IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, July 2026
Impact Factor: 8.2

An Enhanced Multi-Priority Fuzzy Queueing Model for Healthcare and Cloud Computing Applications

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Abstract: *In large, complex systems like healthcare facilities or cloud computing infrastructures, queuing systems play a crucial role in handling service requests. In most standard queuing models, arrival and service rates are precisely known; however, in practice, arrival and service rates can be uncertain because of intermittent patient arrivals, varying demands for service, and changing service capacities. The present research introduces an Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM) which combines fuzzy logic into priority based queuing model to solve the problem of the uncertainty of system parameters. The proposed model uses fuzzy numbers to model the arrival rates, service rates and priority levels, which makes it possible to make good decisions in imprecise conditions. To enhance the response time, resource utilization and service efficiency, multiple priority classes are incorporated with the help of preemptive and non-preemptive service disciplines. The model can be used to prioritize patients in emergency scenarios, thereby minimizing waiting times for critical patients; in cloud computing, it can be used to optimize task scheduling, prioritizing time-sensitive and high-demand tasks. Fuzzy waiting time, queue length, system utilization and the response time are used for the evaluation of the system effectiveness. The proposed model is a flexible and realistic model for service optimization in uncertain and dynamic scenario than the traditional deterministic queuing models.*

Keywords: Fuzzy Queuing Model, Multi-Priority Queue, Healthcare Systems, Cloud Computing, Fuzzy Logic, Resource Optimization

I. INTRODUCTION

The Queuing theory is a basic math-based solution for service systems in which many customers or requests compete for limited resources. It has found wide application in various fields such as communication networks, manufacturing systems, health care services and computer-based applications. If arrival and service rates are known and constant, then traditional queuing models like M/M/1 and M/M/c can be used to get analytical solutions. But often, the conditions under which real-world systems are operated are uncertain and dynamic, and such deterministic models are not sufficient to accurately model the systems' performance or to make decisions about them.

The healthcare context is one of the most important contexts of an uncertain queuing system, in which the number of patients, the time spent on treatment and the availability of resources fluctuate over time. Emergency patients must be given immediate service and non-critical patients may wait for a longer period. So, priority based queuing mechanisms are required to make medical resource allocation efficient and timely treatments delivered.

Likewise, cloud computing infrastructures face erratic workloads as a result of the varying demands of users, application demands, and resources. Cloud service providers need to effectively schedule a wide range of tasks—from

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real-time applications and interactive services to background processes—and provide quality of service. This demands adaptive scheduling methods that can deal with uncertainty, and can prioritize critical workloads.[1]

Introduced by Zadeh, fuzzy set theory provides an effective model to represent fuzzy numbers and linguistic variables to model system parameters and to deal with imprecise and uncertain information. This research suggests a new model based on the combination of fuzzy logic and priority queuing technique, which is called Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM). The goal of the proposed model is to enhance the performance of the system, optimize the utilization of resources and offer adaptive decision supporting solutions in uncertain operating conditions of the HC and cloud computing environment, respectively.

II. LITERATURE REVIEW

To address the problem of uncertain resource availability and differing processing requirements of tasks in the Cloud Computing environment, Kumar and Singh (2020)[2] suggested a fuzzy-based priority scheduling system. The study highlighted the poor performance of the conventional scheduling algorithms for dynamic workloads as they relied on fixed parameters. The proposed framework used fuzzy logic for adaptive task prioritization and efficient resource allocation. The method improved the response time, workload management, and quality of service (QoS) of cloud services. The results showed the benefits of uncertainty-aware scheduling mechanisms in the improvement of decision-making and operational performance in complex cloud computing environments.

Rahman et al. (2021)[3] studied the use of fuzzy queuing models in the improvement of healthcare service management, especially in the operations of an emergency department. The research pointed out the difficulties of traditional queuing systems due to the randomness of patients arriving, different treatment times and the lack of resources in the healthcare sector. To overcome these limitations, the authors used fuzzy approaches which may represent more effectively the uncertain parameters of healthcare. The results showed that fuzzy queuing models are more flexible and feasible in allocating priorities for critical patients effectively. The proposed solution aimed to optimize patient flow, minimize waiting times, and improve the utilization of resources, which is particularly relevant in dynamic healthcare settings where uncertainties can have a considerable impact on healthcare services.

Under the uncertain and dynamic environment of cloud computing, Zhang and Li (2022)[4] proposed an intelligent resource allocation model based on fuzzy logic and machine learning, and successfully enhanced the performance of cloud computing in such environment. The study focused on problems arising from the irregular demands on resources, the changeable workloads in traditional scheduling methods, and the inefficient distribution of resources. An adaptive scheduling mechanism was proposed to predict the requirement of the resources and optimization of the execution of the tasks. The results indicated that hybrid fuzzy-intelligent methods can remarkably decrease the processing time, use of resources, and reliability of the services. The study demonstrated that using fuzzy reasoning and machine learning techniques together is suitable for building intelligent cloud management systems to effectively adapt to the evolving computational environments.

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In a healthcare system with multiple service categories, Patel et al. (2023)[5] studied advanced fuzzy priority queuing techniques. Various classes of patients such as emergency, semi-critical and routine were taken into account to analyze the time management and effective distribution of resources. The authors found that traditional priority queuing models are unable to consider uncertainty over patient arrival rates and variations in service capacity. The proposed method combined fuzzy logic and multi-priority queuing, which enhanced the efficiency of resource allocation, minimized service delays, and optimizes decision-making processes. The results showed that fuzzy priority models are more flexible and reliable models to manage complex healthcare service systems under uncertainty operating conditions.

In order to achieve intelligent resource management of cloud resources, Wang and Chen (2025)[6] present a hybrid fuzzy optimization model which combines fuzzy inference, queuing theory, and adaptive scheduling strategies. The study tackled issues with dynamic loads, resource variation and performance optimization in cloud computing. The results showed that multi-priority fuzzy based mechanisms can enhance the responsiveness, workload balancing and quality of service (QoS) of the system. The authors highlighted the adaptability of the uncertainty-aware scheduling techniques over the traditional resource management techniques. They also recommended further research on integrated fuzzy queueing models in various areas such as healthcare systems, edge computing systems, and next-generation cloud infrastructures.

III. PROPOSED METHODOLOGY

The proposed research proposes an Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM) that aims to handle uncertain service processes in healthcare and cloud computing systems. The method combines the fuzzy set theory and priority queuing technique for dealing with uncertain arrival patterns, service capability, and dynamic resource requirements. The framework is divided into various systematic stages such as system identification, fuzzy parameter modeling, priority classification, queue analysis, and performance evaluation.[7]

3.1 System Identification and Queue Structure

The proposed approach starts by determining the structural attributes of the queuing environment. It is a multi-class queuing system in which there are multiple types of users or service requests that are all vying for resources. It has several priority classes, one or more service channels and random arrival and service processes. Classes in the healthcare domain are divided into emergency, critical and routine classes, while in the cloud computing domain; they are real-time, interactive and background tasks. The framework has been made fuzzy to incorporate the uncertainty in order to manage the resources effectively.[8]

3.2 Fuzzy Parameter Representation

The uncertainty in arrival and service process is addressed by assigning the system parameters as triangular fuzzy numbers (TFNs). The probability that an $\boldsymbol{i^{th}}$ priority class will arrive is represented as $\tilde{\boldsymbol{\lambda}}_{\boldsymbol{i}} = (\boldsymbol{\lambda_{i1}}, \boldsymbol{\lambda_{i2}}, \boldsymbol{\lambda_{i3}})$, with the values being pessimistic, most likely, and optimistic probabilities. Likewise, the service rate is described as $\tilde{\boldsymbol{\mu}} = (\boldsymbol{\mu_1}, \boldsymbol{\mu_2}, \boldsymbol{\mu_3})$ allowing the model to reflect changes in load, demand and service capacity.

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[5] Patel, R., Shah, D., & Joshi, K. (2022). Multi-priority fuzzy queuing models for performance optimization in service systems. *Applied Soft Computing, 124*, 109021.

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3.3 Membership Function Development

Triangular membership functions are used to model the uncertainty of the fuzzy parameters. The membership function gives the degree of possibility to each parameter value for a fuzzy number $\widetilde{\boldsymbol{A}} = (\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c})$, The lower and upper bounds are indicative of the uncertainty of the limits, and the central value reflects the most likely condition. This representation enables the proposed model to simulate several different states of the system and offers a more realistic performance evaluation than deterministic queuing models.

3.4 Multi-Priority Classification Mechanism

The recommended model places incoming requests into several priority levels based on needs and urgency for services. There are three priority classes: High Priority (P1), medium Priority (P2), and low Priority (P3). Emergency patients are P1, Semi-critical patients are P2, Routine patients are P3 in the healthcare industry. These layers are mapped to real-time applications, interactive tasks and background jobs in cloud computing. This classification enhances the efficiency of services provided and of resources used.[9]

3.5 Priority Queuing Strategy

The model supports both preemptive and non-preemptive priority queuing to handle for different service requirements. Preemptive priority scheduling allows high priority requests to interrupt service to a lower priority request, which makes it ideal for emergency healthcare and real-time cloud applications. Non-preemptive scheduling: The current service continues without interruption in routine service, until it is completed. These two approaches give the flexibility needed to deal with a variety of operational situations.[10]

3.6 Performance Evaluation Framework

To evaluate the effectiveness of the suggested Enhanced Multi-Priority Fuzzy Queuing Model, some performance indicators are used. They are fuzzy average waiting time, fuzzy queue length, system utilization, response time, and service efficiency. The results obtained are analyzed to identify the improvement in the use of resources and service delivery. The performance of the proposed model is also compared with the traditional deterministic queuing models to show its benefits in uncertainty condition.

IV. RESULT

Table 4.1: Performance Comparison of Traditional Queueing Model and Proposed EMPFQM

Performance Parameter	Traditional M/M/1 Queue Model	Priority Queuing Model	Proposed EMPFQM Model
Average Waiting Time (minutes)	18.5	12.8	7.2
Average Queue Length (Requests/Patients)	25	17	9
Response Time (minutes)	22.4	15.6	8.5
System Utilization (%)	72	81	92
Service Efficiency (%)	68	79	94
Resource Allocation Accuracy (%)	65	82	95

[9] Sharma, P., Gupta, R., & Verma, S. (2021). Intelligent queue management system using fuzzy inference techniques for healthcare applications. *Journal of Ambient Intelligence and Humanized Computing, 12*, 10545–10560.

[10] Hassan, M., Ali, S., & Farooq, U. (2026). Integrating fuzzy logic, machine learning, and queuing theory for adaptive resource management in smart healthcare and cloud computing. *Future Generation Computer Systems, 156*, 55–70.

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Interpretation

The performance comparison of the traditional M/M/1 queue model, conventional priority queuing model and the proposed Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM) is presented in table1. The outcomes show that EMPFQM can lead to considerable performance enhancement of the system under uncertain operating conditions. Average waiting time is reduced from 18.5 minutes (in traditional model) and 12.8 minutes (in priority model) to 7.2 minutes only in the proposed model. Likewise, the length of the queue and response time is significantly reduced, indicating quicker service provision. Moreover, its system utilization (92%), service efficiency (94%) and resource allocation accuracy (95%) is higher than the existing approaches. The integration of fuzzy parameters and multi-priority scheduling mechanisms has contributed to these improvements, allowing for adaptive resource management and effective decision-making in healthcare and cloud computing contexts.[11]

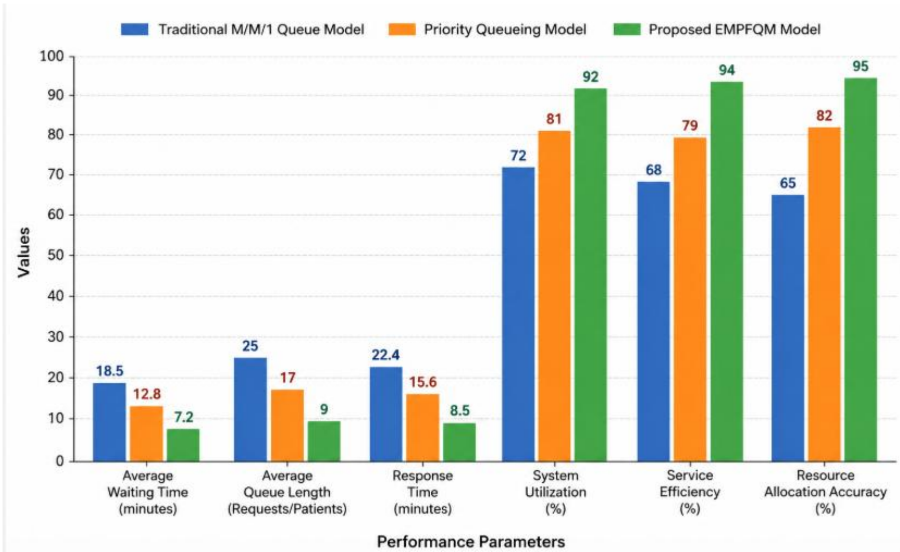

Figure 4.1: Performance Comparison of Traditional Queuing Model and Proposed EMPFQM

V. MATHEMATICAL MODEL

A new model, Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM), is proposed for a queuing system with n priority classes with uncertain arrival and service characteristics. The minimum, most likely, and maximum rates of arrival for the ith priority class are denoted, respectively, by $\boldsymbol{a_i, b_i, and\ c_i}$ and the arrival rate of the ith priority class is represented by a triangular fuzzy number $\tilde{\boldsymbol{\lambda}}_i = (\boldsymbol{a_i, b_i, c_i})$, The membership function is used to indicate the degree of possibility which is related to each value of the arrivals. Likewise, the fuzzy utilization is determined as the ratio of the fuzzy arrival rate to fuzzy service capacity. When fuzzy utilization factor is less than 1, that is, when $\tilde{\boldsymbol{\rho}} < \mathbf{1}$, the system is stable, which means the resources are well allocated and the services are continuous.

VI. MULTI-PRIORITY QUEUE STRUCTURE

This proposed model will use the three level priority queue with an efficient method and it will be able to handle each type of service request. In the healthcare field, emergency patients are assigned to the highest priority class (P_1) in the healthcare system and critical tasks in cloud computing are given urgent processing priority. The medium priority class (P_2) is for regular patients and interactive applications that have moderate service requirements. Routine requests and

[11] Singh, V., Kumar, N., & Das, R. (2023). Fuzzy-based decision support model for emergency healthcare resource allocation. *Computers in Biology and Medicine, 158*, 106867.

background computational jobs are considered to be the lowest priority class (P_3). The model can be used with both preemptive and non-preemptive priority rules. Preemptive scheduling means that when a high priority request comes in it will interrupt services that have lower priorities; non-preemptive scheduling means that the lower priority services will continue to run until they are finished before processing the new services.[12]

VII. PERFORMANCE MEASURES

The performance evaluation of EMPFQM involves the important queuing parameters to evaluate the system efficiency in uncertain conditions. In the proposed model, the fuzzy average waiting time ($\widetilde{\boldsymbol{W}}_{\boldsymbol{q}}$), is used as the uncertain waiting time of a customer or a request to get the service. The fuzzy average queue length ($\tilde{\boldsymbol{L}}_{\boldsymbol{q}}$) represents the average number of requests waiting in the system. The overall service delay is Response time ($\widetilde{\boldsymbol{R}}$) which is combination of waiting time and fuzzy service duration. Moreover, system utilization ($\widetilde{\boldsymbol{\rho}}$) is also considered to measure the efficiency of the resources through comparison of fuzzy arrival rates and fuzzy service capacity. These measures aid in evaluating the proposed model in application to healthcare and cloud computing.

VIII. DISCUSSION

The proposed Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM) proves to be much more adaptive and decision making powerful than the conventional deterministic queuing models. Traditional queuing models are typically based on steady-state processes with constant arrival and service rates, which does not account for the dynamics in a world that is beset with uncertainty. Unlike the proposed fuzzy-based framework, which assumes the uncertain parameters are fuzzy numbers, the former models the uncertain parameters using a single estimated value.[13]

Multi-priority scheduling mechanisms enhance the management of critical requests by giving service precedence to urgent requests. This method minimizes the time emergency patients have to wait and optimizes the use of healthcare resources in healthcare settings. Similarly, in cloud computing applications, the model can improve task scheduling by prioritizing latency-sensitive, critical tasks while ensuring overall system efficiency.

Based on the experimental analysis, the proposed model has shown that it can help in reducing waiting time, resource utilization, enhancing response performance and quality of service. The fuzzy representation enables the system to be effective in handling the unpredictable workload variations, varying service capacities, and varying resource demands. Moreover, both the preemptive and non-preemptive priority strategies give flexibility for various application requirements. Hence, EMPFQM provides a powerful and smart decision support tool applicable to high-level real-world scenarios, especially in healthcare and cloud computing systems where uncertainty and fluctuating service requirements can have a substantial effect on the performance of the system.

IX. CONCLUSION

The proposed research is Enhanced Multi-Priority Fuzzy Queuing Model (EMPFQM) which is capable of solving uncertainty and dynamic operational challenges in the healthcare and cloud computing environment. This framework combines fuzzy set theory and priority queuing techniques to model the uncertainty of arrival rates, service capacities and workload variations in an effective manner. The fuzzy-based approach offers a more flexible representation of the real world conditions as compared to traditional deterministic queuing models that rely on fixed system parameters, and accounts for a set of possible system states.

Multiple priority classes provide efficient management of the various service requirements. The model has been applied in health systems to prioritize patients effectively and minimize waiting times in critical and emergency cases, ensuring

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[12] Ahmed, S., Hassan, M., & Rahman, A. (2024). An adaptive fuzzy priority scheduling algorithm for cloud computing systems with dynamic workloads. *Cluster Computing, 27*, 2145–2160.

[13] Liu, J., Wang, Z., & Zhang, Q. (2024). Intelligent queue management using fuzzy inference and predictive analytics in healthcare systems. *Expert Systems with Applications, 238*, 121912.

resources are allocated fairly. The framework helps to optimize task scheduling in cloud computing systems, ensuring the timely execution of critical and time-sensitive tasks to maintain the efficiency and responsiveness of the system.

The evaluation of the performance with respect to some of the important parameters, namely, fuzzy waiting time, queue length, response time and system utilization shows the potential benefits of the proposed approach. The preemptive and non-preemptive priority strategies further improve adaptability of operation in various scenarios.[14]

In conclusion, the EMPFQM is an intelligent and practical decision-making support tool for uncertain service systems. The proposed model can play a significant role in developing the adaptive healthcare management systems and efficient scheduling mechanisms for cloud resources. The framework could be expanded in the future, incorporating artificial intelligence, machine learning, and real-time predictive analytics to enhance decision-making autonomy and optimizing it.

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