Application of Queuing Theory to Traffic Congestion Analysis on the Asaba–Onitsha Bridge, Nigeria

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ABSTRACT

Traffic congestion on major transportation corridors poses significant economic and social challenges, particularly in developing urban regions. This study applies queuing theory to analyze traffic congestion on the Asaba–Onitsha Bridge, a critical transportation link between Delta State and Anambra State, Nigeria. Using real-life traffic data, the study evaluates the performance of the bridge in terms of traffic intensity, queue length, and waiting time under varying service capacity conditions. A quantitative and observational research design was adopted. Primary traffic data were collected through direct field observation during morning and afternoon periods, with vehicles classified into small and big categories to reflect traffic composition. An M/M/2 queuing model was employed. Traffic performance was analyzed under three assumed service rates of 600 veh/hr, 800 veh/hr, and 1000 veh/hr to assess the impact of service capacity on congestion levels. The results reveal clear temporal variations in traffic flow, with the morning period experiencing significantly higher traffic volumes, largely due to the dominance of small vehicles, while the flow of big vehicles remains relatively stable throughout the day. At a service rate of 600 veh/hr, the system operates close to capacity during the morning peak, resulting in higher traffic intensity, noticeable queues, and increased waiting times, indicating a marginally adequate service level. Increasing the service rate to 800 veh/hr leads to substantial reductions in queue length and waiting time, producing efficient traffic flow during both peak and off-peak periods. The best performance is observed at a service rate of 1000 veh/hr, where traffic intensity remains low and near free-flow conditions are achieved even during peak demand. The study concludes that congestion on the Asaba–Onitsha Bridge is strongly influenced by service capacity and temporal traffic demand variations. Enhancing service capacity through improved traffic management or infrastructure expansion can significantly reduce congestion, minimize delays, and improve overall traffic flow on the bridge. The findings provide quantitative evidence to support capacity enhancement through improved traffic management, infrastructure development, and the integration of Intelligent Transportation Systems that provides a modern, cost-effective, and adaptive approach for optimizing existing infrastructure and minimizing traffic delays.

Keywords: Queuing Theory, M/M/2 Model, Traffic Flow Analysis, Traffic Congestion, Asaba–Onitsha Bridge.

INTRODUCTION

Queuing theory deals with the systematic study of waiting for service at service points of various kinds and seeks to explain the formation, behavior, and performance of queues in systems where demand for service is random (Sztrik, 2012). In most service systems, including transportation facilities, it is generally desirable for users to spend as little time as possible waiting in queues. However, reducing waiting time often requires additional capacity or infrastructural investment, which may involve substantial capital outlay. Consequently, decision makers must evaluate whether such investments yield sufficient operational benefits in terms of reduced congestion and improved service efficiency.

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Queuing models provide a powerful analytical framework for addressing such decisions by quantifying system performance measures such as waiting time, queue length, and server utilization. These models have been widely applied in production systems, transportation networks, communication systems, inventory control, and information processing systems, particularly for system design with respect to layout, capacity, and control (Sztrik, 2010; Taha, 2002). By isolating critical stochastic elements such as arrival patterns and service times, queuing models allow analysts to understand how random demand interacts with limited service capacity to generate congestion.

Historically, queuing theory originated from the pioneering work of Erlang (1909), who first applied probabilistic methods to analyze congestion problems in telephone traffic. Since then, the theory has evolved into one of the most widely used analytical tools in operations research, with applications spanning telecommunications, traffic engineering, computing systems, manufacturing, healthcare delivery, banking, and public service operations (Srivastava, Shenoy & Sharma, 2008). In transportation systems, queuing theory is particularly useful for modeling traffic bottlenecks where arrivals are unpredictable and service capacity is finite, leading to conflicts for resource usage and the formation of queues (Kleinrock, 1975).

In real-world queuing systems, arrivals often follow a Poisson process with exponentially distributed inter-arrival times, while service times are frequently assumed to be exponentially distributed and independent of arrival processes (Sztrik, 2012). Service is commonly rendered on a first-come-first-served basis, and system capacity may consist of one or multiple parallel servers. Under such assumptions, queuing models enable the derivation of key performance measures, including the expected waiting time in the queue and the system, the average queue length, server utilization, and the probability of the system being in specific states such as empty or congested (Makwana, 2012; Nafees, 2007).

Queues are a pervasive feature of everyday life and are encountered in hospitals, banks, schools, offices, fuel stations, airports, and road traffic systems. In traffic engineering, queues form when vehicle arrival rates exceed or approach the service capacity of a roadway section, intersection, or bridge, resulting in delays and congestion. The severity of such queues depends not only on the average arrival rate but also on the variability of traffic flow and service processes (Kleinrock, 1975). As such, queuing theory provides a suitable framework for analyzing traffic congestion problems and evaluating alternative capacity and control strategies.

Several empirical studies have demonstrated the applicability of queuing theory to service systems. Adeleke et al. (2009) applied queuing models to analyze outpatient waiting times in hospitals, while Ogunwale and Olubiyi (2012) conducted a comparative analysis of customer waiting times in banks. Tsarouhas (2011) applied queuing theory to production lines in food processing, and Kumar and Jain (2013) investigated queue control policies for managing arrivals and services. These studies highlight the versatility of queuing models in evaluating system efficiency and guiding operational improvements.

Within the Nigerian context, transportation infrastructure, particularly critical corridors and bridges, experiences frequent congestion due to high traffic demand, limited capacity, and heterogeneous vehicle composition. The Asaba–Onitsha Bridge serves as a major transportation link between the South-East and South-South regions of Nigeria and is characterized by heavy daily traffic comprising both small and large vehicles. Persistent congestion on this bridge results in increased travel time, economic losses, and reduced service quality for road users.

Against this background, this study applies queuing theory to analyze traffic congestion on the Asaba–Onitsha Bridge using real-life traffic data. By modeling vehicle arrivals and service processes under different operational assumptions, the study evaluates the bridge’s performance in terms of traffic intensity, queue length, and waiting time. The analysis further examines the impact of varying service capacities through multi-server queuing models, with the aim of identifying effective traffic management strategies capable of reducing congestion and improving overall traffic flow on the bridge.

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LITERATURE REVIEW

This section presents a review of relevant literature on the application of queuing theory to traffic congestion and service systems. Queuing theory is a mathematical framework developed to analyze situations in which entities arrive randomly to receive service from limited facilities. Priyanka Rani and Sharma (2024) describe queuing theory as a practical and adaptive tool that extends beyond abstract mathematics into real-world problem solving. According to their study, queuing theory has found wide application in sectors such as transportation, healthcare, telecommunications, retail, and cloud computing, where demand fluctuates unpredictably and resources are constrained. The authors emphasize that queuing models provide quantitative measures of system performance, including average waiting time, queue length, service utilization, and overall efficiency. By applying appropriate queuing models, system managers are able to improve operational efficiency, reduce congestion, and enhance user satisfaction.

In the transportation sector, queuing theory has been widely applied to analyze traffic congestion, particularly at urban intersections and major road networks. Urhode and Tsetimi (2022) investigated traffic congestion and travel time at the Iwo Road intersection in Ibadan, Oyo State, Nigeria, using queuing models. Their study employed direct observation and manual vehicle counting during peak and off-peak periods to capture daily variations in traffic flow. The findings revealed that congestion at the intersection was particularly severe on Mondays, Saturdays, and Sundays, reflecting both weekday commuter pressure and increased weekend travel demand. The study further established that vehicle arrival rates frequently exceeded the service capacity of the intersection, leading to prolonged queues and increased travel time. These results demonstrated the effectiveness of queuing models in diagnosing congestion problems and assessing traffic performance in urban settings.

Further evidence of the relevance of queuing theory in traffic analysis is provided by Aderinola, Elemure, and Laoye (2020), who examined congestion at Jattu Junction in Auchi using queuing theory supported by TORA and SIDRA traffic analysis software. Their study combined theoretical queuing models with simulation tools to evaluate traffic performance indicators such as queue length, waiting time, and level of service. The integration of queuing theory with specialized traffic analysis software allows for more realistic modeling of complex traffic conditions and improves the accuracy of congestion assessment (Bhattarai et al., 2025). The findings confirmed that queuing-based approaches are suitable for evaluating traffic bottlenecks and testing the effectiveness of traffic control measures.

Beyond transportation systems, queuing theory has been widely applied to service-oriented environments, particularly within the banking sector. Adeleke, Adebiyi, and Akinyemi (2005) applied queuing theory to customer service operations at Omega Bank Plc in Ado Ekiti, Nigeria, assuming that customers arrive randomly and are served by a limited number of service counters. Their analysis focused on key performance indicators such as average waiting time, queue length, and server utilization, demonstrating that queuing models provide valuable insights into service efficiency and help determine whether existing service capacity is sufficient to meet customer demand. Similar conclusions have been reported in more recent studies, which confirm the continued relevance of queuing theory for evaluating and optimizing service performance in banking and other service systems (Ibukun-Falayi, 2021; Paveun & Danyaro, 2025). Although these studies were conducted in a banking context, the methodological framework is equally applicable to traffic systems, where vehicles can be conceptualized as customers and road lanes as service channels.Multi-server queuing models have also been applied in industrial settings where multiple service points operate simultaneously. Tsetimi and Orighoyeghe (2021) examined the application of an M/M/S queuing model to selected tank farms in Oghara, Delta State, Nigeria. The study assumed that service requests followed a Poisson arrival process, while service times were exponentially distributed. Using this framework, the authors estimated system performance measures such as traffic intensity, average number of customers in the system and in the queue, average waiting time, and server utilization. The findings indicated that increasing the number of service channels significantly reduced congestion and waiting time. Although the study focused on an industrial system, its conclusions are highly relevant to traffic congestion analysis, particularly in situations where multiple lanes or parallel service facilities are available.

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Queuing theory is a robust and versatile tool for analyzing congestion and service efficiency across diverse systems. However, most traffic-related studies in Nigeria have concentrated on road intersections and junctions, with limited emphasis on major bridge corridors that serve as critical traffic bottlenecks. In addition, few studies have examined the effect of varying service rate assumptions within multi-server queuing models using real-life traffic data. These gaps highlight the need for a focused study on the Asaba–Onitsha Bridge, which is a key transportation link with significant economic importance. The present study seeks to address these gaps by applying an M/M/2 queuing model to analyze traffic congestion on the bridge and to provide evidence-based recommendations for improving traffic flow and reducing congestion.

METHODOLOGY

This study adopts a quantitative and observational research design to analyze traffic congestion on the Asaba–Onitsha Bridge using queuing theory. The methodology is based on the collection and analysis of real-life traffic flow data and the application of stochastic queuing models to evaluate system performance under varying traffic demand and service capacity assumptions.

Study Area

The study was conducted on the Asaba–Onitsha Bridge also known as second Niger Bridge, a major transportation corridor linking Delta State and Anambra State in Nigeria. The bridge serves as a critical economic and social link, accommodating high volumes of vehicular traffic daily. Due to its strategic importance and limited service capacity, the bridge frequently experiences traffic congestion, especially during peak periods.

Source and Method of Data Collection

Primary data were collected through direct field observation. Research members were stationed at designated observation points on the bridge to record vehicle arrivals during the morning and afternoon traffic sessions. Data collection focused on capturing real-time traffic flow characteristics under natural operating conditions.

Vehicles were classified by type, specifically into small and big vehicles, to reflect differences in traffic composition. Observations were conducted during selected peak periods to ensure that congestion-prone conditions were adequately represented. The data collected included the number of vehicles arriving per unit time, which formed the basis for estimating arrival rates for the queuing model.

Model Assumptions

To model traffic flow on the Asaba–Onitsha Bridge, the following assumptions were made in line with standard queuing theory:

1. Vehicle arrivals follow a Poisson process, implying that inter-arrival times are exponentially distributed.
2. Service times are assumed to be exponentially distributed, representing random variations in vehicle service completion.
3. The traffic system operates under a First-Come, First-Served (FCFS) service discipline.
4. The bridge is modeled as a multi-server system (M/M/2), where the two servers represent parallel service channels or effective traffic lanes.
5. The system has an infinite queue capacity, meaning that all arriving vehicles join the queue and none are turned away.
6. Arrival and service processes are independent.

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These assumptions allow the traffic system to be represented as an M/M/2 queuing model, which is suitable for analyzing multi-lane traffic flow under congested conditions.

DATA ANALYSIS

The collected traffic data were analyzed using queuing theory analytical techniques. Vehicle arrival counts were first converted into arrival rates (λ), expressed as the average number of vehicles arriving per unit time for both morning and afternoon sessions.

Different service rate (μ) assumptions were considered to reflect variations in traffic handling capacity due to factors such as driver behavior, traffic control measures, and road conditions. This enabled the evaluation of congestion levels under alternative operational scenarios.

Queuing Model Formulation

The traffic system was modeled using the M/M/2 queuing model, where:

Symbol	Definition
λ	Average arrival rate of vehicles (vehicles/unit time)
μ	Average service rate per server (vehicles/unit time)
c	Number of servers = 2
ρ	Traffic intensity per server $\rho = \dfrac{\lambda}{c\mu}$
P_0	Probability that there are no vehicles in the system
L_q	Expected number of vehicles in the queue
L	Expected number of vehicles in the system (queue + service)
W_q	Expected waiting time in the queue
W	Expected waiting time in the system

Steady-State Probabilities

For an M/M/2 queue, the probability that there are n vehicles in the system, P_n, is

$$P_n = \begin{cases} \dfrac{(\lambda/\mu)^n}{n!} P_0, & 0 \le n < 2 \\ \dfrac{(\lambda/\mu)^n}{2 * 2^{n-2}} P_0, & n \ge 2 \end{cases} \tag{1}$$

The normalization constant P_0 is

$$P_0 = \left[\sum_{n=0}^{1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^n}{2!} * \frac{1}{1-\rho} \right], \quad \rho = \frac{\lambda}{2\mu} < 1 \tag{2}$$

Performance Measures

Average number of vehicles in the queue (L_q)

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$$L_q = \frac{(\lambda/\mu)^2 \rho}{2(1-\rho)^2} P_0 \quad (3)$$

Average number of vehicles in the system (L):

$$L = L_q + \frac{\lambda}{\mu} \quad (4)$$

Average waiting time in the queue (W_q):

$$W_q = \frac{L_q}{\lambda} \quad (5)$$

Average waiting time in the system (W):

$$W = W_q + \frac{1}{\mu} \quad (6)$$

Server Utilization (ρ)

$$\rho = \frac{\lambda}{2\mu} \quad (7)$$

ANALYSIS AND DISCUSSION

This section presents the analysis of traffic flow on the Asaba–Onitsha Bridge using queuing theory. The study adopts an M/M/2 queuing model, reflecting two parallel traffic lanes operating as service channels. Real-life traffic arrival data collected for morning and afternoon sessions were analyzed under three assumed service rates (600 veh/hr, 800 veh/hr, and 1000 veh/hr) to assess system performance under varying capacity conditions

Table 1: Traffic flow on Asaba-Onisha Bridge

Session	Vehicle Type	Arrival Rate (veh/hr)
Morning	Small vehicles	700 veh/hr
	Big vehicles	76 veh/hr
Afternoon	Small vehicles	428 veh/hr
	Big vehicles	77 veh/hr

Table 1 shows that traffic flow on the Asaba–Onitsha Bridge varies between the morning and afternoon periods. During the morning session, the bridge experiences a high volume of small vehicles, with an average arrival rate of 700 vehicles per hour, while the flow of big vehicles is much lower at 76 vehicles per hour. In the afternoon, the traffic of small vehicles decreases to 428 vehicles per hour, whereas the arrival rate of big

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vehicles remains relatively stable at 77 vehicles per hour. The bridge experiences its heaviest traffic in the morning, primarily due to the large number of small vehicles, while the flow of big vehicles remains fairly constant throughout the day.

Arrival Rate for each Session

Morning Session:

$$\lambda_{morning} = 700 + 76 = 776 veh/hr$$

Afternoon Session:

$$\lambda_{afternoon} = 428 + 77 = 505 veh/hr$$

Analysis Using M/M/2 Model

Case I: Service Rate of 600 Vehicles per Hour

Morning Session: $\rho = \frac{776}{2(600)} = 0.647$

Afternoon Session: $\rho = \frac{505}{1200} = 0.421$

Case 2: Service Rate of 800 Vehicles per Hour

Morning Session: $\rho = \frac{776}{1600} = 0.485$

Afternoon Session: $\rho = \frac{505}{1600} = 0.316$

Case 3: Service Rate of 1000 Vehicles per Hour

Morning Session: $\rho = \frac{776}{2000} = 0.388$

Afternoon Session: $\rho = \frac{505}{2000} = 0.253$

Table 2: Summarized performance of Queuing system under difference assumed service rate

μ (veh/hr)	Session		ρ	Lq (veh)	Wq (hr)	W (hr)
600	Morning		0.647	0.63	0.049	0.051
600	Afternoon		0.421	0.16	0.019	0.12
800	Morning		0.485	0.24	0.018	0.093
800	Afternoon		0.316	0.07	0.008	0.083
1000	Morning		0.388	0.11	0.009	0.069
1000	Afternoon		0.253	0.03	0.004	0.064

The summarized results in Table 2 describe how the traffic queuing system on the Asaba–Onitsha Bridge performs under different assumed service rates during morning and afternoon periods. Overall, the results show that traffic conditions improve steadily as the service rate increases, and that congestion is more pronounced during the morning session than in the afternoon.

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At a service rate of 600 veh/hr, the system experiences relatively high utilization, especially during the morning period. The traffic intensity in the morning is approximately 0.65, indicating that a significant proportion of the available service capacity is being utilized. This level of utilization results in noticeable queuing, with an average of approximately 0.63 of the vehicles waiting, and a small but measurable waiting time before vehicles are served. Although the system remains stable, it is close to a congested state during peak morning traffic. In the afternoon, demand is lower, resulting in a reduced traffic intensity of about 0.42, shorter queues, and smaller waiting times. This suggests that a service rate of 600 veh/hr is barely sufficient for off-peak periods and is less suitable for peak morning traffic.

When the service rate is increased to 800 veh/hr, the performance of the queuing system improves significantly. In the morning session, traffic intensity drops below 0.50, indicating a better balance between arrival and service rates. As a result, the average queue length and waiting time are substantially reduced. The afternoon session shows even better conditions, with low utilization, very short queues, and minimal waiting times. At this service level, the bridge operates efficiently for both peak and off-peak traffic periods.

At a service rate of 1000 veh/hr, the system demonstrates the best overall performance. Traffic intensity is low in both sessions, particularly in the afternoon, where the system operates far below capacity. Queue lengths become almost negligible, and waiting times are extremely short, even during the morning peak. These conditions reflect near free-flow traffic and indicate that the system has sufficient capacity to absorb fluctuations in demand without congestion.

CONCLUSION

This study applied queuing theory to analyze traffic flow on the Asaba–Onitsha Bridge using an M/M/2 queuing model, representing two parallel traffic lanes operating as service channels. Real-life traffic arrival data for morning and afternoon periods were used to evaluate system performance under different assumed service rates. The analysis provided quantitative insight into the congestion patterns on the bridge and the influence of service capacity on traffic performance.

The findings reveal clear temporal variations in traffic flow on the Asaba–Onitsha Bridge. Morning traffic is significantly heavier than afternoon traffic, largely due to the high volume of small vehicles, while the flow of big vehicles remains relatively constant throughout the day. This imbalance places greater pressure on the bridge during the morning period, making it more susceptible to congestion and queuing.

The queuing analysis shows that system performance is highly sensitive to the assumed service rate. At a service rate of 600 veh/hr, the bridge operates close to its capacity during the morning peak, resulting in higher traffic intensity, noticeable queues, and increased waiting times. Although the system remains stable, this service level is only marginally adequate and poses a risk of congestion under peak demand conditions. In contrast, the same service rate performs more satisfactorily during the afternoon, when traffic demand is lower.

Increasing the service rate to 800 veh/hr leads to a substantial improvement in system performance. Traffic intensity decreases, queue lengths are significantly reduced, and waiting times become minimal in both morning and afternoon sessions. This service level provides a more balanced and efficient operation of the bridge, accommodating both peak and off-peak traffic with minimal congestion.

The best performance is observed at a service rate of 1000 veh/hr. Under this condition, traffic intensity remains low across both periods, queue lengths are almost negligible, and waiting times are very short, even during the morning peak. These results indicate near-free-flow traffic conditions and demonstrate that higher service capacity enables the bridge to absorb fluctuations in traffic demand without experiencing congestion.

Beyond physical capacity enhancement, the integration of modern traffic management technologies, particularly Intelligent Transportation Systems (ITS), can provide a contemporary and sustainable approach to congestion mitigation on the Asaba–Onitsha Bridge. ITS applications such as real-time traffic monitoring using cameras and sensors, adaptive traffic control systems, incident detection and management tools, and traveler information systems can significantly improve operational efficiency. By enabling real-time assessment of traffic conditions, ITS can dynamically adjust traffic control strategies, optimize lane usage, and provide timely information to road users, thereby reducing arrival rates during peak periods and effectively increasing the operational service rate of the bridge.

Furthermore, the use of ITS can complement the queuing model framework by transforming it from a purely analytical tool into a real-time decision support system. Continuous data collection would allow for more accurate estimation of arrival and service rates, better forecasting of congestion patterns, and quicker response to unexpected incidents such as accidents or vehicle breakdowns that temporarily reduce service capacity. In this way, technology-driven traffic management can enhance the practical applicability of queuing theory results and support proactive congestion control.

In conclusion, congestion on the Asaba–Onitsha Bridge is strongly influenced by service capacity and temporal variations in traffic demand, with morning traffic imposing the greatest strain on the system. While a service rate of 600 veh/hr is only marginally sufficient, increasing the service rate to 800 veh/hr or above significantly enhances traffic performance, and a service rate of 1000 veh/hr provides optimal operating conditions. However, sustainable congestion management should not rely solely on increasing physical capacity. The integration of Intelligent Transportation Systems offers a modern, cost-effective, and adaptive approach that can optimize existing infrastructure, minimize queues and delays, and ensure smooth and reliable traffic flow throughout the day.

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REFERENCES

1. Adeleke, A. A., Adebiyi, A. O., & Akinyemi, O. O. (2005). Application of queuing theory to customer service operations in a Nigerian bank. Journal of Social Sciences, 11(2), 123–130.
2. Adeleke, A. A., Ogunwale, O. A., & Olubiyi, E. A. (2009). Application of queuing theory to outpatient waiting time in hospitals. International Journal of Management Science, 4(1), 45–53.
3. Aderinola, O. A., Elemure, O. J., & Laoye, O. O. (2020). Application of queuing theory to traffic congestion analysis at Jattu Junction, Auchi, Nigeria. Journal of Engineering and Applied Sciences, 15(4), 987–995.
4. Bhattarai, S., Prasad, K. S., Chaudhary, A. K., Ojha, P. R., & Sahani, S. K. (2025). Application of queuing theory in traffic flow and congestion management: A Nepalese context. Power System Technology.
5. Erlang, A. K. (1909). The theory of probabilities and telephone conversations. Nyt Tidsskrift for Matematik B, 20, 33–39.
6. Ibukun-Falayi, O. R. (2021). Queuing theory application and customers' time management in deposit money banks in Nigeria. KIU Interdisciplinary Journal of Humanities and Social Sciences, 2(1), 65–83.
7. Kleinrock, L. (1975). Queueing systems, volume I: Theory. New York, NY: John Wiley & Sons.
8. Kumar, A., & Jain, R. (2013). Queue management policies for controlling waiting lines. International Journal of Computer Applications, 70(7), 15–20.
9. Makwana, M. (2012). Performance evaluation of queuing systems using analytical techniques. International Journal of Engineering Research and Applications, 2(3), 1650–1656.
10. Nafees, L. (2007). An introduction to queuing theory and its applications. Journal of Operations Research, 5(2), 89–96.
11. Ogunwale, O. A., & Olubiyi, E. A. (2012). Comparative analysis of customer waiting time in selected banks using queuing models. Journal of Management and Sustainability, 2(3), 56–64.
12. Paveun, P. F., & Danyaro, M. L. (2025). Optimal queuing model to optimize banking service performances: A study of Zenith Bank Plc, Bwari Branch, FCT Abuja, Nigeria. International Journal of Research and Innovation in Applied Science (IJRIAS), 10(8), 608–622.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue I, January 2026

13. Priyanka Rani, & Sharma, R. (2024). Applications of queuing theory in real-world service systems: A review. International Journal of Mathematics and Computer Applications, 9(1), 22–31.
14. Srivastava, U. K., Shenoy, G. V., & Sharma, S. C. (2008). Quantitative techniques for managerial decision making (2nd ed.). New Delhi, India: New Age International Publishers.
15. Sztrik, J. (2010). Basic queuing theory. Saarbrücken, Germany: Lambert Academic Publishing.
16. Sztrik, J. (2012). Analytical and simulation modeling of queuing systems. Saarbrücken, Germany: Lambert Academic Publishing.
17. Taha, H. A. (2002). Operations research: An introduction (7th ed.). Upper Saddle River, NJ: Prentice Hall.
18. Tsarouhas, P. H. (2011). Application of queuing theory to production line performance improvement. International Journal of Production Research, 49(24), 7391–7405.
19. Tsetimi, J. T., & Orighoyeghe, G. (2021). Application of M/M/S queuing model to tank farm operations in Oghara, Delta State, Nigeria. Journal of Applied Sciences and Environmental Management, 25(6), 1015–1023.
20. Urhode, P. E., & Tsetimi, J. T. (2022). Traffic congestion analysis at Iwo Road intersection, Ibadan, using queuing theory. Nigerian Journal of Transportation Engineering, 4(2), 66–78.