European Economic Letters
ISSN 2323-5233
Vol 14, Issue 4 (2024)
http://eelet.org.uk

Queueing Theory and Their Role in Measuring Service Performance: An Analytical and Applied Study of the Mobilis Agency – Laghouat, Algeria.

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Received: 10/08/2024 Accepted: 02/11/2024 Published: 14/11/2024

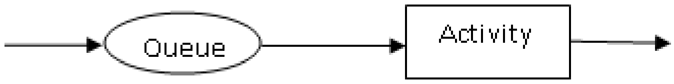
Abstract

This research presents the fundamental principles of queueing theory and models, considering the mathematical study of waiting times and service times experienced by customers, as well as the average cost incurred by customers while waiting in line and the service cost per service center to improve the system. In this study, both single-server and multi-server queueing models were used to model the waiting process. Data was collected from the Mobilis Agency branch in Laghouat for one month (January 2022, randomly chosen), and the data was analyzed to formulate a queueing model (using one and two service counters). The analysis results showed that the average queue length and customer waiting time in the queue and system significantly improved with the use of two service counters.
Keyword: Queueing, performance, and improvement.
JEL Classification: C6, M1.

1- Introduction :

Queueing theory is the mathematical study of lines or queues, where a queue model is created to predict queue lengths and waiting times. This theory is generally considered a branch of operations research, as the results are often used when making business decisions regarding the resources needed to provide service. As we know, waiting in line is a common daily experience. It is economically logical to consider factors such as: how many checkout counters in a supermarket might be needed to avoid queues? How many buses or trains would be required if queues were to be avoided or eliminated? In designing queueing systems, we need to balance the service provided to customers (short queues with many service centers) against economic considerations (not having too many of these centers). Essentially, all queueing systems can be divided into individual subsystems consisting of entities waiting in line for certain activities.

Figure No. (1): A simple waiting line



Source: Prepared by researchers

Queueing theory was first introduced in the early 20th century by Danish engineer Agner Krarup Erlang. Erlang worked at the Copenhagen Telephone Exchange and sought to analyze and improve its operations. He aimed to determine the number of circuits required to provide an acceptable level of telephone service, ensuring that people were not "waiting" (or in the telephone queue) for too long. He was also interested in knowing how many telephone operators were needed to handle a specific volume of calls. His mathematical analysis culminated in his 1920 paper titled "The Theory of Probability and its Application to Telephone Traffic," which served as the foundation for applied queueing theory. In his honor, the international unit of telephone traffic is named the Erlang .

This research is based on a key hypothesis: "The use of queueing theory at a company like Mobilis contributes to increased customer loyalty by reducing their waiting times while services are being provided and also allows for performance improvement."

The aim of this research is to demonstrate how queueing theory can assist managers and company officials in making better decisions by focusing on customer comfort and satisfaction. We will cover the fundamentals of queueing theory (analytical study) and attempt to apply it to the Mobilis agency in Laghouat. Additionally, this research has another significance: it highlights and clarifies this theory from a statistical perspective and adapts it to the field of business management.

2- Basic Terminologies :

- Queuing Model :
A suitable model used to represent a service-oriented problem where customers arrive randomly to receive services, and the service time is also a random variable.

-Arrival:
The statistical pattern of arrival can be described by the probability distribution of the number of arrivals in a given time period. (Vohra, 2008, p. 507)

-Service Time:
The time taken by the service center to complete the service is known as the service time.

-Server:
It is the mechanism through which the service is provided.

-Queue Discipline:
The order in which service is provided to members of the queue. For example, the rule used to select customers for service when a queue forms. The Most Common types are :

- First-Come, First-Served (FCFS)
- Last-Come, First-Served (LCFS)
- Service in Random Order (SIRO)

-Queue (Waiting Lines):
A collection of items waiting to receive service (including those currently being served) is referred to as a queue. (Badawi, 2022, p. 133)

-Mean Waiting Time in the Queue:
The average time a customer spends in the queue before receiving service.

- Mean Waiting Time in the System:
The average length of time from the moment a customer arrives until they leave the system (also called the time in the system).

- Mean Number of Customers in the Queue:
The average number of units (customers) present in the queue.

-Mean Number of Customers in the System:
The average number of customers in the system, including all customers waiting in the queue and those being served.

-Mean Idle Time:
The average time the system remains idle.

Mean Number of Customers in Service:
The average number of units (customers) being served at any given time.

-Mean Time a Customer Spends in Service:
The average time a customer spends receiving service.

-Bulk Arrivals:

When more than one customer enters the system at the same moment, it is referred to as bulk arrivals (not covered in our chapter).

3- Results and Analysis of the Study:

To measure the service performance at the Mobilis agency in Laghouat, queuing theory was used. We modeled customer arrival at the agency, including their wait time and service delivery. To analyze this phenomenon, queuing theory indicators were utilized to enable the agency's management to make informed decisions that ensure customer loyalty to the company. Additionally, the study examined the costs associated with adding new

Table 1: Number of Arrivals During January 2022 (25 Working Days)

127	**90**	**130**	**91**	**122**	**100**	**160**	**131**	**89**
139	86	125	114	137	112	170	151	215
160	172	120	184	136	132	110		

Source: Mobilis Agency - Maamoura - Laghouat –

After using the Kolmogorov-Smirnov test, it was found that the customer arrival distribution at this agency follows a Poisson distribution.

$$\lambda = \frac{3303}{25 \cdot 8 \cdot 60} = 0.275 \text{ arrivals/min}$$

Hypotheses:

Null Hypothesis (H0): The customer arrival times at the Mobilis agency in Laghouat follow a Poisson distribution with a parameter of 0.275.

Alternative Hypothesis (H1): The customer arrival times at the Mobilis agency in Laghouat do not follow a Poisson distribution with a parameter of 0.275.

After running the SPSS program, we obtained an acceptance result, and thus we conclude that the customer arrival times at the agency follow a Poisson distribution.

a. Customer Service Time:

The waiting time for customer service at the Mobilis agency was measured (where customer A arrives at the service counter and another customer who arrived before them is being served at the same time). We consider customer service times to be Markovian (random) and vary from customer to customer. To determine the time a customer spends at the counter until they leave, data from January 9, 2022, was selected, and the average service time in minutes was calculated. The results for the average service time in minutes are as follows:

Table 2: Average Service Duration on January 9, 2022

1	3	1	1	1	3	1
1	1	6	2	3	3	2
1	1	1	18	1	-	-

Source: Mobilis Agency - Maamoura - Laghouat -

The mathematical estimate of the exponential distribution is $E\left(X\right)=\frac{1}{\mu}$, to estimate μ It is sufficient to estimate it in points by taking the arithmetic average of the service provided to the customer, which is: $\frac{1}{\mu}=\frac{1+3+.....+1}{19}=2.68$

And from it: $\mu=0.373$ services/ min

The hypothesis is formulated as follows:

The length of customer service at the Mobilis agency - Laghouat - follows an exponential distribution according to the parameter $0.373 : H_0$

The length of customer service at the Laghouat Mobilis agency does not follow an exponential distribution according to the parameter $H_1 : 0.373$

After running SPSS program got us $p-value=0.051>\alpha=0.05$, Acceptance H_0 Therefore, we conclude that the customer service period is subject to an exponential distribution.

We note that the common unit of measurement in this topic is the minute, so:

λ=0.275 arrivals/min
μ=0.373 services/min

b. single counter:

- Utilization factor (traffic intensity in the agency) $\rho=\frac{\lambda}{\mu}=\frac{0.275}{0.373}=0.737$.

-Probability of no customer in the system (average idle): $P_0=1-\frac{\lambda}{\mu}=0.263$.

- Probability of Having 5 Customers in the, for example: $P_5=0.072\left(0.928\right)^5=0.0495$

-Average number of customers in the system: $L=\frac{\lambda}{\mu-\lambda}=\frac{0.275}{0.373-0.275}=2.8$.

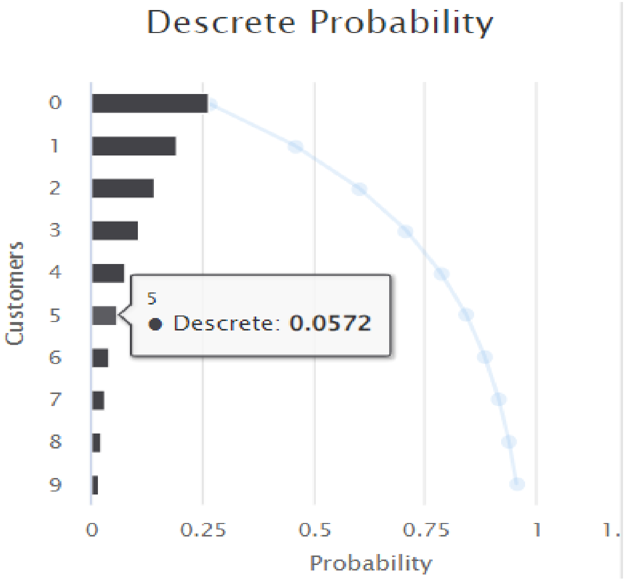
-Average time a customer spend in the system to order: $W=\frac{L}{\lambda}=\frac{2.8}{0.275}=10.18\min$.

-Average time a customer spend in the Queue: $W_q=W-\frac{1}{\mu}=10.18-\frac{1}{0.373}=7.5\ \min$.

- Average number of customers in the Queue : $L_q=\lambda\cdot W_q=0.275\cdot 7.5=2.0625$.

-The representation of the probabilities of having customers in the system is shown in the following figure:

Figure No. (6): Calculation of the Discrete probabilities for the M/M/1 Model



Source: From the output of the Algorithm at https://www.supositorio.com/rcalc/rcalclite.htm (Que221)

c. Two counters:

-Utilization factor (Traffic Intensity in the Agency): $\frac{\lambda}{\mu S} = \frac{0.275}{0.373 \times 2} = 0.368$

- Possibility of no units in the system (Average Idle Time):

$$P_0 = \frac{1}{\left[\sum_{n=0}^{s-1} \frac{\rho^n}{n!} + \frac{\rho^s}{(S-1)!(S-\rho)}\right]} = \frac{1}{1.737 + \frac{(0.737)^2}{1 \cdot (1.263)}} = 0.461$$

-Average Number of Customers in the Queue:

$$L_q = P_0 \frac{\rho^{s+1}}{(s-1)!(s-\rho)^2} = 0.461 \cdot \frac{(0.737)^3}{1 \cdot (1.263)^2} = 0.115$$

-Average number of customers in the system: $L = L_s + L_q = 0.737 + 0.115 = 0.852$.

-Average time a customer spend in the system to order: $W = \frac{L}{\lambda} = \frac{0.852}{0.275} = 3.098 \text{ min}$.

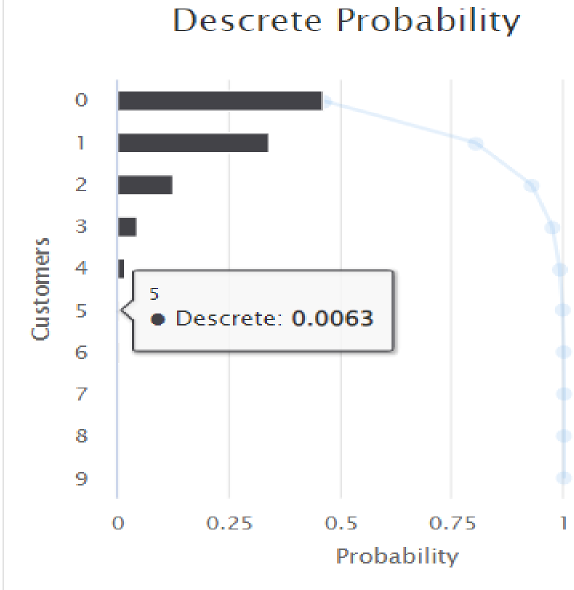
-Average time a customer spends in Queue: $W_q = \frac{L_q}{\lambda} = 0.418 \text{ min}$.

-Probability of Having 5 Customers in the System, , for example:

$$P_n = \frac{\rho^n}{S^{n-S} S!} P_0 \; ; \; P_5 = \frac{(0.737)^5}{2^3 2!} \cdot 0.461 = 0.0062.$$

- The representation of the probabilities of having customers in the system is shown in the following figure:

Figure No. (7): Calculation discrete probabilities for the M/M/S model



Source: From the output of the website algorithmhttps://www.supositorio.com/rcalc/rcalclite.htm （Que221）

It is clear that service performance improved after adding a second counter.
According to the study of both models and their application at the Mobilis agency in El-Maamoura, it was found that service performance increased after adding a second counter. However, when considering the costs associated with waiting, such as employee salaries, it is noted that the agency could suffice with only two counters instead of the three currently in operation.

Regarding the sole main hypothesis, which states: "The use of queuing theory in Mobilis contributes to increasing customer loyalty by reducing their waiting time during service delivery, and also allows for improved performance," after conducting the field study at the Mobilis agency in Laghouat, this hypothesis was confirmed to be valid.

8. Conclusion:

Based on the results of the study analysis, it can be concluded that queuing theory is a strong mathematical approach for addressing queuing issues in the system and providing solutions to enhance service levels. In light of this, the study recommends that the management of the Mobilis agency consider the issue of increasing service counters, which incurs additional employee salaries. The agency needs only two counters instead of the current three. In this era of digital economy and the acceleration of digital transformation and online services, people no longer want to wait in lines. They expect immediate service even when visiting a branch and are willing to switch service providers to avoid queuing. Therefore, companies need to find smart solutions to eliminate queues and increase customer retention.

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