

International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452

NAAS Rating (2025): 4.49

Maths 2025; 10(9): 62-66

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<https://www.mathsjournal.com>

Received: 20-07-2025

Accepted: 22-08-2025

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Simulation- based performance analysis of two commercial banks using multi-server queuing models

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DOI: <https://www.doi.org/10.22271/math.2025.v10.i9a.2168>

Abstract

Enhancing the effectiveness of service sectors with human employees performing random arrival and service times is a challenging decision-making environment. The banking sector is a good example of the current situation. In this study, Python-based simulation in multi-server queuing model is applied to compare the customer service performance of two commercial banks. The overall operation of two private banks Bank A and Bank B are examined in this case study. However, in view of confidentiality of data concerns, the name of the bank is not disclosed in this study. The simulation results indicate which bank is more efficient in terms of customer handling capacity and service delivery speed. The paper evaluates key performance indicators like average queue length, customer waiting time, server utilization, and idle time by simulating real-world customer arrivals and service processes. According to the research outcomes, Bank A performs more effectively than Bank B, with an average waiting time of around 9.9 minutes as compared to 17.7 minutes for Bank B. In addition, Bank A managed shorter and more stable queue waits along with more balanced server utilization whereas Bank B displayed a longer waiting time of customers and greater queue variations. Based on the results, Bank A's service system is superior in terms of managing customers during peak hours, whereas Bank B would benefit through expanding its capacity for service or improving teller performance. The study highlighted how valuable simulation tools are for operational decision-making and provide suggestions for the best manning and queue handling methods.

Keywords: Discrete-Event Simulation, Python, Queuing Theory, Simpy, Multi-Server Model, and Customer Service Efficiency

Introduction

In the current competitive financial environment, banks must prioritize operational efficiency and consumer satisfaction. Long lines and wait periods might make the consumer experience less satisfactory. Service systems may be analyzed in an organized manner using queuing theory. Although they offer theoretical information, traditional analytical models like queuing theory may fail to take into consideration the irregularity of arrival and service patterns in the real world. A suitable replacement is discrete-event simulation (DES), a technique that allows both researchers and practitioners to test management techniques, evaluate performance indicators, and model complicated structures without compromising with operations in the real world. For the purpose of examining waiting times, queue lengths, and server utilization to deliver useful information for resource allocation and efficiency of operation, this study aims to replicate the banking queuing process. In this study, the performance of two banks is evaluated and compared using a Python-based simulation of the multi-server queuing model (M/M/c). Using metrics for queue performance, the goal is to identify which bank provides superior customer service.

Brief Literature Review

In Today's time, Mostly researcher used simulation techniques in their researches because today's real world complex problem in uncertain condition is easily modeled, analysed and understood by simulation. Simulation quickly analysis testing of multiple scenarios and predict the system's behavior easily without investing too much money and time.

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Previous studies showed that Analysis of banking cash counter using simulation in queuing by Swati Shilpi (2025) [4] focused on Transaction on cash counter in the banking environment. Working Cash counter set up was analyzed by Simulation approach. System investigated by various parameter on different strategies and successfully evaluated the effect of various configuration on service efficiency and optimization of cost. The analysis found that inserting of the third counter, while raising service costs, lower average waiting time as well as length of a queue, enhancing the cost-service efficiency ratio.

Olamide omolara Olusanya (2021) [5] used Python to evaluate Customer Service Delivery in Banking Activities. Research analyzed the information gathered from the Customer service department of a bank using Jupiter note python programming language framework to realize customer needs and improve customer satisfaction. Analysis result showed that how customer really feel when waiting for the service through service rendered in the bank for a long time and also try to know the level of satisfaction of customer in bank. Result suggested that how to improve service render to provide positive experience to the customer.

Alex Mitewu Kabamba (2019) [6] investigated banking in the Democratic Republic of the Congo, specifically focusing on the country and took single line multi server queuing model. Data for the study was gathered during a one-week observation period and examined through Tora Optimization Software. For the purpose to save economic costs, advised that management apply the six server model determined by the main findings of the investigation of various management methods.

M. Mutingi (2015) [2] focused on an analysis and simulation of a bank's queuing technique. The study's goal is to provide a bank with an Excel-based simulation and analysis approach. The most essential sector is transaction zone service that boosts operational productivity. Study contain three phases, firstly adopting an appropriate performance metric, second one behavioral performance simulation and the last one is Assessment of and development of the quality of system services. Adopted all of three phases finally system waiting time is reduced.

Research on Simulating and modeling the banking queue system done by Najmeh Madadi (2013) [1] Constructed a Computer based simulation model to enhance the quality of service in the bank. Research Study worked with Witness software to modify the conceptual model into a simulation model. Multiple options were suggested and their output result were compared. After that result that can be drawn after multiple comparison under various condition indicated that after adding new counter and regulating the shift of all counters that decrease the Customer average waiting times in the bank.

Research Methodology

The present section discusses the method used to apply Python's discrete-event simulation (DES) for examining queue behavior and customer service performance in a multi-server banking environment. The two main components of the methodology are

1. The Description of the queuing model
2. The Design of the simulation framework using Python.

Queuing Model Description

Type of Model: M/M/C.

The M/M/c queuing model used in the simulation will work

for service systems that have lots of service counters running at the same time, such as bank branches, where customers come at random.

- M stands for Poisson arrivals with exponentially distributed inter-arrival times.
- M stands for exponentially distributed service times.
- C stands for multiple identical servers.

Basic Presumptions

- Customers arrive using a Poisson process that is, inter-arrival times are exponentially distributed.
- Each customer's service time is independently distributed exponentially.
- One client at a time is served by each of the C identical servers.
- First-Come, First-Served (FCFS) is the system's basic principle.
- The arrival rate keeps constant over time due to an unlimited source of customers.
- The processes of arrival and service are statistically distinct.

Standard Terminology

- Lambda (λ) is the average number of customers each minute.
- μ (mu): The average service rate per minute for each teller, referred to in services.
- N: The entire number of servers.
- T: the whole simulation time (for instance, 480 minutes during an 8-hour workday).

Overview of Python Simulation

We utilized Python to construct a discrete-event simulation model in order to model and compare various aspects of customer queuing in banking systems. The simpy library, a process-based environment for simulating practical queuing situations, was used for constructing the simulation. Analyzing significant performance indicators including the customer wait times, queue lengths, and server utilization under different scenarios was the main objective.

Useful Libraries in Discrete Event simulation:

- Numpy and Random for event generation
- Simpy for discrete event simulation
- Matplotlib / Seaborn for graph plotting.

Essential parts of the implementation consist of:

- **Simpy Environment:** Controls time progression and event scheduling.
- **Bank Resource:** Simpy Resource was implemented to model a fixed amount of service counters.
- **Arrival Process:** Based on an assumed arrival rate, it generates customers dynamically at random intervals.
- **Customer Process:** Uses an exponentially distributed service time to simulate service and collects individual waiting times.
- Metrics like average wait time, average queue length, total number of customers serviced, server utilization, and idle time are collected in statistics collection.

Data Analysis

In this section, we are going to discussed of the alogarithm, its Input parameter, output parameter, and analyze result through graphs and other visualization.

Algorithm Summary

In this study, the developed algorithm is designed to analyze the functioning of two banking systems, each of which is showed as an M/M/c queuing model. The entire procedure begins by collecting some fundamental parameters for both banks, including the number of available servers (c), the mean service rate per server (μ), the average customer arriving rate (λ), and the total observed duration (T). The traffic intensity ρ can be determined using these variables to measure system stability; if $\rho > 1$, the system becomes unstable because customer demand goes beyond the available capacity for service and the queue extends infinitely.

The technique uses standard M/M/c analytical formulas to calculate significant performance indicators for stable systems where $\rho < 1$. These include the percentage of server utilization, the expected queue length of the queue (Lq), the average waiting time in the queue (Wq), the expected number of customers in the system (Ls), the average total time a customer spends in the system (Ws), the expected total idle time of servers during the period of observation, and the probability that the system is empty (Po).

Once these measurements have been determined for both banks, the algorithm provides a tabular comparison that makes the system differences in performance visible. The technique also generates mathematical simulation data to allow graphical representation as an addition to the analytical results. Finally, a combination of visual and numerical statistics result are presented including histograms of

Customer waiting times, line charts of queue growth over time, and bar charts utilization of server.

By this simulation, the behavior of queuing system under different configuration of Counter, arrival and service rate of customer can be easily seen.

Input Parameter

For this study the input Data were gathered simultaneously from both banks in the duration of peak hours between 10:00 AM and 2:00 PM, right before lunch. The primary aims of the observation were to keep track of the average service rate of each server, the number of current service counters, and the number of customer arrivals each hour.

Introduce the parameters used:

- Bank A: $\lambda = 55$ customers/hour, $\mu = 15$ customers/hour per server, Active server $c = 4$, $T = 240$ minutes (4 hours).
- Bank B: $\lambda = 45$ customers/hour, $\mu = 16$ customers/hour per server,

Active server $c = 3$, $T = 240$ minutes (4 hours).

Output Parameter

In this section, output were obtained from the analysis of the collected data and simulation of both banking systems. The findings are summarized in terms of queue length, waiting time, server utilization, and overall system performance.

Table 1: Represents the performance metrics Bank A and Bank B

Metric	Bank A	Bank B
System Status	Stable	Stable
Server Busy%	91.67%	93.75%
Empty-chance (Po)	0.0091	0.0149
Avg Queue Length (Lq)	9.0392	13.2634
Avg Wait Time in Queue (Wq)	0.1643	0.2947
Avg Customers in System (L)	12.7058	16.0759
Avg Total Time in System (W)	0.2310	0.3572
Total Idle Time over T	8.7287	10.7313

Output obtained through Graphs

Distribution of Customer Waiting Time in System (in Histogram)

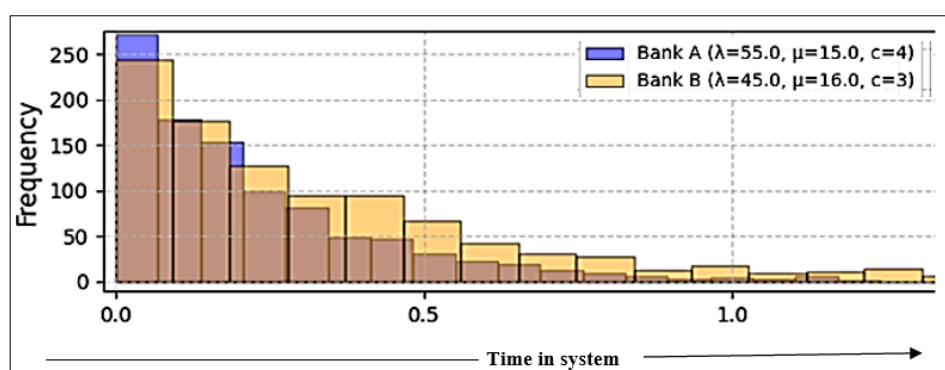


Fig 1: Distribution of waiting times of customers in Bank A and Bank B during peak hours

According to the histogram, Bank A typically has shorter customer waiting times than Bank B. The significantly longer distribution tail of Bank B demonstrates that specific

customers have to wait significantly more time. This indicates that Bank A handles queues properly at busy times.

Server Utilization versus Simulation Time (In Bar Diagram)

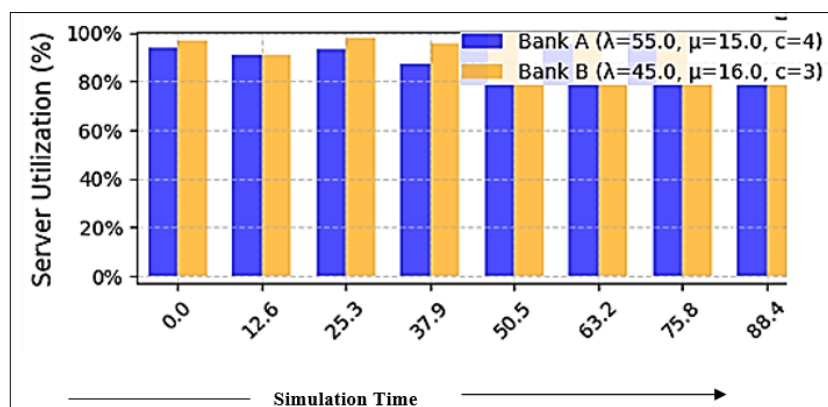


Fig 2: Server utilization comparison of both banks across the simulation time

For both of the banks, the bar graph represents Server Utilization (%) over different periods of time. During the simulation period, both banks maintain to have significant

utilization rates (around or above 90%). At every time point, Bank B appeared to have just slightly higher utilization rate.

Queue Length versus Time

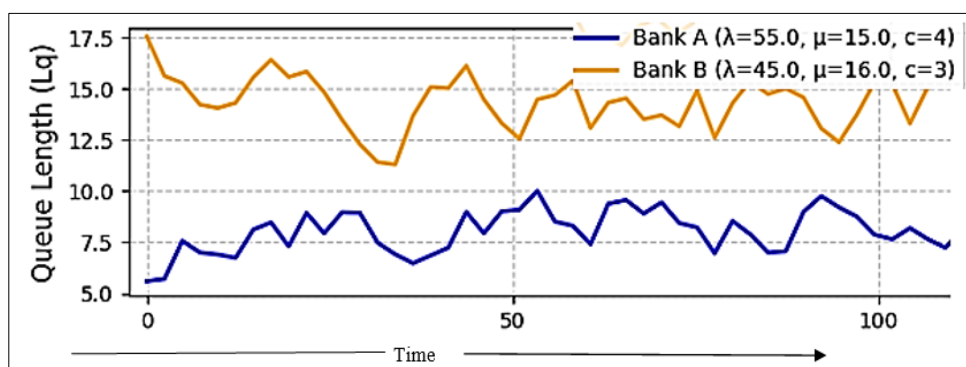


Fig 3: Queue length variation in both banks showing higher congestion in Bank B

The graph demonstrates that Bank A constantly maintains a shorter and more stable queue length compared to Bank B, despite having a higher arrival rate. Bank B's longer and irregular queues indicate it is under more pressure due to lower number servers, leading to longer customer wait times.

Results

The research study is to evaluate the queuing performance of two banks Bank A and Bank B) using customer arrival rates per hour, number of service counters in both banks, and service rates of service counter. The estimated distribution of customer waiting times confirmed that Bank A had a considerably shorter average waiting time of 0.1643 hours (approximately 9.9 minutes), whereas customers in Bank B waited for approximately 0.2947 hours (17.7 minutes). This indicates that compared to Bank A, customers in Bank B waited approximately twice as long. The histogram of waiting times of customers further verified that most of the customers in Bank A were served immediately, while Bank B displayed a longer tail of customers, reflecting higher probability of prolonged delays.

Both banks achieved at high efficiency levels above 85% in the area of server utilization. In terms of server utilization, both banks operated at high efficiency levels above 85%. However, Bank A preserved a more balanced utilization throughout its systems, whereas Bank B displayed greater fluctuation, indicating signs of overload. The analysis of queue length over time also highlighted clear variations. The queue of Bank A remained shorter and more uniform during

the simulation, while Bank B consistently exhibited longer queues with greater fluctuations, indicating a lower handling capacity during periods of high traffic. Overall, Bank A performed faster service, shorter queues, and more operational stability compared to Bank B, which experienced longer customer waiting times and relatively pressured server performance.

Conclusion

An investigation finding demonstrate that Bank A provides a more effective queuing system than Bank B. By providing shorter waiting times of customers, balanced server utilization, and stable queue lengths, Bank A make sure a smoother customer experience and more satisfactory service delivery.

On the other hand, Bank B's prolonged waiting times and higher queue fluctuation provide restriction in its current service capacity, which may detrimental affect customer satisfaction. All things considered, available information suggests that Bank A's operational style is more effective in dealing with arrivals of customers and demands for service. Structural improvements such as introducing more servers or improving teller service efficiency for reducing demand during periods of high demand would help Bank B perform effectively. These studies highlight how important effective. Queue management is to banking processes and how resource allocation can be purposefully modified to substantially improve worker efficiency and enhance customer satisfaction.

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