANALYSIS OF PATIENT FLOW IN A CLINIC: A QUEUING THEORY APPROACH

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Abstract:
This research paper investigates the patient flow dynamics in a clinic, where patients arrive according to a Poisson distribution and the waiting room has a limited capacity. The examination time per patient is modeled as an exponential distribution. The study aims to determine the effective arrival rate, probability of a patient not waiting, and the expected waiting time until discharge.

Keywords: Queuing theory, Poisson distribution, Exponential distribution, Effective arrival rate, Probability of not waiting, Expected waiting time, Little's Law.

Introduction:

Healthcare facilities, especially clinics, face significant challenges in managing patient flow efficiently. The dynamics of patient arrivals and the limited capacity of waiting rooms are critical factors that influence the overall effectiveness of healthcare services. In this study, we focus on a clinic where patients arrive following a Poisson distribution with a rate of 25 patients per hour. The waiting room, a crucial component of the patient journey, has a maximum capacity of 12 patients at any given time.

Understanding and optimizing the patient flow in clinics is essential not only for improving the patient experience but also for ensuring that medical professionals can provide timely and effective care. The waiting room serves as a buffer between patient arrivals and the examination process, and its capacity plays a pivotal role in determining the overall efficiency of the clinic.

Additionally, the examination time per patient is modeled as an exponential distribution with a mean rate of 17 per hour. This means that the time each patient spends with the healthcare provider follows a probability distribution, and this randomness contributes to the complexity of the queuing system within the clinic.

[1] A comparative study of two banks, Wema and Skye Bank, in Owo Local Government Area of Ondo state, used a queuing model to measure customer behavior. The data was collected over three days and analyzed separately. Results showed that Wema bank had a high waiting service time value (0.019%), which negatively affected customers on waiting lines. Skye bank had an advantageous service time value (0.000022%), which positively affected customers experiencing little or no queues. This indicates that for optimal efficiency, the number of servers should be --increased. The study recommends that banks review their queuing models for better efficiency and performance. The results show that the queuing number, the number of servers, and the optimal probability service are the three measures that improve the efficiency of commercial

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banks. The analysis is effective and practical, and the optimal queuing model is feasible.
[4] In order to identify the most effective queuing model, this study transforms the M/M/Z/∞:FCFS model into M/M/1/∞:FCFS. The optimization model is established, the ideal number of service stations is determined, and the ideal service rate and efficiency are computed. The findings demonstrate how these actions boost customer happiness, shorten wait times, and increase efficiency in commercial banks.

[5] Lakhan Patidar, Trilok Singh Bisoniya, Aditya Abhishek, Pulak Kamar Ray (2014)[2] - Customers that frequent a number of well-known restaurants regularly voice their discontent with the lengthy wait times that they experience in the reservation queue. It would be beneficial for the management of the restaurant to use a quantitative model in order to acquire a more thorough grasp of the issue. By utilising a circumstance that occurs in the real world, the purpose of this research is to demonstrate how queuing theory may be used. Both Little's Theorem and the M/M/1 queuing model are utilised in the analysis of the data that has been gathered. During the time that we were doing our study, the rate at which services were supplied at "Bapu Ki Kutiya" in Bhopal was 3.27 customers per minute. On the other hand, the rate at which customers arrived at the busiest time of the day was 3.25 customers per minute. The restaurant has a utilisation rate of 0.993, which indicates that it is typically overcrowded and serves an average of 210 customers at any given time.

[6] Babicheva T.S. (2015)[3] - Using Poisson processes, one may simulate the flow of automobiles on streets with many lanes. This study indicates that the best flow of traffic may be attained by employing the notion of effective number of lanes in conjunction with the construction of several traffic signal systems. Through the course of this research, the feasibility of applying queuing theory techniques to the modelling of traffic patterns at signal-controlled intersections is being investigated. The discovered formulae could be simplified, implemented in a larger variety of transportation networks, and the optimisation problem of traffic flow at signal-controlled intersections might be addressed. These are some of the further efforts that could be done to improve the topic.

[7] David de la Fuenteb (2007)[1] - It has been demonstrated that fuzzy subset theory is useful for a variety of queuing systems, and it provides a wide range of applications that may be generalised. It is noteworthy that complicated fuzzy queuing models, such as priority disciplined queue models and queuing decision models, have been largely ignored in the academic literature. In a number of different situations that occur in real life, priority discipline queuing models are really used. This is especially true in emergency departments in hospitals, where some patients are assured to receive priority attention. In terms of the investigation and modelling of communication networks and the transmission of data across the Internet, they also serve an important purpose. It is possible that the parameters of queuing decision models are not properly understood due to the presence of a number of components that cannot be controlled in real-world circumstances. This might lead to a lack of clarity on the measures that measure system performance as well as the average overall cost of idleness. When findings are obtained and reported as exact figures, it is inevitable that vital information is also sacrificed. In this work,

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membership functions are utilised, which ensure that the intrinsic uncertainty of the initial information is totally preserved, even when some model parameters are fuzzy. These membership functions are utilised in order to provide a description of the expenditures that are linked with the functions as well as the measurements that are required to execute the fuzzy queuing model. We are able to generate credible answers for each and every instance by utilising the approach that is provided in the paper. This is true regardless of the degree of optimism or pessimism that is linked with the situation. Additionally, additional information on the building of fuzzy priority-discipline queuing systems is included in the article below. As a result of the capability to assess fuzzy priority discipline queue models, which is presented in this discussion, as well as the progress of decision models in fuzzy settings, the application of priority discipline queuing models may be expanded to encompass a wider variety of scenarios. Through the effective resolution of two fuzzy queuing systems that are often encountered, we can illustrate the validity of the approach that we have proposed. In spite of the fact that our research only takes into account two different performance metrics, the approach that we provide is obviously relevant to a broad variety of circumstances.

[8] Yaheli Hernandeza, Kathryn Cormicana (2016)[5] - The purpose of this research is to improve the understanding of social innovation projects among both academics and practitioners in the field. In this process, we collect and categorise all of the definitions, arranging them in accordance with the qualities that are shared by the detected definitions in the literature. Through the process of analysing and contrasting social innovation initiatives with standard industry-focused projects, we are able to find distinctive qualities and qualities that are unique. After doing our research, we came to the conclusion that social innovation efforts require a new organisational framework. It is recommended that the framework be altered so that it is in line with the specifics of social innovation activities while also being founded on the findings of extensive study. We are certain that the expertise that we now possess in the field of project management will be able to aid us in achieving this target. On the other hand, we are aware of the fact that further research is required in order to solve the severe problems that we have highlighted.

[9] Cássio L. M., Belussoa, b, Sandro Sawickib, Fabricia Roos-Frantzb, Rafael Z. Frantzb (2016)[6]
The purpose of EAI is to develop tools and procedures for designing and executing integration solutions that are conceptualised at a high degree of abstraction. This will be accomplished through the development of technologies. A simulation model may be created by transforming the core components of a conceptual model into a simulation model, which can then be used to depict an integrated solution. The authors of the study have created a simulated version of the system by converting three mathematical models that were developed from Pipes and Filters. Consequently, this makes it possible to examine the behaviour of the system during the design process, which in turn reduces the costs associated with the implementation of integration solutions. A diagram that relates the Slot and Task components of the Guaraná technology with their corresponding models in Petri Nets, Markov Chains, and Queuing Theory was built by us in order to show the viability of the project. The findings of the study suggest that there is a significant amount of room for further growth in the field of Enterprise Application Integration (EAI), more especially in the area of integrated solution simulation. For this reason, it is

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anticipated that the subsequent study will give methods and tools that will be of assistance in this crucial stage of system modelling and simulation. More specifically, it will be used to assess whether or not a suggested model accurately describes the system that is being investigated.

[10] Boyang Zhang, Yanpeng Zhang, Guimin Sheng (2016)[7] - Using queuing theory as a foundation, this research makes a unique contribution to the field of repeater coordination. When the value of Pw is fixed at a particular level, the model suggests that the correlation between S and λ is approximately linear inside a terrain that is level. However, when the value of λ approaches a particular threshold, the correlation may evolve into a very nonlinear condition. A very clear contrast may be seen between a sample size of one thousand people and a population that is substantially bigger, consisting of ten thousand users. A way for determining the waiting probability is provided by the model. This approach may be employed as a metric for assessing the effectiveness of the communication system. Consequently, this determines the necessary quantity of repeaters to be used.

Peng Wang, Jiandong Zhao, Yuan Gao, Miguel Angel Sotelo and Zhixiong Li. (2022)[12] - The purpose of this paper is to propose an all-encompassing strategy for lane work. The model takes into account three different variables: the average waiting time, the length of service, and the volume of traffic. The value that it produces is the average amount of time spent waiting for the hour that follows. With the help of this model, we are able to ascertain the number of MTC lanes that were opened all throughout the various time intervals. When we compare the outcomes that were generated by the Support Vector Regression (SVR) model to the results of the forecasts, we are able to evaluate the results of the forecasts. Last but not least, the work schedule for the toll lane is evaluated based on the amount of money that the toll station costs to operate.

Objective:

The primary objective of this research is to apply queuing theory principles to analyze the patient flow in the clinic. Specifically, we aim to:

a) Determine the effective arrival rate at the clinic, considering the limited capacity of the waiting room.
b) Calculate the probability that an arriving patient will not have to wait before being examined.
c) Estimate the expected waiting time until a patient is discharged from the clinic, taking into account both the arrival rate and examination time distribution.

By achieving these objectives, we aim to provide insights into the clinic's operational efficiency and contribute to the ongoing efforts to enhance patient care and optimize resource utilization in healthcare settings. The findings of this study may have implications for the design of waiting areas, appointment scheduling, and overall patient management strategies in similar healthcare environments.

Methodology:

Effective Arrival Rate:

The effective arrival rate λ eff is calculated by considering the actual arrival rate (λ) and the

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probability of an arriving patient finding an available seat in the waiting room. The effective arrival rate is given by the formula:

$$\lambda_{eff} = \lambda \times (1 - P_{full})$$

where λ is the actual arrival rate of patients per hour, and full P_{full} is the probability that the waiting room is at its maximum capacity.

Probability of Not Waiting:

The probability that an arriving patient will not wait P not wait is calculated as the complement of the probability that the waiting room is full:

$$P_{not\ wait} = 1 - P_{full}$$

Expected Waiting Time:

The expected waiting time until a patient is discharged W waiting is calculated using Little's Law:

$$W_{waiting} = L / \lambda_{eff}$$

where L is the average number of patients in the system.

In the given situation, where patients arrive at a clinic according to a Poisson distribution, the waiting room has a limited capacity, and the examination time per patient follows an exponential distribution, an appropriate queuing model to analyze and optimize the system is the M/M/1 queue.

The notation M/M/1 represents:

M: Stands for a Poisson arrival process.

M: Stands for an exponential service time distribution.

1: Signifies a single server.

Reasons for Choosing M/M/1 Queue:

1. Poisson Arrival Process (M): The Poisson arrival process accurately reflects the random and independent nature of patient arrivals, which aligns with the given scenario where patients arrive at a rate of 25 per hour.
2. Exponential Service Time Distribution (M): The exponential service time distribution is suitable for modeling the random duration each patient spends in the examination process, which has a mean rate of 17 per hour.
3. Single Server (1): The assumption of a single server is appropriate for this scenario, as each patient undergoes examination by one healthcare provider.

The M/M/1 queue is well-studied and provides analytical solutions for performance metrics such as the effective arrival rate, probability of not waiting, and expected waiting time. Little's Law, which was used in the analysis above, is a fundamental result of the M/M/1 queue. By applying the M/M/1 queuing model, the clinic can gain insights into the system's efficiency, identify potential areas for improvement, and make informed decisions to enhance the overall patient experience. Additionally, this model allows for sensitivity analysis, enabling the clinic to evaluate the impact of changes in parameters on system performance.

Queuing Model: M/M/1 Queue

Notation:

M: Poisson arrival process - Patients arrive at the clinic following a Poisson distribution with a rate (λ) of 25 patients per hour.

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M: Exponential service time distribution - The examination time per patient follows an exponential distribution with a mean rate (μ) of 17 per hour.
1: Single server - Each patient undergoes examination by a single healthcare provider.

Analysis:

Arrival Rate (λ):

λ=25 patients per hour

Service Rate (μ):

μ=17 patients per hour

Traffic Intensity (Utilization Factor – (ρ):

$\rho = \lambda/\mu = 1.471$

If $\rho < 1$, the system is stable; otherwise, it is unstable.

Effective Arrival Rate (λ_{eff}):

$$\lambda_{eff} = \lambda \times (1 - P_{full}) \quad , P_{full} = e^{-\rho} = 0.2299$$

$$\lambda_{eff} = 25 \times (1 - 0.2299) = 12.3345$$

Probability of Not Waiting ($P_{not\ wait}$):

$P_{not\ wait} = 1 - P_{full}$

$P_{not\ wait} = 1 - 0.2299 = 0.7701$

Expected Waiting Time ($W_{waiting}$):

W waiting=1/μ−λ

W waiting =1/17−12.3345 = 0.2143

Conclusion:

Traffic Intensity (ρ) Analysis:

With $\rho \approx 1.471$, the system is unstable, indicating that the clinic is overwhelmed with patient demand for a single server.

Effective Arrival Rate (λ_{eff}) Analysis:

The effective arrival rate λ_{eff} is approximately 12.3345 patients per hour, reflecting the adjusted rate considering the limited waiting room capacity and a single healthcare provider.

Probability of Not Waiting ($P_{not\ wait}$) Analysis:

The probability of not waiting $P_{not\ wait}$ is approximately 0.7701 or 77.01 %, indicating a relatively high likelihood that patients will not have to wait upon arrival.

Expected Waiting Time ($W_{waiting}$) Analysis:

The expected waiting time $W_{waiting}$ is approximately 0.2143 hours or 12.8 minutes, suggesting a relatively short waiting time for patients.

In conclusion, the M/M/1 queuing model allows for a comprehensive analysis of the clinic's operational efficiency. The traffic intensity, effective arrival rate, probability of not waiting, and expected waiting time collectively provide valuable insights into the system's performance. The clinic should strive to maintain stability, optimize resource utilization, and enhance the patient experience by carefully managing these queuing parameters.

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