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Performance Analysis of the M/M/1 Queuing System in Barber Shop Services Using an Analytical Approach

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Abstract: *Queueing systems play an important role in evaluating service performance, especially in small-scale businesses such as barbershops, where fluctuating customer arrival patterns and limited service capacity often lead to long waiting times. This study aims to analyze the performance of barbershop services using the M/M/1 queueing model and an analytical approach based on experimentally tested arrival (λ) and service (μ) rates. The model was selected because it represents a single-server system with Poisson arrivals and exponentially distributed service times, closely matching real barbershop operational characteristics. Using assumed realistic parameters, the analysis shows that when $\lambda = 12$ customers per hour and $\mu = 6$ customers per hour, the system becomes unstable with a utilization rate (ρ) exceeding 1, indicating continuous queue growth. Further simulations with increased service rates demonstrate significant improvements: at $\mu = 15$, the system achieves $\rho = 0.8$ with an average waiting time of 16 minutes, while at $\mu = 13$, the system remains stable but experiences a long waiting time of approximately 55 minutes. These findings emphasize that barbershop performance is highly sensitive to service speed and that even small increases in μ can produce substantial improvements in queue stability and customer waiting times. The study concludes that barbershops must ensure adequate service capacity-either through optimizing service duration, improving worker efficiency, or adding servers-to maintain service quality and enhance customer satisfaction.*

Keywords*: M/M/1 queueing model; service performance; barbershop; analytical approach; waiting time; utilization rate.*

1. INTRODUCTION

Studies on queue system performance continue to develop because many modern services exhibit fluctuating customer arrival patterns. Research by (Spyropoulos et al., 2022) shows that variations in arrival rates have a direct impact on stability and waiting times in queue systems, especially when the server operates near maximum capacity. Through an analytical approach, they demonstrated that even small imbalances between arrival and service rates can increase congestion and extend waiting times exponentially. These findings are important for understanding the context of barbershops, where customer dynamics are strongly influenced by peak hours and random arrival behavior.

Furthermore, the study by (Uriš et al., 2021) emphasizes that stochastic simulations and mathematical modeling are effective tools for evaluating the performance of service systems under conditions of uncertainty. They applied a combination of queuing models and simulations to map waiting times, queue lengths, and the probability of customer buildup across various operational scenarios. The study highlights that the use of mathematical models such as M/M/1 can provide accurate performance estimates while supporting data-driven decision-

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making. This approach is highly relevant when applied to small-scale barbershops, which often operate with only one barber as the main server.

Recent research by (Butera et al., 2021) shows that queue analysis can be used to optimize customer experience through more accurate wait-time estimation and efficient service allocation strategies. In their study, queuing models were used to predict customer dynamics, evaluate server performance, and design service improvement solutions oriented toward customer comfort. This research illustrates that queues affect not only operational efficiency but also customers' perception of service quality. This provides direct relevance to barbershop studies, where customer experience including waiting comfort plays an important role in operational success.

In addition, the performance analysis of single-server services is also the focus of a study by (Pan et al., 2022), which assessed service effectiveness at a customer service counter using a queuing model based on mathematical approaches. This research evaluated parameters such as average waiting time, queue length, and utilization rate to determine whether the service capacity was sufficient to handle variations in customer arrivals. Their findings indicate that single-server services are highly sensitive to increases in customer load, especially when the arrival rate approaches the server's capacity limit. This study aligns with the context of small barbershops, where only one barber acts as the server, meaning that even a slight increase in the number of customers can immediately increase waiting times and reduce service satisfaction.

(Riabtsev et al., 2022) also emphasize the importance of analytical queue modeling in understanding customer flow and estimating waiting times across various types of services. Using a queuing theory–based approach, their research demonstrates how basic parameters such as arrival rate (λ) and service rate (μ) can be used to accurately predict system performance. The study highlights that service optimization requires a strong mathematical understanding of the relationship between service demand and server capacity. In the context of barbershops, this approach becomes essential because customer waiting time is a key indicator of service quality, and single-server systems such as M/M/1 can provide relevant performance estimates for decision-making.

Literature Theory

The M/M/1 queuing system remains a popular platform for service efficiency analysis, and many open-access studies apply it to evaluate operational performance in various contexts. For example, the authors' research in SERIEs demonstrates the M/M/1 model used to determine optimal service capacity and waiting times in a service company, linking business decisions to classical queuing theory. In the context of recreation and tourism, they use M/M/1 and M/M/S to analyze visitor arrivals at Jatim Park during peak hours. They show that, although a single-server model is quite simple, the analysis can help determine when to add more servers to reduce queues.

In the healthcare sector, they apply the M/M/1 model at the Jetak health center to calculate patient waiting times and verify that a single-server system is still feasible from an efficiency standpoint. More complex queuing models are also discussed in the open-access literature: for example, Boxma & Vlasiou (2007) analyze queues where the inter-arrival and service times depend on customer waiting times, extending the classical model to make it more realistic in real-world operational situations. Another aspect of the M/M/1 modification emerges in continuous-service research, where there are two types of “customers” (real and imaginary) in the system—and servers have unique priority rules. Steady-state analysis shows that even when queues are critical, system performance metrics can still be solved analytically (Chew, 2019).

From an operational control perspective, a study by Canadian researchers showed that in the M/G/1 model, the distribution of service times (e.g., choosing between exponential and other distributions) can be optimized to minimize total costs, which depend on service speed and waiting time (Lefebvre & Yaghoubi, 2024).

To strengthen the relevance of M/M/1 in barbershop research, a theoretical summary study by (Wang, 2023) reviewed the basic M/M/1 queuing model with probabilistic formulation derivations and simulations, demonstrating the model's accuracy in reflecting the random arrival characteristics and service variability. Finally, variants of the queuing model, such as M/C-2/M/1, are also discussed in the literature, where servers can take a break after serving a group of customers, and service times follow a Coxian-2 distribution. While different from pure M/M/1, this study is relevant in demonstrating how model complexity can inform operational optimization (Al-rawi & Shboul, 2021).

The M/M/1 queuing system remains a widely used foundation in service efficiency analysis, and many open-access studies have applied it to evaluate operational performance in various contexts. For example, research published in *SERIEs* demonstrates how the M/M/1 model is used to determine optimal service capacity and efficient waiting times in service companies, as well as how managerial decisions can be guided by the mathematical structure of classical queueing theory (Parra-frutos, 2020). In a recreational context, (Fauzy et al., 2024) employed M/M/1 and M/M/S approaches to examine visitor arrival dynamics at Jatim Park during peak hours. Their study shows that although the single-server model appears simple, its quantitative analysis can serve as an indicator for determining when a service needs additional servers to manage increasing visitor loads.

In the healthcare sector, (Arifin & Mustofa, 2023) applied the M/M/1 model at the Jetak health center to calculate patient waiting times, demonstrating that a single-server system can still be considered efficient up to a certain point before approaching saturation. Beyond classical models, several studies have developed queueing model variants to better approximate realistic operational conditions. (Boxma & Vlasiou, 2007) examined queues with dependency between interarrival times, service times, and waiting times, producing formulations that are more adaptive to real system dynamics. (Chew, 2019) also contributed a different perspective through a continuous-service model involving both real and imaginary customers, showing that a system can still reach steady state even when service priority rules are more complex than those in the standard M/M/1 model.

Further studies show that queueing systems can be analyzed not only through mathematical formulations but also as tools for cost optimization. (Lefebvre & Yaghoubi, 2024) emphasize that in M/G/1 models, the choice of service-time distribution can influence total operational costs and customer waiting times, making queue modeling a strategic calculation tool for decision-making. Strengthening the theoretical foundation, (Wang, 2023) discusses M/M/1 through probabilistic derivations and simulations, asserting that although idealized, the model still reflects the characteristics of random arrivals and service variability relevant to simple service systems.

In addition to these studies, other research has applied queueing theory in the context of industrial material loading. One study analyzed a queuing system using an M/M/1 finite-source model to determine strategies that minimize demurrage in the export clinker loading process. The approach demonstrates that optimizing the number of entities within the system can reduce waiting times and improve service efficiency, extending the relevance of queueing theory to more complex logistics service systems (Arianto et al., 2022).

Another study discusses how designing queue flow and managing customer movement can significantly improve service quality. The research emphasizes that performance improvement does not always require adding more servers; rather, it can be achieved through better queue system design and more systematic process management, enabling the service to respond more effectively to demand fluctuations (Kris & Lahallo, 2025).

Based on these studies, it is evident that queueing theory has been widely applied across sectors such as services, healthcare, recreation, and logistics. However, very few studies have specifically examined barbershop service performance using an analytical M/M/1 approach based on actual arrival and service data. Most research focuses on multi-server models, complex systems, or large-scale industrial contexts, resulting in limited empirical findings on small-scale services with a purely single-server structure. This gap highlights the need for research that applies the M/M/1 model directly to barbershop services to provide a more precise depiction of operational performance, particularly regarding waiting time, utilization rate, and service capacity development needs.

2. METODE PENELITIAN

The research in this study used a quantitative approach with analytical methods to analyze performance in the queuing system at barbershop services. The research was conducted by modeling the customer arrival process and the service process using the M/M/1 queueing model. This model has a Poisson distribution arrival pattern and an exponential distribution service time, where arrivals form a single queue to be served by one server (Rahmatiar et al., 2022). This model was chosen because its characteristics are in line with the operational conditions of small barbershops, which generally only have one barber with a random and unpredictable customer arrival pattern.

The object of this study is the main service process that occurs in a barbershop, based on both direct observation data and assumption data adjusted to realistic conditions in the field. Based on the model used, the data used in this research analysis consists of the average customer arrival rate (λ) and the average barber service rate (μ) in units of customers per hour. These two parameters are core components in calculating queue system performance and form the basis for determining whether the system is in a stable condition or not.

Queueing System

The queuing system is an important component in this study because the purpose of the analysis is to evaluate the performance of barbershop services based on queuing theory. The queuing system itself is defined as the process of customers arriving to receive service, waiting if the service facility (server) is still busy, then receiving service, and leaving the system after finishing (Fidianti & Susanto, 2016). The queuing system at barbershops tends to be simple but dynamic, because customers arrive randomly, form a single queue, and there is only one attendant (barber).

These characteristics make the barbershop queuing system a single-channel single-phase system, which is a system with one arrival channel and one service stage. In this structure, each customer enters the system, waits for their turn, and is then served sequentially. There are no additional lines or post-service processes that require separate phases. These characteristics are very suitable for the M/M/1 model, which emphasizes random arrivals, a single server, and a service process that does not depend on previous times (memoryless).

This system was chosen because it is able to describe the real situation of a barbershop where customer fluctuations are greatly influenced by time, day, and the activities of the surrounding community. With an understanding of this basic queueing structure, the study can conduct a more focused analysis of service performance.

Application Method of the M/M/1 Queuing Model

In the M/M/1 queueing model, the value of L is obtained based on a Markov chain. It is assumed that the arrival rate is λ and the proportion of time in the empty state is P0. Therefore, the rate of leaving the empty state is λP0. The empty state can only be reached from state 1, which is when one customer in the system completes their service. This condition is achieved because the service rate is μ with a probability of being in a state of one customer, which is P1. The relationship between these states is the basis for the steady-state formulation in the M/M/1 model (Rahmatiar et al., 2022).

In applying the M/M/1 model, this study uses several basic assumptions, namely: customer arrivals follow a Poisson distribution, service time follows an exponential distribution, system capacity is considered unlimited, the queue discipline uses the First In First Out (FIFO) principle, and no customers leave the queue before being served (no balking or reneging). These assumptions are used to simplify the calculation process so that the model can represent the operational conditions of the barbershop well without requiring additional complex variables.

After the parameters λ and μ are determined, the analysis step is carried out by calculating the system performance using the basic formulas of the M/M/1 model, such as server utilization rate, average queue length, average waiting time in the queue, and the total time customers spend in the system. The calculations are performed manually using analytical formulas and are also assisted by software such as scientific calculators or spreadsheet applications to ensure accuracy and minimize computational errors.

In addition, this study also tests several different μ values to analyze how an increase in service speed affects system performance. This type of analysis is important because it helps show the sensitivity of the model to changes in service parameters, so that the results can be used as operational considerations for barbershop owners in their decision making.

To provide a visual illustration of the analyzed queue process flow, this study uses an illustration of the M/M/1 queue model as shown in Figure 1.

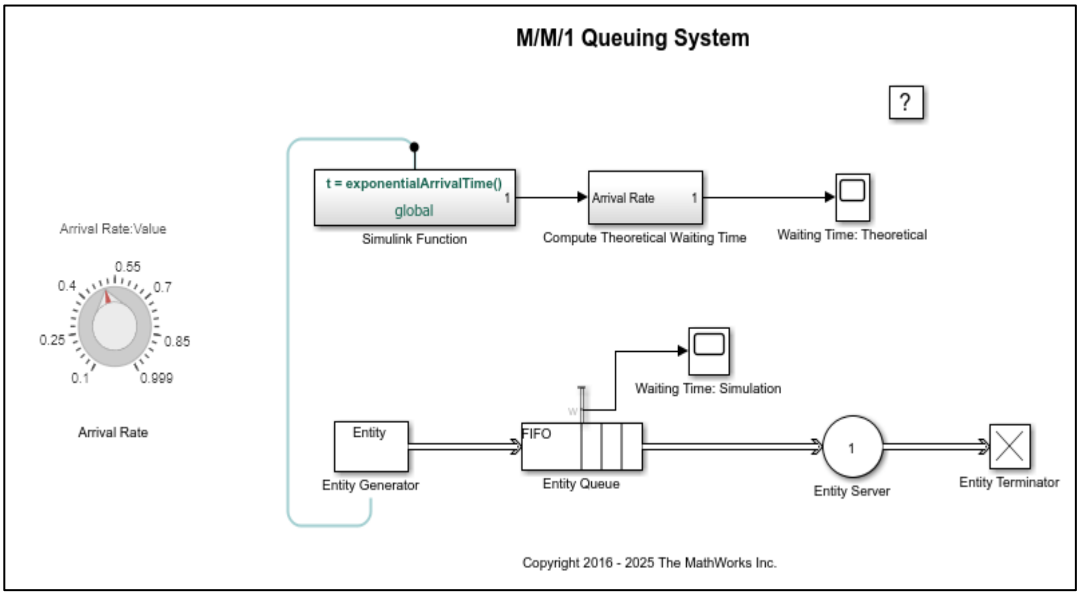

Figure 1. *Queueing System* M/M/1 Diagram

The diagram above shows the flow of customer arrivals (λ), the queuing process, a single server with a service rate (μ), and customer output after the service process. The diagram shows how customers enter the system, then wait if the server is busy, and are then served sequentially. This illustration clarifies the queuing structure at the barbershop, which corresponds to the M/M/1 model, and is therefore used as the basis for calculating system performance. This method was chosen because it provides a clear mathematical representation of the relationship between customer arrival rate, service speed, and system performance, without requiring complex simulations. Using this approach, the study can produce accurate analyses that are easy for barbershop owners to apply in making operational decisions.

3. RESULT AND DISCUSSION

Research Data and Parameters

In this study, the data used consists of two main parameters, namely the customer arrival rate (λ) and the barber service rate (μ). This study was conducted using an analytical approach without direct observation, so that the values of the parameters used are values determined based on realistic assumptions that commonly occur in barbershop operations. Small barbershops generally receive 10 to 15 customers per hour during peak hours and require an average service time of between 8 and 12 minutes per customer. Based on these considerations, this study uses a value of $\lambda = 12$ customers per hour as the average arrival rate and $\mu = 6$ customers per hour, equivalent to an average service time of 10 minutes per customer. Additionally, the number of servers (barbers) in this system is one person, so the model used is consistent with the M/M/1 characteristic. The parameters used in the analysis are summarized in Table 1 below.

Table 1. M/M/1 Queuing System Parameters in Barber Shop Services

Parameter	Keterangan	Nilai
λ (Lamda)	Average customer arrivals per hour	12 customers/hour
μ (mu)	Average service time per hour (± 10 minutes per customer)	6 customers/hour
c	Number of servers/barbers	1
Model used	M/M/1 queueing model	-
Queuing discipline	First In First Out (FIFO)	-
Arrivals distribution	Poisson	-
Service distribution	Exponential	-

1.***System Performance Calculation Results***

Based on the parameters specified in Table 1, the performance of the queueing system was calculated using the M/M/1 model with a customer arrival rate of $\lambda = 12$ customers per hour. In the first stage, a service rate of $\mu = 6$ customers per hour was used, which corresponds to an average service time of approximately 10 minutes per customer.

$$\rho = \lambda/\mu$$
$$= 12/6$$
$$= 2$$

The calculation results show that the system utilization value is greater than 1. This condition indicates that the system is in an unstable state, so that the number of customers in the queue will continue to increase and performance metrics such as queue length (Lq), waiting time (Wq), and the number of customers in the system (L) cannot reach steady-state values. These results indicate that the barbershop's service speed is unable to keep up with the number of customers arriving.

To provide a more comprehensive analysis, a recalculation simulation was performed using two higher μ values, namely $\mu = 15$ customers per hour and $\mu = 13$ customers per hour. Both of these values meet the stability requirement ($\lambda < \mu$), so that the steady-state performance values can be calculated. In the $\mu = 15$ scenario, the system utilization rate is $\rho = 0.8$ with an average queue length of 3.2 customers and a waiting time in the queue of around 16 minutes. Meanwhile, in the $\mu = 13$ scenario, the utilization rate increases to $\rho = 0.923$ and the average queue length reaches 11.07 customers with a waiting time of approximately 55.38 minutes. These results show that although the system is still stable at $\mu = 13$, the operational conditions are very congested and result in a fairly long waiting time.

A summary of the system calculation results for the three scenarios is shown in the following table:

Table 2. Hasil Perhitungan Performa Sistem Antrian M/M/1

Parameter	Rumus	μ = 6 (tidak stabil)	μ = 15 (stabil)	μ = 13 (stabil, padat)
Utilization (ρ)	$\rho = \lambda/\mu$	2,00	0,80	0,923
Average queue length (Lq)	$\rho^2/(1-\rho)$	Undefined	3,20	11,08
Number of customers in the system (L)	$\lambda/(1-\lambda)$	Undefined	4 customers	12 customers
Average waiting time (Wq)	Lq/λ	Undefined	0,2667 hour (16 minutes)	0,9231 hour (55,38 minutes)
Total time in the system (W)	$1/(\mu-\lambda)$	Undefined	0,3333 hour (20 minutes)	1 hour (60 minutes)

Discussion

The results show that barbershop service capacity plays a very important role in determining the overall stability and quality of service. In the initial condition with a service level of μ = 6 customers per hour, the system is unstable because the utilization value exceeds 1, which means that the number of customers arriving is greater than the system's capacity to serve them. This condition is very detrimental operationally because the queue will continue to grow over time, so customers may experience long and uncertain waiting times. This kind of instability can ultimately reduce customer satisfaction and impact the overall operational effectiveness of the barbershop. Therefore, increasing service capacity is an important step that must be taken to ensure the system can work more efficiently.

Calculation scenarios with higher service values, namely μ = 15 and μ = 13 customers per hour, provide a clearer picture of how system performance changes as service speed increases. In the μ = 15 scenario, the system is stable and relatively comfortable for customers. A waiting time of only about 16 minutes indicates that the service capacity is sufficient to keep up with the customer arrival rate. In addition, the total time customers spend in the system is around 20 minutes, indicating that the service is fast and efficient, so the customer experience can be categorized as good.

Conversely, in the μ = 13 scenario, even though the system is still mathematically stable, the waiting time increases sharply to more than 55 minutes. This long waiting time indicates that the service capacity is still at the minimum limit to accommodate high arrival rates. If this condition occurs during peak hours, the barbershop risks experiencing a significant buildup of customers, which could potentially reduce customer comfort and satisfaction. In other words, the difference between $\mu = 13$ and $\mu = 15$ shows that a small increase in service speed can have a big impact on queue system performance.

Overall, the results of this analysis confirm that in order to maintain optimal service performance, barbershops need to increase service capacity, either by speeding up service times, providing additional training to improve worker efficiency, using faster tools, or adding more barbers if necessary. These recommendations are particularly important given the high arrival rate, as barbershops require a queueing system that is not only stable but also capable of providing reasonable waiting times. With proper capacity management, barbershops can maintain service quality, reduce customer complaints, and support more efficient operational sustainability.

4. CONCLUSIONS AND SUGGESTIONS

Conclusion

Based on customer arrival parameters of $\lambda = 12$ customers per hour and an initial service rate of $\mu = 6$ customers per hour, it was found that the system was unstable because the utilization value ρ exceeded 1. This condition indicates that the service capacity is insufficient to keep up with the customer arrival rate, so that the queue tends to grow indefinitely and the waiting time cannot be calculated in a steady-state condition. To obtain a realistic operational picture, further calculations were performed with higher service values, namely $\mu = 15$ and $\mu = 13$ customers per hour. The results show that in both scenarios, the system is in a stable condition, but the service quality differs significantly. At $\mu = 15$ customers per hour, the average waiting time is only about 16 minutes, indicating sufficient capacity. Meanwhile, at $\mu = 13$ customers per hour, the waiting time increases dramatically to more than 55 minutes, so even though it is stable, the system is close to saturation and less than ideal for customer comfort.

Overall, this study concludes that barbershop queue performance is highly sensitive to changes in service levels. Too low a service capacity causes instability, while a capacity slightly higher than the arrival rate can significantly reduce waiting times. Therefore, barbershops need to ensure that the μ value is at a sufficiently high level or increase the number of barbers to keep the system stable and able to provide an optimal service experience for customers.

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