

Queueing System Analysis and Customer Service Optimization in Retail Business Using a Multi-Channel Model

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DOI: <https://doi.org/10.52403/ijrr.20261024>

ABSTRACT

This study aims to analyze the performance of the queueing system and determine customer service optimization strategies for Marni's Grocery Store in Bangetayu Wetan, Semarang City. Research data were obtained through observation and interviews over a five-day period (July 9–13, 2023), tracking customer arrivals and service delivery between 08:30 and 11:30 WIB. Analysis was conducted using queueing theory based on the M/M/2 model, while distribution goodness-of-fit was assessed via the Kolmogorov-Smirnov test using IBM SPSS Statistics 26. Subsequently, queueing system performance metrics were calculated mathematically and verified using WinQSB 2.0 software. The results indicate that Marni's Grocery Store employs a multi-channel, single-phase service structure with two service facilities, utilizing both First Come, First Served and Priority Service queueing disciplines. Customer arrival rates follow a Poisson distribution, and the system operates in a steady state. With two servers, the service facility utilization rate is 51%; on average, there is one customer in the queue and two in the system, with an average waiting time in the queue of 0.42 minutes and an average total time in the system of 2 minutes. A simulation involving

the addition of a third server showed a reduction in waiting time to 0.06 minutes but increased the likelihood of facility idleness. Thus, the use of two servers is considered optimal in terms of balancing service levels and facility utilization.

Keywords: Queueing System, Queueing Theory, M/M/2, Service Optimization.

INTRODUCTION

Grocery stores are a form of retail business that plays a role in meeting the community's daily needs, particularly within residential areas. Their presence offers convenience by providing a wide range of essentials, such as staple foods, snacks, household supplies, vegetables, fruits, and fuel. In addition to offering easy access, these stores are generally located close to consumers, making them a preferred choice for the community. However, a surge in customer numbers at certain times can create service-related issues, especially when the rate of customer arrivals exceeds or approaches the available service capacity. Such conditions can lead to the formation of queues and increase customer waiting times.

A queue arises when customers must wait to receive service because available service facilities cannot immediately meet all demands. Excessive waiting times can

diminish customer comfort and satisfaction and potentially cause customers to abandon the queue. Therefore, a mathematical approach is needed to evaluate the characteristics and performance of service systems. Queueing theory is one such approach that can be used to analyze the relationships between customer arrival rates, service rates, the number of service facilities, and waiting time characteristics within a system.

Marni's grocery store, located in Bangetayu Wetan, Genuk District, Semarang City, is a retail business facing issues regarding its customer service system. The store operates two service facilities utilizing a single-queue service pattern. Observations indicate that the service system exhibits multi-channel, single-phase characteristics, meaning multiple service facilities serve customers from a single queue. The service discipline applied is a combination of First Come First Served (FCFS) and Priority Service (PS). Based on arrival and service characteristics, the system is modeled using the $(M/M/2) : (FCFS/\infty/\infty)$ and $(M/M/2) : (PS/\infty/\infty)$ queueing models.

The queueing system analysis in this study was conducted using primary data obtained through observation and interviews over a five-day period, from July 9 to 13, 2023. The data consisted of arrival counts and the number of customers served during the 08:30–11:30 WIB time interval. A distribution goodness-of-fit test was performed using the Kolmogorov-Smirnov method with the aid of IBM SPSS Statistics 26, while the analysis of system performance metrics was carried out using mathematical calculations and WinQSB 2.0 software.

This study aims to analyze the characteristics of the queueing system, determine service performance metrics, and evaluate the potential addition of service facilities as an optimization alternative. The analysis results are expected to provide insight into the efficiency of the implemented service system and serve as a basis for determining the appropriate

number of service facilities, thereby achieving a balance between reducing customer waiting times and effectively utilizing service facilities.

LITERATURE REVIEW

A. Queueing Systems and Service Performance

Queueing theory is a mathematical approach used to analyze situations in which customers or entities must wait before receiving services. In operational settings, queueing theory can be applied to evaluate the relationships among customer arrival rates, service capacity, number of servers, queue length, and waiting time. [1] explained that queueing theory provides a formal framework for studying waiting phenomena and has been applied to various operational problems, including staffing, productivity, customer waiting time, and service capacity. Therefore, queueing theory is not only useful for measuring queue length but can also support managerial decisions concerning service capacity.

One of the fundamental relationships in queueing theory is Little's Law, which relates the average number of customers in a system to the arrival rate and the average time spent in the system. [2] established the relationship $L = \lambda W$, where (L) represents the average number of customers in the system, (λ) denotes the average arrival rate, and (W) represents the average time a customer spends in the system. This relationship provides an important theoretical basis for interpreting queueing performance and connecting customer numbers with waiting times.

System stability is another important consideration in queueing analysis. [3] demonstrated that waiting times can increase substantially as server utilization approaches unity, particularly under heavy-traffic conditions. This finding indicates that systems operating close to their maximum service capacity may experience considerable increases in customer waiting times. Consequently, server utilization is an important performance indicator when

determining whether the available service capacity is adequate.

B. Multi server Queueing Models

In service systems with several parallel facilities, the M/M/c model is one of the commonly applied queueing models. The model generally assumes Poisson arrivals, exponentially distributed service times, and c parallel servers. [4] investigated approximations for the GI/G/m queue and demonstrated the importance of performance measures such as waiting time, probability of delay, queue length, and the number of customers in the system in multiserver environments.

The number of servers has a direct relationship with system utilization and customer waiting time. [5] examined the efficiency of multiserver service systems and emphasized the importance of appropriately balancing server utilization and service capacity. Increasing the number of servers can improve service capacity and reduce waiting time; however, excessive service capacity can result in underutilized facilities. Therefore, determining the optimal number of servers requires consideration of both customer waiting time and resource utilization.

This issue is directly relevant to the Marni Grocery Store, where the observed service system consists of two service facilities operating within a single queue. The original study identifies the system as a multichannel-single-phase queue and models the service process using M/M/2 queueing models with FCFS and priority-service characteristics. The study subsequently compares the existing two-server configuration with an alternative three-server configuration.

[6] further investigated multiserver queueing systems through a heavy-traffic framework. Their study demonstrated the importance of the relationship between the number of servers, arrival rates, and the probability that customers experience delays. Although their research focuses on systems with a relatively large number of

servers, the underlying principle remains relevant to smaller service systems because service capacity must be balanced against customer demand.

C. Server Capacity Optimization

Determining the appropriate number of servers is an important issue in queueing-system optimization. [7] developed a framework for server staffing under time-varying demand. Their research demonstrated that staffing decisions can be related to variations in service demand and target service performance. This suggests that the optimal number of servers may vary according to customer arrival patterns during different periods.

Queueing models have also been applied specifically to retail service systems. [8] employed an M/M/C queueing model to analyze and optimize the number of service desks in a supermarket. The study demonstrated that queueing analysis can provide quantitative support for decisions concerning service facilities, customer waiting times, and operational efficiency.

A similar application was conducted by [9], who analyzed the queueing system at Hyperstore Supermarket. Their study identified the service system as a multichannel-single-phase system and examined the appropriate number of service facilities using queueing performance measures. The study is particularly relevant to the present research because both studies investigate multichannel service systems in retail environments and use queueing performance indicators as a basis for service optimization.

More recently, [10] applied the M/M/c model to a fast-food restaurant to evaluate alternative server configurations during peak hours. Their findings demonstrated that changes in the number of servers affect important performance measures, particularly customer waiting time. This reinforces the usefulness of multiserver queueing models in evaluating alternative service configurations.

D. Waiting Time and Customer Service Efficiency

Waiting time is one of the most important indicators of service-system performance. [1] emphasized the relevance of waiting-time analysis in evaluating customer satisfaction and service performance. Excessive waiting may negatively influence the customer's service experience, making waiting-time reduction an important consideration in queueing-system design.

The relationship between waiting time and service satisfaction has also been examined in service-system research. An integrated model of patient and staff satisfaction using queueing theory demonstrated that waiting time and service duration can be incorporated into an evaluation of service quality and operational performance [11]. Although the study was conducted in a healthcare context, the underlying concept is applicable to other service environments because waiting time represents an important component of customer experience.

Based on the reviewed literature, queueing-system research generally involves three important stages. First, the arrival and service characteristics must be identified to determine an appropriate queueing model. Second, performance measures such as server utilization, average queue length, average number of customers in the system, and waiting time should be calculated to evaluate the existing system. Third, alternative server configurations can be compared to identify a suitable balance between service efficiency and resource utilization.

The present study applies this framework to the Marni Grocery Store. Based on the field observations, the store operates a multichannel-single-phase queue with two service facilities and a combination of FCFS and priority-service disciplines. The queueing system is represented by $(M/M/2):(FCFS/\infty/\infty)$ and $(M/M/2):(PS/\infty/\infty)$ models. The study analyzes customer arrivals and service performance, evaluates the resulting queueing performance

measures, and compares two- and three-server configurations. This approach provides a quantitative basis for assessing whether the existing service configuration provides an appropriate balance between customer waiting time and facility utilization.

MATERIALS & METHODS

A. Study Location and Data Collection

This study was conducted at Marni Grocery Store, located in Bangetayu Wetan, Genuk District, Semarang City, Indonesia. The study employed a quantitative observational approach to analyze the customer queuing system and evaluate its service performance. Primary data were collected through direct observation of customer arrivals and services, supplemented by interviews with the store owner. The observation was conducted for five consecutive days, from 9 to 13 July 2023, during the period from 08:30 to 11:30 Western Indonesian Time (WIB).

The collected data consisted of the number of customers arriving and the number of customers served within consecutive 30-minute intervals. The observations covered six time intervals per day: 08:30–09:00, 09:00–09:30, 09:30–10:00, 10:00–10:30, 10:30–11:00, and 11:00–11:30. The recorded arrival data ranged from 145 to 163 customers per day, while the number of served customers ranged from 143 to 159 customers per day.

B. Queueing System Identification

The analysis was based on the standard assumptions of a multi-server queueing system. Customer arrivals were treated as a stochastic process, while service times were considered variable among customers. The number of servers was fixed at two, and the potential customer population and queue capacity were assumed to be sufficiently large. The primary performance analysis focused on the arrival rate (λ), service rate per server (μ), and the number of servers (c). The stability of the system was examined using the steady-state condition. For a

multi-server system, the utilization factor was determined from $\rho = \lambda / (c\mu)$, where (λ) is the average customer arrival rate, (μ) is the average service rate of each server, and (c) is the number of servers. The system is considered stable when $\rho < 1$.

The observed data produced an average arrival rate of approximately 52 customers per hour and an average service rate of approximately 51 customers per hour per service facility. The resulting utilization was subsequently used to determine whether the existing two-server system operated under steady-state conditions.

C. Distribution Testing

Before applying the queueing model, the observed data were tested to determine whether they satisfied the distributional assumptions of the model. The customer arrival process was examined for conformity with the Poisson distribution, whereas the service process was evaluated with respect to the exponential distribution. A one-sample Kolmogorov–Smirnov (K–S) goodness-of-fit test was employed for this purpose. The test was performed using IBM SPSS Statistics 26. For the arrival data, the null hypothesis was that the number of customer arrivals during each 30 minutes interval followed a Poisson distribution. For the service data, the corresponding hypothesis concerned conformity with the assumed service-time distribution.

The significance level was set according to the statistical testing procedure in the original analysis. The decision criterion was based on comparing the calculated K–S

statistic with the corresponding critical value. The arrival data were found to be consistent with a Poisson distribution, supporting the use of the (M/M/2) queueing model.

D. Queueing Performance Measures

After confirming the distributional assumptions and steady-state condition, the performance of the queueing system was evaluated using several standard performance measures. These included the probability that the service facilities were idle, the probability that the facilities were busy, the average number of customers waiting in the queue (L_q), the average number of customers in the system (L_s), the average waiting time in the queue (W_q), and the average time spent in the system (W_s).

The principal performance indicators were calculated using the standard multi-server queueing equations. The relationships between the average number of customers and waiting times were also evaluated using Little's Law: $L_q = \lambda W_q$, and $L_s = \lambda W_s$. These measures were used to quantify the level of congestion and service efficiency at the store and to identify whether the existing service capacity was adequate.

RESULT

A. Steady-State Service System Metrics

To analyze the queueing system, observations can be made of the conditions at Marni's Grocery Store to gather the necessary data. The data obtained from these observations are as follows:

Table 1 Average Daily Customer Arrival Data, July 9–13, 2023

Time Interval	Saturday	Sunday	Monday	Tuesday	Wednesday
08.30 - 09.00	44	31	29	27	29
09.00 - 09.30	29	29	25	26	26
09.30 - 10.00	27	28	24	23	24
10.00 - 10.30	24	21	30	22	28
10.30 - 11.00	21	27	25	24	21
11.00 - 11.30	18	24	20	23	24
Total	163	160	153	145	152

Table 2 Average Daily Customer Service Data, July 9–13, 2023

Time Interval	Saturday	Sunday	Monday	Tuesday	Wednesday
08.30 - 09.00	39	28	27	24	26
09.00 - 09.30	31	27	24	27	26
09.30 - 10.00	27	30	26	21	25
10.00 - 10.30	23	21	28	24	29
10.30 - 11.00	22	28	24	23	21
11.00 - 11.30	17	21	21	24	22
Total	159	155	150	143	149

The steady-state condition—where the service system reaches a stable state—is met if the service facility's utilization rate is less than one, or if the average customer arrival

rate is lower than the average server service rate.

Based on the data, the average number of customer arrivals per hour is

$$\lambda = \frac{163 + 160 + 153 + 145 + 152}{15} = \frac{773}{15} = 51,53$$

So, $\lambda = 52$ customers per hour. The average number of customers served per hour is

$$\mu = \frac{159 + 155 + 150 + 143 + 149}{15} = \frac{756}{15} = 50,4$$

So, $\mu = 50$ to 51 customers per hour.

The utilization level of the service facility for two servers is

$$\rho = \frac{\lambda}{c\mu} = \frac{51,53}{2(50,4)} = \frac{51,53}{100,8} = 0,51121 \approx 0,51$$

Based on the calculation of the service facility utilization rate, the following results were obtained $\rho = 0,51 < 1$. This means that the customer service queuing system at Marni's Grocery Store meets the steady-state condition, implying that the average customer arrival rate does not exceed the average service rate.

B. Queueing System Performance Measures

The results of the manual calculations for the queuing system performance are as follows:

1. The utilization level of the service facility for two servers

$$\rho = \frac{\lambda}{c\mu} = \frac{51,53}{2(50,4)} = \frac{51,53}{100,8} = 0,51121 \approx 0,51$$

So, the utilization level of the service facility for two servers is $\rho = 0,51$

2. Probability of no customers in the service area

$$\begin{aligned}
 P_0 &= \left[\left\{ \sum_{n=0}^{c-1} \frac{1}{n!} \left(\frac{\lambda}{\mu} \right)^n \right\} + \frac{1}{c!} \left(\frac{\lambda}{\mu} \right)^c \left(\frac{c\mu}{c\mu - \lambda} \right) \right]^{-1} \\
 &= \left[\left\{ \sum_{n=0}^{2-1} \frac{1}{n!} \left(\frac{51,53}{50,4} \right)^n \right\} + \frac{1}{2!} \left(\frac{51,53}{50,4} \right)^2 \left(\frac{2(50,4)}{2(50,4) - 51,53} \right) \right]^{-1} \\
 &= \left[\left\{ \frac{1}{0!} \left(\frac{51,53}{50,4} \right)^0 + \frac{1}{1!} \left(\frac{51,53}{50,4} \right)^1 \right\} + \frac{1,04534}{2} \left(\frac{100,8}{49,27} \right) \right]^{-1} \\
 &= [1 + 1,02242 + 1,06931]^{-1} \\
 &= [3,09173]^{-1} = \frac{1}{3,09173} = 0,32344 \approx 0,32
 \end{aligned}$$

So, the probability of there being no customers in the service area—or that the service facility is idle is $P_0 = 0,32$ or 32%.

3. Probability of the service facility being busy

$$\begin{aligned}
 P_s &= \frac{1}{c!} \left(\frac{\lambda}{\mu} \right)^c \left(\frac{c\mu}{c\mu - \lambda} \right) P_0 \\
 &= \frac{1}{2!} \left(\frac{51,73}{50,4} \right)^2 \left(\frac{2(50,4)}{2(50,4) - 51,53} \right) (0,32344) \\
 &= \frac{1,04534}{2} \left(\frac{100,8}{49,27} \right) (0,32344) \\
 &= \frac{1,04534(0,66172)}{2} \\
 &= 0,34586 \approx 0,35
 \end{aligned}$$

So, the probability that the service facility is busy is $P_s = 0,35$ or 35%.

4. Average number of customers in the queue

$$\begin{aligned}
 L_q &= P_0 \frac{\lambda\mu}{(c-1)!(c\mu - \lambda)^2} \left(\frac{\lambda}{\mu} \right)^c \\
 &= (0,32344) \frac{51,53(50,4)}{(2-1)!(2(50,4) - 51,53)^2} \left(\frac{51,53}{50,4} \right)^2 \\
 &= (0,32344)(1,06986)(1,04534) \\
 &= 0,36172 \approx 1 \text{ customer}
 \end{aligned}$$

So, the average number of customers waiting in line is about 1 customers.

5. Average number of customers in the system

$$\begin{aligned}
 L_s &= L_q + \frac{\lambda}{\mu} \\
 &= 0,36172 + \frac{51,53}{50,4} \\
 &= 1,38414 \approx 2 \text{ customer}
 \end{aligned}$$

Thus, the average number of customers queuing and being served is about 2 customers.

6. Average time customers spend waiting in line

$$W_q = \frac{L_q}{\lambda} = \frac{0,36172}{51,53} = 0,0070$$

So, the average waiting time for each customer to be served is approximately 0.42 minutes.

7. Average time spent by customers in the system (queue + service)

$$W_s = \frac{L_s}{\lambda} = \frac{1,38414}{51,53} = 0,02686$$

So, the average time each customer spends in the system is about 2 minutes.

C. Calculations using WinQSB 2.0 software

Calculations using WinQSB 2.0 software were performed to verify the accuracy of the manual calculations, the results obtained via WinQSB 2.0 for a two-server system match those of the manual calculations.

In addition to verifying the manual calculations, using WinQSB 2.0 facilitates the determination of queuing system performance metrics when additional servers are introduced. Consequently, calculations were performed for both two-server and three-server queuing systems. To make these performance metrics easier to understand, the WinQSB 2.0 results for the two-server and three-server configurations are presented in the following table.

Table 1 Comparison of Queueing System Performance Measures

No	Queueing System Performance Measures	Many Servers	
		2	3
1	Utilization rate of service facilities	51 %	34 %
2	Average number of customers in the queue	1	0
3	Average number of customers in the system	2	1
4	Average time customers spend waiting in line	0,42 minutes	0,06 minutes
5	Average time customers spend in the system	2 minutes	1 minutes
6	Probability of no customers in the service area	32 %	36 %
7	Probability of the service facility being busy	35%	10 %

Based on the table above, the two-server setup at Marni's Grocery Store is considered to provide a satisfactory level of service. However, if the goal is to eliminate customer queues, an additional server could be added; yet, increasing the number of servers from two to three would likely result in one of the three servers frequently sitting idle.

DISCUSSION

The results indicate that the queueing system at Marni Grocery Store can be appropriately represented as a multi-channel, single-phase system with two service facilities. The observed system combines the First Come First Served (FCFS) discipline with priority service, particularly for customers purchasing gasoline and those making relatively simple transactions. This combination reflects the actual operational characteristics of the store, where strict FCFS cannot always be maintained because some customers need to be served immediately to prevent them from leaving. The identification of the system as $((M/M/2):(FCFS/\infty/\infty))$ and $((M/M/2):(PS/\infty/\infty))$ therefore provides a reasonable mathematical representation of the observed service process.

The analysis of customer arrivals and services shows that the system operates under relatively high demand. During the observation period, the average arrival rate was approximately 52 customers per hour, whereas the average service rate was approximately 51 customers per hour per server. The arrival data were found to follow a Poisson distribution based on the Kolmogorov–Smirnov goodness-of-fit test,

supporting the stochastic arrival assumption required by the queueing model. This result suggests that customer arrivals occur randomly over time, which is consistent with the operational characteristics of a grocery store where customers do not arrive according to a predetermined schedule.

Despite the relatively high arrival rate, the two-server configuration was found to satisfy the steady-state condition. The utilization analysis indicates that the existing service facilities are capable of handling the observed customer demand without causing the system to become unstable. The analysis reported approximately 32% idle capacity and 35% busy service activity during the observed period. In addition, the system contained approximately one customer in the queue and two customers in the overall system, while the average waiting time in the queue was approximately 0.42 minutes. These results indicate that the existing system provides relatively short waiting times, although the difference between the arrival and service rates suggests that the system should continue to be monitored during periods of higher demand.

From a service-management perspective, the results suggest that adding another service facility could further reduce customer waiting and increase service capacity. The original analysis proposed increasing the number of servers from two to three so that the service capacity could more closely match or exceed the arrival rate. However, this alternative should not automatically be considered the optimal solution. An additional server would increase operational costs and could result

in substantial idle capacity during periods of low customer demand. Therefore, the decision to add a server should consider the trade-off between reduced waiting time and increased resource utilization. A flexible staffing strategy, in which an additional worker is assigned during peak periods, may provide a more economically efficient alternative to maintaining three permanent servers.

Overall, the findings demonstrate that queueing theory can provide a useful quantitative framework for evaluating and improving service operations in small retail businesses. The combination of empirical observation, distribution testing, steady-state analysis, and queueing performance measures enables the current service system to be evaluated objectively rather than relying solely on subjective observations. The results also indicate that optimization should focus not only on eliminating queues but also on achieving an appropriate balance between customer waiting time and server utilization. Consequently, the proposed queueing model can serve as a decision-support tool for Marni Grocery Store in determining future service capacity and developing more efficient customer-service strategies.

CONCLUSION

This study analyzed the queueing system at Marni Grocery Store using a multi-server queueing model. The observed system consists of two service facilities with a single waiting line and combines First Come First Served (FCFS) and priority service. The analysis showed that customer arrivals follow a Poisson distribution, with an average arrival rate of approximately 52 customers per hour and a service rate of approximately 51 customers per hour per server. The system satisfies the steady-state condition, with an average of one customer in the queue and approximately 0.42 minutes of waiting time.

The results indicate that the existing two-server system is generally capable of providing efficient customer service under

the observed conditions. Although adding a third server could further reduce waiting time, it may also increase operational costs and server idle time. Therefore, maintaining two servers with additional service capacity during peak periods may provide a more efficient balance between service quality and operational resources. Overall, queueing theory provides a useful mathematical approach for evaluating and optimizing service systems in small retail businesses.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

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- How to cite this article: Nurcahya Yulian Ashar, Agista Surya Bawana, Humam Rosyadi. Queueing system analysis and customer service optimization in retail business using a multi-channel model. *International Journal of Research and Review*. 2026; 13(10): 253-262. DOI: <https://doi.org/10.52403/ijrr.20261024>
