

Single-Server Queue System of Shuttle Bus Performance: Federal University of Technology Akure as Case Study

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Abstract

This study has examined the performance of University transport bus shuttle based on utilization using a Single-server queue system which occur if arrival and service rate is Poisson distributed (single queue) (M/M/I) queue. In the methodology, Single-server queue system was modelled based on Poisson Process with the introduction of Laplace Transform. It is concluded that the performance of University transport bus shuttle is 96.6 percent which indicates a very good performance such that the supply of shuttle bus in FUTA is capable of meeting the demand.

Keywords: Single-Server Queue System; Shuttle Buses; FUTA

I. Introduction

The issues arising from transportation has continually subjected to various debates in the urban societies. Globally, several attempts have been made to tackle the challenges, although the situation is not getting much better (Aderamo, 2012; Adanikin, Olutaiwo, and Obafemi, 2017). Managing transport infrastructures is crucial to facilitate accessible, affordable, reliable, safe, and efficient that movement of people and goods, which can be achieved by continuous assessment of transport performance indicators. Among the various modes of transport, the road transport is highly predominant which offers door-to-door service as in the case of the Federal University of Technology Akure (FUTA). Road transport infrastructure in the University is commonly plied by shuttle buses for the movement of the students, staff, members and non-members of the Institution to and from the University on a daily basis.

Among the noticeable transportation problems in the University are traffic congestion; longer commuting; public transport inadequacy; difficulties for tricycles to have access to routes being plied by shuttle buses, challenge of freight distribution from one end of the University to another end, and other challenges which all impacts the performance of the University transport shuttle. This study concentrates on the performance of University transport bus shuttle with the aim of examining the bus shuttle efficiency based on utilization.

Adeniran and Kanyio (2019) have laid a foundation of model on single-server queue system which this study will absolutely rely on. A similar study was conducted by Adanikin, Olutaiwo, and Obafemi (2017) on the performance study of University of Ado Ekiti (UNAD) transit shuttle buses. They adopted traffic volume, speed, density and revenue as main parameters of performance of transport shuttles, and find that the morning peak period (8.00am to 9.00am) has 234 vehicles/hr, evening peak period (2.00pm to 3.00pm) has 284 vehicles/hr, while the off-peak period (11.00am to 12.00pm) has 156 vehicles/hr. Also, The average stopping time was 6.55 minutes, average interval between arrivals of motorists was 16.40 seconds, the average queue length was 14.23 people, and the average waiting time at the bus-stop 4.17 minutes. These values were obtained using the queuing theory and shows much commuters time is lost on transit queues. This study focuses on the performance of bus terminal in FUTA, and does not factor in other parameters such as peak period, traffic volume, traffic speed, density, and others.

2. Methodology

2.1 Queuing System

The concept of queue was first used for the analysis of telephone call traffic in 1913 (Copper, 1981; Gross and Harris, 1985; Bastani, 2009). In a system that deals with the rate of arrival and service rate, waiting time is inevitable and it is always



influenced by queue length. It is therefore crucial to minimize the waiting time to the lowest level in the bus terminal (Jain, Mohanty and Bohm, 2007). This is referred to as queuing system (Adeniran and Kanyio, 2019). The basic application of queue is shown in Figure I, also the basic quantities are:

- i. Number of customers in queue L (for length);
- ii. Time spent in queue W for (wait)



Figure I: Basic application of queue

Source: Adeniran and Kanyio (2019)

Examples of queue system are:

- 1. Single-server queue system: This is also referred to as single queue, single server. It is simple if arrivals and services are Poisson distributed (M/M/1) queue. It has limited number of spots and not difficult. Figure 2 depicts single-server queue system.



Figure 2: Single-server queue system

Source: Adeniran and Kanyio (2019)

- 2. Multi-server queue system: This is comprises of single queue, many servers (M/M/c) queue. The c is referred to as Poisson servers. Figure 3 depicts multiple-server queue system.

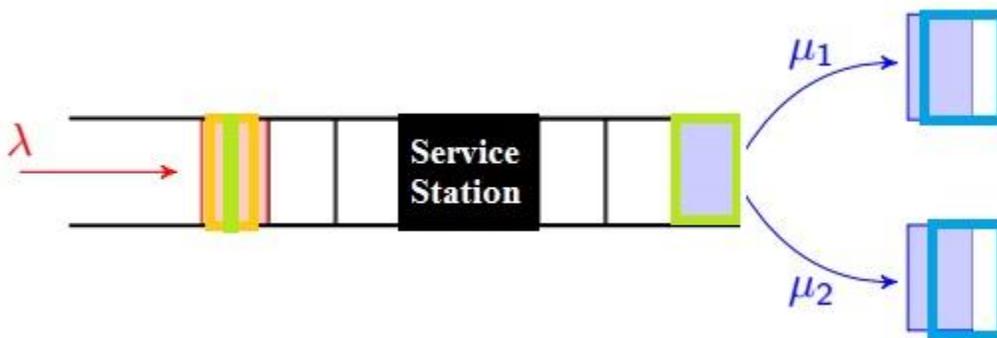


Figure 3: Multiple-server queue system

Source: Adeniran and Kanyio (2019)

In single-server queue system, arrival and service processes are Poisson such that

- a. Customers arrive at an average rate of λ per unit time;

- b. Customers are serviced at an average rate of μ per unit time;
- c. Interarrival and inter-service time are exponential and independent;
- d. Hypothesis of Poisson arrivals is reasonable; and
- e. Hypothesis of exponential service times are not so reasonable (Adeniran and Kanyio, 2019)

In order to explain how the queuing system works, there is need to first introduce the *Poisson Process* (PP). It has exceptional properties and is a very important process in queuing theory. To simplify the model, we often assume customer arrivals follow a PP. The *Laplace Transform* (LT) is also a very powerful tool that was adopted in the analysis (Trani, 2011). Apart from PP and LT, there is focus on the queue model itself (Adeniran and Kanyio, 2019).

2.2 Modelling of Single Queue System

2.2.1 Laplace Transform

The Laplace transform $L_X(s)$ of a nonnegative random variable X with distribution function $f(x)$ is define as:

$$L_X(s) = E(e^{-sx}) = \int_{x=0}^{\infty} e^{-sx} f(x)dx \dots\dots\dots \text{Equation 1}$$

It can be noted that

$$L_X(0) = E(e^{-x \cdot 0}) = E(1) = 1 \dots\dots\dots \text{Equation 2}$$

and

$$\begin{aligned} L'_X(0) &= E((e^{-sx})')|_{s=0} \\ &= E(-Xe^{-sx})|_{s=0} \\ &= -E(X) \dots\dots\dots \text{Equation 3} \end{aligned}$$

Correspondingly,

$$L_X^{(k)}(0) = (-1)^k E(X^k) \dots\dots\dots \text{Equation 4}$$

There are many useful properties of Laplace Transform. These properties can make calculations easier when dealing with probability. For instance, let X, Y, Z be three random variables with

$Z = X + Y$ and X, Y are independent.

Then the Laplace Transform of Z can be found as:

$$L_Z(s) = L_X(s) \cdot L_Y(s) \dots\dots\dots \text{Equation 5}$$

Moreover, when Z with probability P equals X , with probability $1 - P$ equals Y , then

$$L_Z(s) = PL_X(s) + (1 - P)L_Y(s) \dots\dots\dots \text{Equation 6}$$

Laplace Transforms of some useful distributions can now be introduced.

- a. Suppose X is a random variable which follows an exponential distribution with rate λ . The Laplace Transform of X is $L_X(s) = \frac{\lambda}{\lambda + s} \dots\dots\dots \text{Equation 7}$
- b. Suppose X is a random variable which follows an Erlang - r distribution with rate λ . Then X can be written as: $X = X_1 + X_2 + \dots + X_r \dots\dots\dots \text{Equation 8}$ where X_i are i.i.d. exponential with rate λ . Therefore, we have $L_X(s) = L_{X_1}(s) \cdot L_{X_2}(s) \dots L_{X_r}(s) = \left(\frac{\lambda}{\lambda + s}\right)^n \dots\dots\dots \text{Equation 9}$
- c. Suppose X is a constant real number c , then $L_X(s) = E(e^{-sx})$



$$\begin{aligned}
 &= E(e^{-sc}) \\
 &= e^{-sc} \dots\dots\dots \text{Equation 10 (culled from Adeniran and Kanyio, 2019)}
 \end{aligned}$$

2.2.2 Basic queuing systems

Kendall's notation shall be used to describe a queuing system as denoted by:

A/B/m/K/n/D Equation 11 (Adan and Resing, 2016)

Where

- A: distribution of the interarrival times
- B: distribution of the service times
- m: number of servers
- K: capacity of the system, the maximum number of passengers in the system including the one being serviced
- n: population size of sources of passengers
- D: service discipline

G shall be used to denote general distribution, M used for exponential distribution (M stands for Memoryless), D be used for deterministic times (Sztrik, 2016).

A/B/m is also used to describe a queuing system, where:

- A stands for distribution of interarrival times,
- B stands for distribution of service times and
- m stands for number of servers.

Hence M/M/I denotes a system with Poisson arrivals, exponentially distributed service times and a single server.

M/G/m denotes an m- server system with Poisson arrivals and generally distributed service times, and so on.

In this section, the basic queuing models (M/M/I system), which is a system with Poisson arrivals, exponentially distributed service times and a single server. The following part is retrieved from Queuing Systems (Adan and Resing, 2016).

Firstly, it is assumed that inter-arrivals follow an exponential distribution with rate λ , and service time follows the exponential distribution with rate μ . Further, in the single service model, to avoid queue length instability, it is assume that:

According to Adanikin, Olutaiwo and Obafemi (2017),

$$\text{Utilization (R)} = \frac{\text{Average Arrival Rate } (\lambda)}{\text{Average service rate } (\mu)} < 1 \dots\dots\dots \text{Equation 12}$$

Here R is the fraction of time the server is working (called the utility factor) limiting probability p_k in the M/M/I system.

The expected queue length L is given by

$$\begin{aligned}
 E(L) &= \sum_{i=0}^{\infty} i \cdot p_i \\
 &= \sum_{i=0}^{\infty} i \cdot R^i (1 - R) \\
 &= R(1 - R) \sum_{i=0}^{\infty} i \cdot R^i \\
 &= R(1 - R) \left(\sum_{i=1}^{\infty} [(i \cdot R^i)^i] \right) \\
 &= R(1-R) \left(\frac{1}{1-R} \right)^i \\
 &= \frac{R}{1-R} \dots\dots\dots \text{Equation 13 (Adeniran and Kanyio, 2019)}
 \end{aligned}$$



3. Results and Discussions

3.1. Traffic Survey

3.1.1 Stopping time of shuttle bus

Stopping time refers to the total time duration the shuttle bus spends at the bus stop. The stopping time is made up of:

- The boarding stop time "A": This is also made up of the time taken to close the door = 15 seconds; time taken by the driver to check the traffic before take-off = 9 seconds; and time taken to park the bus and open the bus for commuters = 7 seconds.
 $A = (15+9+7) = 31$ seconds
- The average boarding time per passenger = "B₁" = 9 seconds
- Number of passengers boarding = n₁ = 18 passengers.

Mathematically, stopping time T = A + B₁* n₁

Stopping Time = (31 + (9*18)) = (22+162) = 184 seconds

Stopping Time = 3.07 minutes

3.2 Waiting Time

This is the length of time spent by the passengers at the bus stop before boarding a bus. It is also referred to as *Delay*. The queuing theory is employed in this study.

- Average arrival rate (λ) = 204 passengers/hour
 $\lambda = \frac{204}{3600} = 0.057$
- Average service rate (μ) = 213 passengers/hour
 $\mu = \frac{213}{3600} = 0.059$
- Average interval between arrival = $\frac{1}{\lambda}$
 $= \frac{1}{0.057} = 17.54$ Seconds
- Average interval between service rate = $\frac{1}{\mu}$
 $= \frac{1}{0.059} = 16.95$ Seconds
- Average queue length = $\frac{\lambda^2}{\mu(\mu-\lambda)}$
 $= \frac{0.057^2}{0.059(0.059-0.057)} = \frac{0.0033}{0.00012} = 25.5$ Passengers
- Average waiting time in the queue = $\frac{\lambda}{\mu(\mu-\lambda)}$
 $= \frac{0.057}{0.059(0.059-0.057)} = \frac{0.057}{0.00012} = 475$ Seconds = 7.92 Minutes
- Average time spent in the system (bus stop) = $\frac{1}{\mu-\lambda}$
 $= \frac{1}{0.059 - 0.057} = 500$ Seconds = 8.33 Minutes
- Efficiency of shuttle bus operation based on bus stop utilization (R) = $\frac{\lambda}{\mu}$
 $R = \frac{0.057}{0.059} = 0.966$

It is important to note that the Utilization factor is less than 1 (R < 1), hence the performance of University transport bus shuttle is 96.6 percent which indicates a very good performance such that the supply of shuttle bus in FUTA is capable of meeting the demand.

4. Conclusion and Recommendation

This study has carefully explored the quantitative performance of University transport bus shuttle based on utilization using a Single-server queue system which occur if arrival and service rate is Poisson distributed (single queue) (M/M/1) queue. It is concluded that the performance of University transport bus shuttle is 96.6 percent which indicates a very good performance such that the supply of shuttle bus in FUTA is capable of meeting the demand.



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