Queue and Waiting time in Public Transport Management in Kigali

Case Study: Rwanda Federation Transport Cooperative (RFTC)

By

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A dissertation submitted in partial fulfilment of the requirements for the degree of Msc in Information and Communication Technology (Option: Operational Communication), College of Science and Technology, School of ICT.

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Declaration

I, Andre Mutambuka with Reg Number: 220017857 do hereby declare that all the work presented in this research is my own original work unless otherwise acknowledged. It has never been presented either in part or in full for publication or award of degree in any university.

I therefore, present it for the awards of Master of Science in Information and Communication Technology, Option: Operational Communication; of University of Rwanda, college of Sciences and Technology, School of ICT.

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May God bless you!

Abstract

In Rwanda and particularly in Kigali, as time goes the demand for public transport increases with number of population and thus the travel demand growth is linked to the growth of population. According to the Census of 2012, only 7% of private households owned vehicles in City of Kigali (CoK) and this shows that the demand of public transport is at high level.

On another hand, transport sector is one of the key engines of development, and hence improving the reliability of its infrastructure and quality of transport in general is major cornerstone to population lives.

Some operations such as, payment means, capacity per bus, speed governor, road infrastructure, etc, have shown some improvement, but there is still a big room for improvement as well.

Specifically in the way the service is offered to the passengers mostly on waiting time (time to be spent in queue, time needed to reach destination), number of passengers on queue utilizing a certain line at a given time. There is no visibility of the bus arrival time and headways, and these lead to uncertain fleet management performance. Furthermore, the mentioned challenges prevent both the Public Transport Service Providers (PTSP) and passengers to plan their trips in a proper way.

In this work, various factors explain the reasons associated to the above issues in public transportation, and the relationship existing among them.

Using the queue theory M/M/1 system, we developed an algorithm that optimizes the transport management system in Rwanda Federal of Transport Cooperative (RFTC) in Kigali whereby the optimum bus capacity, headways, and number of buses to allocate to a certain line is determined.

We achieve the objectives by assessing existing data and means for buses' allocation, assessing the number of passengers in queue, the arrival patterns, computing waiting time and related significances in system and in queue, and hence the proposal of new system that optimizes the service offered to Public Transport Services (PTS).

The developed algorithm helps planning such as; Public Transport Service Providers (PTSP) to allocate efficiently resources and at same time to predict the bus arrival time, utilization rate and waiting time and thus improvement on the Quality of Service (QoS) offered to passengers.

List of acronyms

Bc: Bus seating Capacity

CBD: Central Business District

CCTV: Closed Circuit Television

CoK: City of Kigali

D: Distance between two-bus terminals

FICFS: First Come, First Served

FIFO: First In First Out

Ha: Alternative Hypothesis

Ho: Null Hypothesis

ICT: Information and Communication Technology

ITS: Intelligent Transport Systems

JTL: Jali Transport Limited

KBC: Kigali Business Center

KBS: Kigali Bus Service

L: Number of Passengers in system

LCFS: Last Come, First Served

Lq: Number of Passengers in queue

M/M/1: Queueing System with one server and one serving line

M/M/c: Queueing System with multiple servers and one serving line

N: number of buses allocated to one line

NICI: National Information Communication Infrastructure

PTS: Public Transport Service

PTSP: Public Transport Service Provider

QoS: Quality of Service

RFTC: Rwanda Federal of Transport Cooperative

RT: Round Trip

RTLS: Real Time Location Systems

RURA: Rwanda Utilities Regulations Authority

S: Speed of the bus between two terminal

T: Time used between two terminals

UoK: University of Kigali

W: Waiting time in system

Wa: Alighting time

WB: Boarding Time

Wb: Time for waiting in bus at station

Wh: Headways

Wq: Waiting time in queue

List of symbols

p_0: Probability of zero Passengers in queue

e: Degree of confidence or absolute error

n=Desired sample population

p: Expected proportion in population based on previous studies or pilot

Z=Critical value

λ: Lamda

μ: Mu

Σ: Sum

ρ: Rho

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CHAPTER 1: INTRODUCTION

1.1 Introduction

In our daily operations in different disciplines from various areas and corners of life where we get services, we are experiencing or have experienced the annoyance of having to wait in line. This waiting has been there and continues to exist being in the rural or urban areas and it becomes a big issue in the common congested areas such as in the cars in traffic jams or at the bank, at hospitals, in the restaurants, etc. The same phenomenon is observed at supermarkets, in telephone systems where the caller has to wait for some time to get the call through in order to reach the intended service of conversation with the other part.

Waiting is not desirable being at the customers' side or service provider's side, however waiting on line is there and in the book John F. Shortle et all, [1] says that waiting on line may be caused by many reasons such as: more demand for service than the facility for service available, may be a shortage of available servers, etc. It is infeasible economically for a business to provide the level of service necessary to prevent waiting or there may be a space limit to the amount of service provided. To know how much service to make available one needs to know how long must a customer wait? In addition, how many people will form in line?

On another hand, thanks to the Information and Communication Technology (ICT) infrastructure laid across many countries, the National Information Communication Infrastructure (NICI) has promoted the use of the technologies and most especially for the internet and other online services. Governments invested in the ICT infrastructure in order to enhance provisioning of improved communication and information exchange, facilitate ICT for education, vocational training, trading, health, agriculture, transport, etc. The way the humanity is living has changed and as matter of fact, the way of doing business has changed due to ICT, it has reached to the extent where one can perform his/her duties from home and interacts with his/her counterpart/ colleague, supervisor, accordingly while at away from each other. In business, the information plays a key factor in its growth and this is tremendously through the ICT thanks to internet and other digital means.

On the public transport and most specifically in Kigali transport was not left behind from other sectors and has shown some improvement through various means such as being the payment model, ticketing, dedicated lanes for different destinations, bus capacity, etc.

Volkswagen-Rwanda branch has implemented the tracking system and this has been made popular and available, however this is limited to their vehicles and it is not massively utilized for the general public in Kigali, though there is no case of queue neither the vehicle parking locations available for public.

With ICT infrastructure in place and coverage of almost above 94.2% for 4G as per RURA report [2]. With the support of wireless network the tracking of location of the vehicle, has become doable with GPS that facilitates for locating the locations of different vehicles and other connected stuffs in motion [3, 4].

Nevertheless, if not always, people still line up on a queue waiting for the bus arrival without knowing when the waited buses are to arrive and mainly with no information on the number of passengers that will be served by the bus to come. Many organizations in public transport in Rwanda use random method to dispatch and allocate buses to a given line. Thus, despite being on the queue and expecting to be served, there is no significance way or certainty on how and when one will be served.

1.2. Background and Motivation

In last decade, the City of Kigali has noticed remarkable development of infrastructure such as road construction, public streetlights, CCTV for security, tall buildings and malls, Telecommunication facilities and other ICT programs, etc.

The improvement has been based on different plans and investments from government and its partners.

ICTs facilitate accessing and adapting information and knowledge, which can dramatically improve the performance of both the government and the private sector, as it affects individual producers, firms and markets, transparency and accountability of government institutions, etc.

A very concrete example are in the e learning, e-commerce, e-government, e-tax, e-health, e-recruitment, etc.

According to Paulo Jorge Gomes Pereira, 2011 [5], Real Time Location Systems (RTLS) are expected to have a fast growing market, thus benefits they offer in many areas of application, transport, logistics, hospitals, manufacturing, state services, etc. Furthermore, its implementation will bring benefits that will save resources and time that are wasted today.

In general, ICTs can help to promote a wider range of lives by increasing or amplifying the existing opportunities. ICT infrastructure makes institutions and markets more efficient and responsive by reducing the costs through the competition, increase the speed, and ease way of communicating while offering as well the real visibility on the business running to both the consumers and serving organs.

Thanks to GPS, accidents have been reduced with speed governors installed in the buses to limit the speed and this has provided significant improvement on reducing number of accidents. The ICT brought a very well known way of e-payment with Tap & go card.

When it comes to transportation, the improvement can be regarded in terms of the public transport including national, international and local passengers transport services.

Various companies, private owners and associations provide public transport services in countrywide and at international range and this has increased the numbers of lines or lanes and the covered areas with Public transport services increased as well.

In the 2013 master plan [6], the CoK, has set objectives regarding transportation and among others are to ensure that a high public transport to private transport participation ratio of 70:30, and to provide a public transport network which provides an average public transport continuing time of 60 minutes or less within the City.

In Kigali areas specifically, RURA has signed a contract with three companies to offer the services in order to enhance the quantities and needed quality of service (QoS) in Kigali where the passengers had high waiting time and very long queue being at bus stations or at bus stops [7].

The three companies have introduced buses that can accommodate many passengers at once from the so-called coaster to the big buses with a capacity of 29 passengers to 70 passengers respectively.

However, though some facilities are ready, in transport domain and specifically in Kigali, there is a gap in travel planning in general and in other means that can facilitate to plan the trip with respects to time. Most especially in the public transportation whereby the citizens and the transport service providers have no real visibility on the number of passengers in queue, waiting time in queue or related significances of each delay and buses' locations during the operations period and therefore challenging the way to optimize the PTS efficiency.

1.3 Problem Statement

In present period, transport in Rwanda, no one can predict with small error when he/she will be served and it becomes challenging for the dispatchers who don't have the real information given that anything can happen being to the drivers or to the road congestion and other factors that exist in the real life of transportation.

Secondly, the allocation of resources is random, thus the allocation of buses is not optimum, and consequently for any change in the planned schedule, the dispatchers will need to call again each driver to seek for the information on their locations. At the time, the call gets to end there might be another change caused by the delay due to the time of call and this becomes an issue in the fleet management that is based on uncertain data information. The situation becomes very challenging during the peak hours where the passengers are in high demand and thus the long queues.

Thirdly, some passengers may not continue to wait until they are served due to long waiting time or other reasons that cause the impatience known as, balking, reneged, jockey, etc.

The above issues at some extend make the transport more expensive to the passengers as well and on another hand prevent transport agency to gain some number of passengers due to the utilization of private vehicles and motorcycles.

It is from the above perspective we are interested in conducting a research in Public transportation in Kigali in order to propose an algorithm/system that will enhance the resources allocation and optimize the waiting time for passengers.

1.4 Study Objectives

1.4.1 General Objective

Our main aim is to design an algorithm that improves the passengers' waiting time at the RFTC bus station.

1.4.2 Specific Objectives

The specific objectives are as per below:

1. Analyzing the existing system
2. Designing an algorithm that will improve the challenges found in the existing systems
3. Comparing proposed algorithm and the existing method to determine the improvements that contributed by new algorithm.

1.5. Research Questions

To perform our research, we have formulated questions such as:

- What are the sources of queue at public transport at bus station in Kigali, case of RFTC? (specifically, what is the average time needed for a complete trip considering all the times in, at bus stop, in queue, in the system, at payment station, spent in bus waiting to departure, in road, in jam, etc)
- What is the average number of passengers on queue for given time-period?
- What is the existing serving capacity?
- How can the dispatcher know when the passenger on the queue will be served and by which bus?
- What is the significance of time management in improving fleet management and enhancing public transport to a given line in RFTC?

1.6. Hypotheses

The following hypotheses are proposed:

- **Null Hypothesis (Ho):** There is no significant difference between the existing buses' allocation management systems and the one designed.
- **Alternative Hypothesis (Ha):** There is significance between the existing buses' allocation management systems and the one designed.

1.7. Significance of the Study

This research project provides the number of passengers on queue within an interval of a minute and thus facilitate to improve in buses allocations. The current project minimizes the margin of error, which exists in the existing management system and hence provides the model to optimize the resources in places. The present research project gives more insights in the public transport services that contains little documentation.

1.8. Scope of the Research Project

We limited our research project to public transport in Kigali and to RFTC case, in order to make a feasible study with realistic time dedicated to the thesis; and due to financial constraints, this project is narrowed again to Kimironko-Town line.

1.9. Organization of the Study

The present research is composed of six chapters

Chapter 1 contains general introduction to the research and concepts of the intended work, problem statement, Objectives, hypothesis, justification, and scope of the study research

Chapter 2 consists of a detailed review of the existing literature; highlights theoretical frameworks and analyzes models related to the present research area, highlighted related work and gaps as well as the expected solutions to the identified gaps within the literature analysis.

Chapter 3 describes the methodology adopted for the research project. It details the research related design, data collection methods and used sampling method to analyze and process the collected data.

Chapter 4 focuses on model analysis and design; describes the models, proposed modeling & simulated parameters.

Chapter 5, this chapter consists of results and their analysis interpretation and discussion of the research project findings.

Chapter 6 deals with conclusion and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 General Overview

Basic system elements of queues (or waiting lines) help facilities or businesses to provide service in an orderly fashion. Forming a queue being a social phenomenon, it is beneficial to the society when managed so that both the unit that waits and the one that serves get the most benefit. For instance, there was a time when in airline terminals passengers formed separate queues in front of check-in counters. Now we see invariably only one line feeding into several counters. This is a result of the realization that a single line policy serves better for the passengers as well as the airline management. Such a conclusion has come from analyzing the mode by which a queue is formed and the service is provided [8].

In the book Contemporary Challenges of Transport Systems and Traffic Engineering [9], it states that the growing transportation needs of passengers in cities around them are satisfied by various means of transportation; including public transport. It emphasized that the use of competing tools such as: prices, quality of service (communication, and information) and attractiveness of public transport particularly to individual transport can allow for sustainable development in urban areas, reducing emissions and saving energy resources.

The analysis is based on building a mathematical model representing the process of arrival of passengers who join the queue, the rules by which they are allowed into service, and the time it takes to serve the passengers.

According to W.J Stewart (2009), Queueing theory embodies the full gamut of such models covering all perceivable systems that incorporate characteristics of a queue [10].

2.2. Characteristics of queue at the public transport system

As per [9], in general below items are the main related characteristics of the queue to public transport:

2.2.1. Arrival pattern of customers

It describes how the passengers arrive on queue and their behaviors depending on the decision made upon the arrival and along period on queue.

Some passengers may decide to spend no time in queue; therefore leave immediately without lining up in queue, this is called balking.

Others are called reneged, these are the ones that will spend their time on the queue however according to the long waiting period then decide to leave the queue.

Jockey passengers, sometimes, there are two or more parallel waiting lines and passengers can switch from one to another. All these are the results or consequences of the waiting at the bus stations [1, 8, 10].

2.2.2. Service mechanism

The uncertainties involved in the service mechanism are the number of servers, the number of customers being served at any time, the duration and mode of service. Networks of queues consist of more than one server arranged in series and/or in parallel [1, 10].

Since service's times in public transportation are more stochastic probability, distribution is needed to describe the sequence of customer service's times [9].

Service at public transportation is of batch, which means that many customers are being served simultaneously by same bus. The service process may also depend on the number of passengers waiting on the queue, which is the real case for the public transportation.

2.2.3. System capacity

The number of passengers that can wait at a time in a queueing system is a significant factor for consideration. If the waiting room is large, one can assume that, for all practical purposes, it is infinite. The bus seating capacity is also a key factor to consider for the system, depending on the day time the number of passengers are either less or much more than one bus's capacity.

2.2.4. Queue discipline

All other factors regarding the rules of conduct of the queue can be pooled under this heading. One of these is the rule followed by the server in accepting customers for service. In this context, rules such as "first come, first served'' (FCFS), "last come, first served'' (LCFS), and "random selection for service'' (RSS) are self-explanatory. Others such as "round robin (RR)'' and "shortest processing time'' may need some elaboration [8].

Random variables are used to represent service times, and the number of servers, when appropriate. If service is provided for customers in groups, their size can also be a random variable.

In many situations, customers in some classes have priority in service over others [10]. However, for our research, we consider all the passengers to be with equal priority.

2.2.5. Number of service stages

A queuing system can have only a single stage like one line and that is served via only one station or it can consist of many stages where the passengers need to pass through several stages before being served or entering into the buses.

As per the buses' station the queue is characterized by a line (queue), payment station (mainly at the entrance of the bus) and serving station (which is the bus itself).

2.2.6. Design and control

The study of real systems is motivated by the objectives of improving their design, control, and effectiveness and mostly for the waiting time and other related parameters that are of paramount in our research study.

2.2.7. Traffic and travel information

Traffic and travel information includes information about prevailing current conditions and regulations concerning the transport infrastructure, points of interest, traffic, and weather. This information is usually categorized into pre-trip and on-trip information.

According to A. Adamski & A. Turnau (1998) [11], Pre-trip information is used to plan the transport. The transport demand, i.e. the decision whether a transport is done or not, may depend on pre-trip information concerning travel distances and times, tolls, and multi-modal interchange possibilities such as roll-on/roll-off on piggy-back trains or ferries.

2.3. Measures of System Performance

The task of the queueing analyst is generally one of two things – to determine some measures of effectiveness for a given process or to design an "optimal" system according to some criterion.

To do the former, one must determine waiting delays and queue lengths from the given properties of the input stream and the service procedures. For the latter, the analyst might want to balance customer-waiting time against the idle time of servers according to some cost structure. If the costs of waiting and idle service can be obtained directly, they can be used to determine the optimum number of servers [12].

System performance can be defined by different metrics depending on the nature of the system under study. Among others in the queueing system we have: waiting time that a customer spends at the queue, number of customers that can be accommodated by the systems to indicate its capacity, and some can measure the idle time that a system spend without service to indicate the off time of the system.

Correspondingly, there are two customer accumulation measures – the number of customers in the queue and the total number of customers in the system [10].

It illustrates that all measures corresponding to our case, are of stochastic elements, and these measures are often random variables, so their probability distributions or at least their expected values are sought.

For waiting times, in his book John f. Shortle et al [1], stated that there are two types of time: a time that customer spends in the queue and total time a customer spends on queue plus service.

2.4. Queuing System Configurations

2.4.1. Single-Channel, Single-Phase System

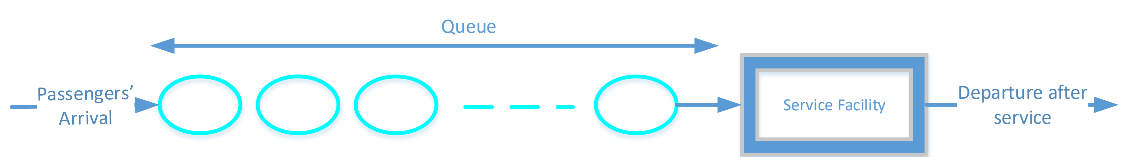


Figure 1: Single-Channel, Single-Phase System

2.4.2. Single-Channel, Single-Multiphase System

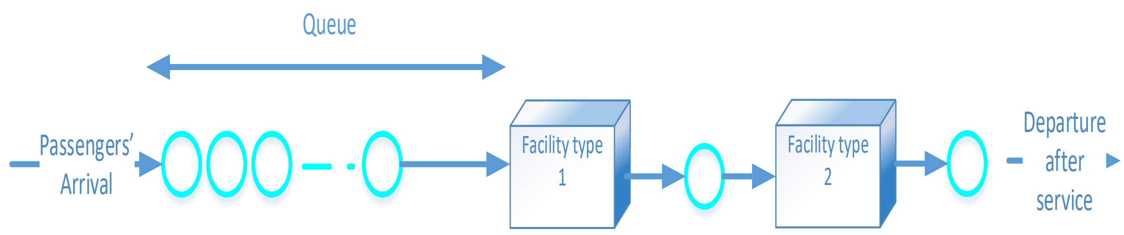


Figure 2: Single-Channel multiphase system

2.4.3. Multichannel, single-Phase System

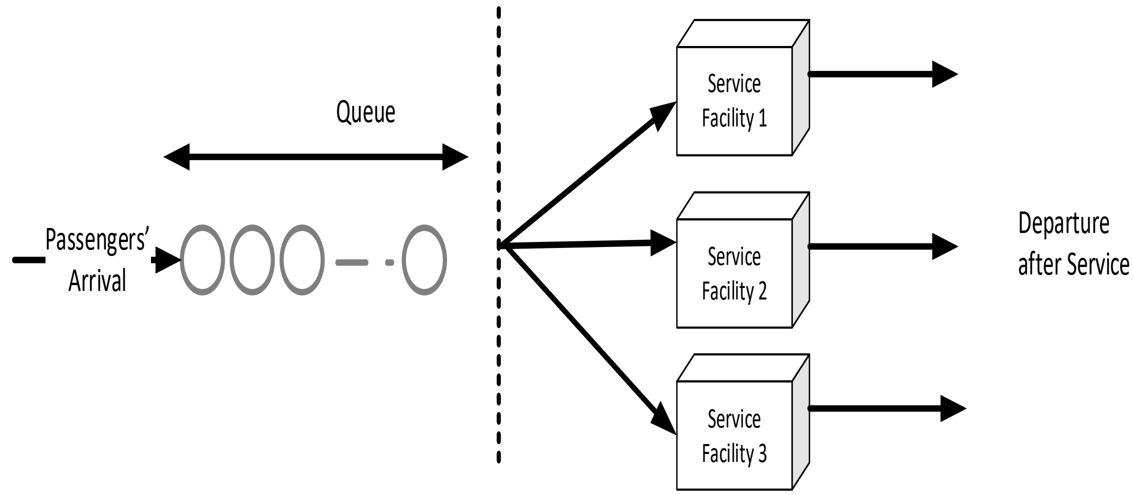


Figure 3: Multichannel, single-Phase System

2.4.4. Multichannel, Multiphase System

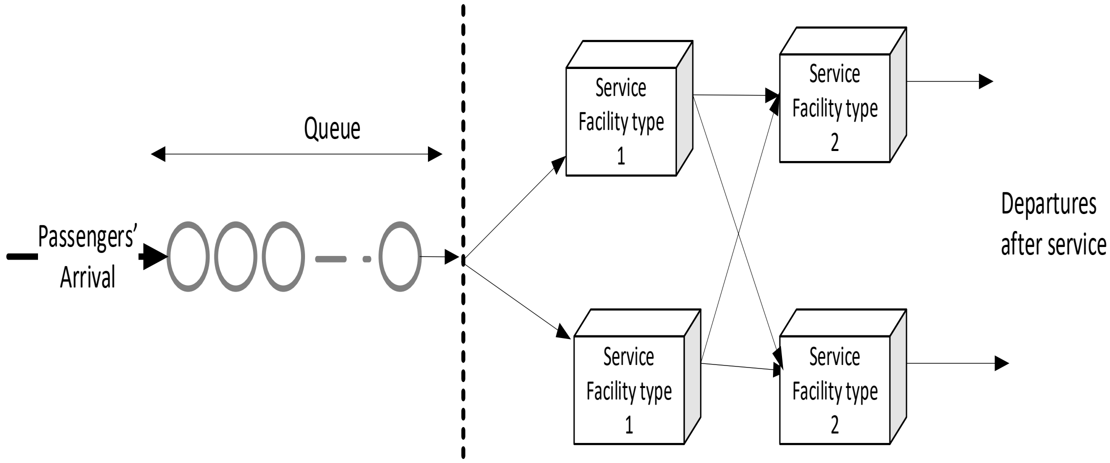


Figure 4: Multichannel, Multiphase System

2.5. Payment station

With tap and go, or any other means of payment available at public transport in Kigali, tap and go is another consideration factor for the waiting time to a passenger.

2.6. Operations between two Bus stations

From the above section, it is clear that the queue and its characteristics are covered and the passengers are considered to be served once they are boarded into the bus and the bus starts the trip from the station until the end of the line or destination/terminal.

According to Paulo Jorge Gomes Pereira [5], the need for improving industrial processes is constant, perpetuating the transformation of its workflow, seeking for resources reduction and process optimization, thus rendering more competitive products; both in price and quality.

Now our next step will be to provide the parameters that affect or contribute to the completion or quality of service (QoS) offered to the passengers.

2.6.1. Travel trip & Round trip

It refers to the time spent and distance performed between one-bus station (considered as source) and another bus station considered as the destination. The service in transport is highly affected by the time to spend in the travel time being on the trip or Round Trip (RT), thus this element is one of the major contributing factors to waiting time on the queue.

2.6.2. Traffic jam

This is the characteristic of the route occupancy and it affects the service offered to the passengers depending on the number of vehicles on the road at same time. Traffic Jams also affect the waiting time in queue.

It is possible to reduce the waiting time on queue by increasing number of busses on crowded routes. Additional the travel time includes also the time the bus stops at the bus stops while dropping or picking new passengers and sometimes the driver delay at the bus stop waiting to passengers that are not already at the place.

As described in [9], to shorten the time elapsed or needed at the bus stop to extent of shortening the waiting time on queue at bus station, the public transport routes must be dense enough, and the pathways to bus must be short, of good quality, comfortable, safe, without a need to pass obstacles, aesthetic and ergonomic.

This aspect is rarely of interest to transport organizers, yet it belongs to the obligations of the municipality. The convenience of travelling means much more than just the comfort of ride [9].

2.6.3. Quality of Service for the trip

The comfort of ride depends on the quality and technical condition of the vehicle, its equipment, the number of seats, the level of congestion, the driving technique of the driver, etc. According to Olga Lebedeva and Marina Kripak [13], Liu, Ronghui and Sinha, Shalini [14], Leila Dianat [15], the number of passengers in vehicles is affected by the organizer's decision on the size of vehicles used, the number of rides on the lane, regularity and frequency of communication lines. The size of vehicles can be easily adapted to the size of passenger flows.

2.7. Real time location and fleet management

In his book, Nauman Ahmad Khan [16], he described Intelligent Transport Systems (ITS) as the concept that emerged in late 1970s before the growth of digital devices and availability of platforms to share the data produced or consumed by these devices. ITS is a wide domain that covers both private and commercial transportation systems and is defined as a group of technologies, systems and services for better and secure transport services.

The ITS systems have provided new domain of intelligent technology integration, resulting in many new opportunities for building safe, reliable and scalable service infrastructures for transport.

During his work Goel [17], realized that communication between dispatchers and drivers in small and medium-sized companies is often entirely realized by voice communication and that many decisions are often made manually with only basic support by computer-based decisions support tools. The lack of timely and reliable information about current vehicle positions and states certainly creates challenges in updating vehicle tours taking into account the dynamic nature of transportation processes as well as new transportation requests arriving with short advance notice.

The question to consider will be how to link the Bus location with the number of passengers in queue.

The speed of serving from first passenger to the last within the same Bus need to be computed as well to be able to estimate the time needed for the passenger to enter into a bus to last destination for one trip. With the Fleet management & monitoring system, the line with more passengers can be served before the other lines that contains short queue in order to optimize the speed.

2.8. Conclusion

We have identified related works, gaps in the literature and the suggested solutions to highlighted gaps that relates to the current project.

2.8.1 Related work

We have seen that there is relationship between the literatures and our case in public transport, mostly in the queue system theory and the waiting time. The M/M/1 queue system relates well to the way the queue is formed in public transport.

The queue theory of Single-Channel, Single-Phase System illustrates the similarity in public transportation system on the queue and their performance system measures.

It provides more insights and shows that it is possible to reduce the waiting time on queue by increasing number of busses on crowded routes or the option of dedicating lanes for the public transport in order to reduce the time and hence avoiding traffic jam mostly during the peak time period.

2.8.2 Identified gaps

While reviewing the existing literature, the literature related to our case study area was limited and some parameters are not found, we have few information that do not reveal in details about passengers' arrival rate. Same case the lack of information on waiting time and serving rate were not identified and yet the convenience of travelling means much more than just the comfort of ride, rather the time management and other plannable models and cases must be able for computation beforehand.

There is gap residing in identifying waiting time in queue, serving rate and the number of passengers at a queue or system.

The literature review shows that the transport service on one hand considers the passengers to be served once the passengers are boarded or on another hand are departed from the bus station. This aspect leads to the service offered to be counted partially and therefore the time related to trip sometimes is not counted as the elapsed time or waiting while service is being offered.

There is time a bus spent at the bus stops while waiting passengers that are not already at the place.

Moreover, the buses' capacity and their allocation follow a random way and it lacks a systematized method that facilitates passengers' flows in RFTC.

The organizer's decision affects the number of passengers in vehicles, the size of vehicles used, and the number of rides on the line, regularity and frequency of communication lines.

2.8.3 Suggested solutions to identified gaps

The proposed solution takes into account the travel time, the time the bus stops at the bus stops while dropping or picking new passengers and related driver delays at the bus stop waiting passengers that are not already at the place.

This research determines the passenger's arrival rate, existing buses headways and serving rate, the number of buses allocated to Kimironko-Town line and the average bus seating capacity; to fill the identified gaps in the available documentation. Furthermore, we are designing a new system that optimizes the existing system and provides improvement in terms of waiting time and serving rate hence reduction of the queue size as well. The designed system takes into account that the size of vehicles can be easily adapted to the size of passenger flows.

The service offered considers passengers to get fully the intended service and the waiting time includes the time waiting at both queue and in system such as boarding time and travelling time until it gets to the terminal or at any bus stop between the terminals.

CHAPTER 3: RESEARCH METHODOLOGY

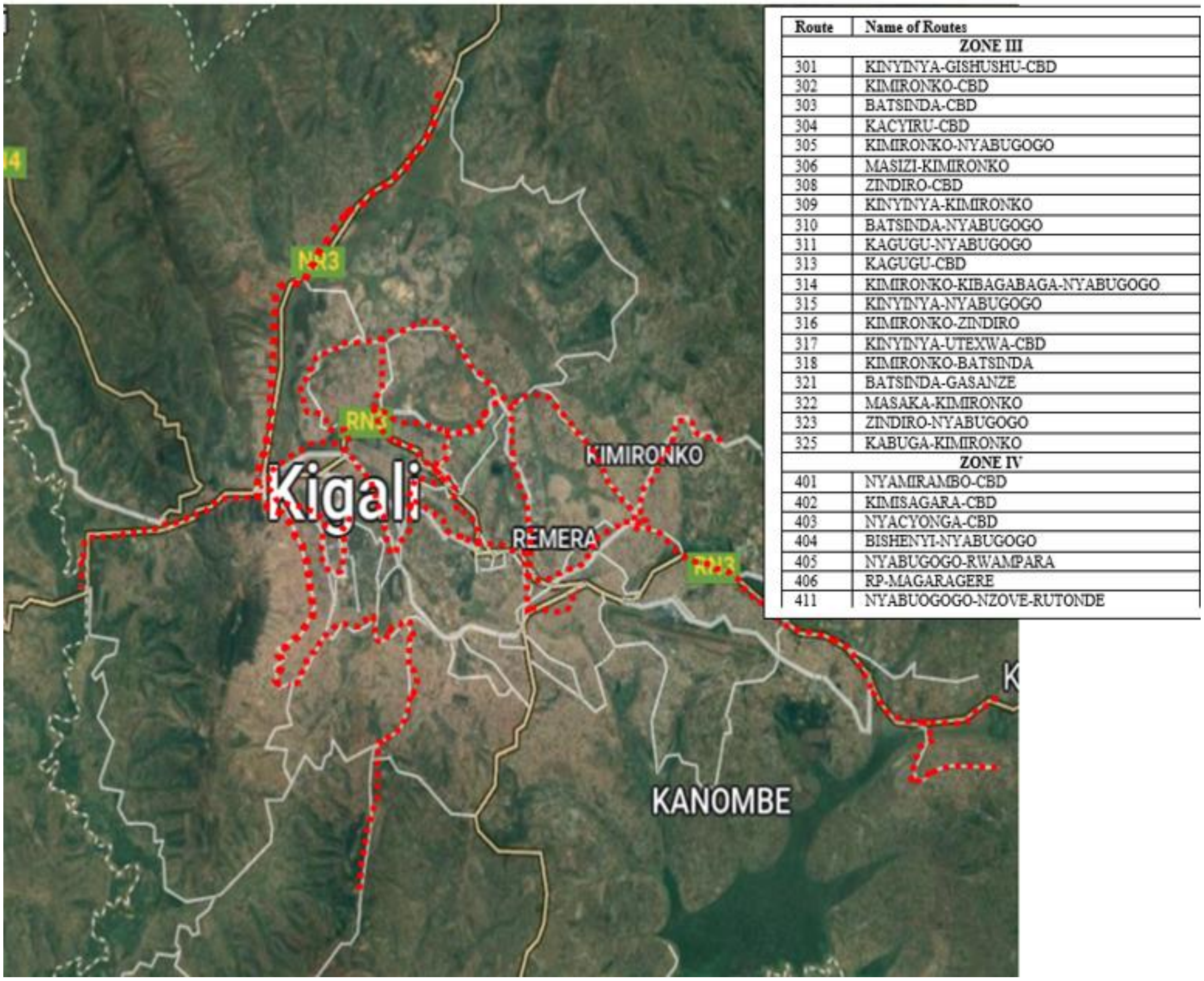
3.1. Introduction

Research methodology describes scientifically how the research is being done; by illustrating the approved methods, models and other standardized means by which the intended works and related results will be interpreted. Among others, this chapter covers mainly the research area, methodology to follow, tools and techniques/procedures for data collection, research population, sample size and sampling technique, tools/instruments for processing/analyzing data collected, etc.

3.2. Research Area

The research project is conducted in Rwanda Federation of Transport Cooperatives (RFTC) also known as Jali Transport Limited (JTL), which is a public transport service provider (PTSP). RFTC is one of the three companies such as (RFTC), Kigali Bus Service (KBS), and Royal Express; with contract to operate as PTSP in City of Kigali (CoK). According to RURA and the PTSP contracts, the network is structured in different zones basing on the geography such as Zone one is for KBS, zone two is for Royal Express and zone three and zone four are for RFTC.

More specifically, RFTC operates in the areas such as: Kabuga, Kimironko, Town, Nyabugogo, Kacyiru, Gakinjiro, Gatsata, Nyacyonga, Batsinda, Kagugu, Nyarutarama, Zindiro, Kinyinya, Gisozi, Nyamirambo, Kimisagara, etc. Details are given in next figure [7]



Route	Name of Routes
ZONE III	
301	KINYINYA-GISHUSHU-CBD
302	KIMIRONKO-CBD
303	BATSINDA-CBD
304	KACYIRU-CBD
305	KIMIRONKO-NYABUGOGO
306	MASIZI-KIMIRONKO
308	ZINDIRO-CBD
309	KINYINYA-KIMIRONKO
310	BATSINDA-NYABUGOGO
311	KAGUGU-NYABUGOGO
313	KAGUGU-CBD
314	KIMIRONKO-KIBAGABAGA-NYABUGOGO
315	KINYINYA-NYABUGOGO
316	KIMIRONKO-ZINDIRO
317	KINYINYA-UTEXWA-CBD
318	KIMIRONKO-BATSINDA
321	BATSINDA-GASANZE
322	MASAKA-KIMIRONKO
323	ZINDIRO-NYABUGOGO
325	KABUGA-KIMIRONKO
ZONE IV	
401	NYAMIRAMBO-CBD
402	KIMISAGARA-CBD
403	NYACYONGA-CBD
404	BISHENYI-NYABUGOGO
405	NYABUGOGO-RWAMPARA
406	RP-MAGARAGERE
411	NYABUOGOGO-NZOVE-RUTONDE

Figure 5: Map for RFTC Operation areas

Our work focuses particularly on two bus stations/terminals such as Kimironko and Town bus station (aka CBD) and more specifically on the lanes linking these two bus stations, i.e: Kimironko-CBD line.

This lane has 11.2km and different bus stops such as: Kimironko-Rwahama-Stadium-Chez Lando-Gishushu-UoK-KBC-Kimihurura-Kimicanga-Peage-Kwa Rubangura-CBD/Down Town.

3.3. Current Service processing model at RFTC bus station.

To design the waiting facility, it is necessary to have information regarding the possible size of the queue.

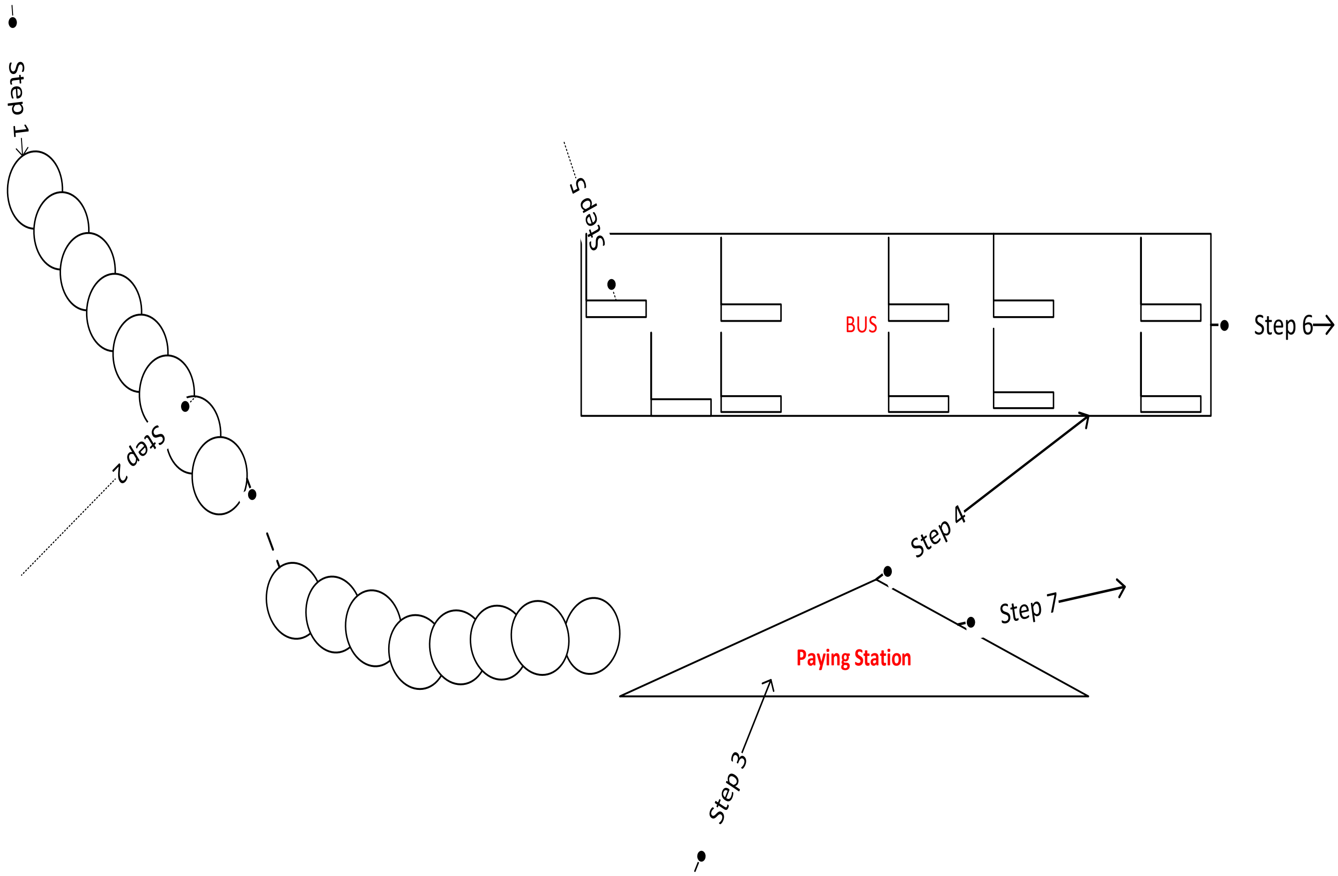


Figure 6: Service processing at bus station

We can illustrate the process at bus station in 7 main steps as per below:

Step 1: starting point of the queue where the passengers arrive and choose the line to queue in accordance to their destination.

Step 2: At the queue itself, where the passengers form the queue and wait that when their time arrive to be served depending on the number of passengers that arrived before and the bus space availability

Step 3: At paying station, where the payment is checked or done depending on the arrangement in place. For the case of the public transport, the payment station is location at the entrance of the bus and is controlled by driver or an agent of the PTSP.

Step 4: this comes when the payment checking provides positive feedback and precedent the step of entering into the bus

Step 5: this step comes when confirmation of payment is positive and the passengers proceed to the bus where he/she finds the seat.

Step 6: this is the final step for the eligible passengers where the bus get full and none can find the place in the bus and therefore the driver starts the trip.

Step 7: This is undesirable step where the passenger is not eligible to enter into the bus due to the negative feedback from payment checking and thus no access is given to passenger to proceed to the bus. At this step the passenger needs to load his/her card and come back to the payment checking point.

The same steps are undergone by every passengers and the FIFO method is used.

At each step there is waiting time and the faster the process, the better the service is given to the passengers.

There may also be a time that should be considered along with customer-waiting and idle-server costs to obtain the optimal system design. In any case, the analyst can first try to solve this problem by analytical means; if these fail, he or she may use simulation. Ultimately, the issue generally comes down to a trade-off between better customer service and the expense of providing more service capability, that is, determining the increase in investment of service for a corresponding decrease in customer delay. [8]

3.4. Research Population

The research population describes the concerned group by the research to which the experience or any other form of exercise will be applied to and to whom the results will be applicable to as well. With the size of the population, the data collected took place in different sessions across the time of the research.

Given that we are interested in providing an algorithm that optimizes the waiting time at PTSP, it is with great importance to determine the population with diligence to be able to compare the two systems. Our research focuses on the passengers attending Kimironko-CBD line at Kimironko Bus Station.

3.5. Sample Size and Sampling Techniques

According to Ranjit Kumar, sampling is the process of selecting a few from a bigger group (sampling population) to become the basis for estimating or predicting the prevalence of an unknown piece of information, situation or outcome regarding the bigger group. In addition, a sample is a subgroup of the population you are interested in [18, 19].

Moreover, to estimate parameters of system elements, one has to establish a sampling plan identifying the data elements to be collected with reference to specific parameters.

Cochran sampling formula for sample size is used and it is as per below:

Thus: $$n = \frac{z^2 * p * q}{e^2} \quad (1)$$

Where:

n=desired sample population

Z=Critical value and for our case we will use a confidence of 90% and our critical value will be equal to 1.64.

e= 0.01(degree of confidence or absolute error)

e^2= 0.0001

p: expected proportion in population based on previous studies or pilot studies.

$$q = 1 - p \quad \textbf{(2)}$$

Given that there is no similar previous study found, the formula for sample size will be with p=50% and q=1-p=50%

From the above formula, our sample size is estimated to n=1.64^2*(0.5)*0.5/(0.01)^2, which makes a total number of 6724 minutes.

For our research project, we use simple random technique from the total that is determined from the sampling size and this gives equal chance to any day of the week and month as we consider collecting data needed for the sake of the project in consideration from RFTC at Kimironko Bus station for Kimironko-CBD line.

3.6. Data Collection Techniques

Any research especially the quantitative one, is characterized by collecting information that will be analyzed and the results can be either numerically or analytically presented throughout tables, statistical graphs, etc.

Observation is a purposeful, systematic and selective way of watching and listening to an interaction or phenomenon as it takes place [18]. In our project, the observation method was used for the time management calculation and buses allocation to examine the efficiency of existing techniques and thus the benchmarking for the proposed new system.

The watch was used to record the starting time of a given passenger and the waiting time between the processing steps until he/she departs.

This helped us to have the number of served passengers within a given period, the number of buses, headways and the time elapsed in inter levels at the line and the records also facilitated to optimize the process by proposing an algorithm from the collected data.

We use the primary data from onsite survey (waiting time in the bus, in queue, at payment point, boarding time, headways, etc…) and the secondary data from the existing data of the PTSP.

The secondary data consist of the time needed as target from contract, number of bus stops, bus seating capacities, and categorization, starting time and ending time, etc.

3.7. Instrument for Data Collection

Report, books, and papers are our documents for research project that facilitate to come up with the correlation between the theoretical and practical aspects of our work.

Observation has been main tool for reaching out to the set objectives.

3.8. Validity

Validity is defined as the degree to which a measuring instrument measures what it is designed to measure. Here the researcher is concerned with the ability of measuring what designed system is ought to measure referring to the hypotheses and research questions.

3.9. Reliability

Reliability of an instrument refers to the degree to which the instrument consistently measures what it intends to measure. Thus, an instrument is reliable if it gives the same result when administered repeatedly under similar condition.

3.10. Data Processing and analysis

Data analysis involves the arrangement, computation and evaluation of certain statistical measures as well as finding the pattern of relationship that exist among the data group.

It deals with the procedures of evaluating value of unknown parameters of the population and testing of hypothesis for the purpose of drawing inferences.

Data Analysis is the process of systematically applying statistical and/or logical techniques to describe and illustrate, condense and recap, and evaluate data. Indeed, Savenye and Robinson, (2004) researchers generally analyze for patterns in observations through the entire data collection phase [20].

3.11. Functional system characteristics

3.11.1 Performance measures and system effectiveness.

By analyzing a queueing system, it is for obtaining the corresponding values of certain system elements such as: the number of passengers in the system, waiting time for a passenger, length of a busy or idle period, headways, etc.

The effectiveness parameters are random variables and to find their complete probabilistic descriptions (PDFs), most times we must be content to be able to derive their few moments such as mean, variance, etc [1].

By modeling the queueing systems mathematically, we have been able to provide the quantitative answers to specific questions of our research including: what is the improvement occurring when the waiting time is reduced to any percentage or what is required to have the serving rate equivalent to a certain number in PTSP?

What is the impact when there is increase of the number of buses by certain percentage? Or by varying the bus seating capacity to any range of capacity?

3.11.2 System utilization

System utilization is given by two factors that are mostly important in the queuing system such as: arrival rate and serving rate.

System utilization is defined as the fraction of time that the passengers' arrival and passengers serviced.

3.11.3 Single server queueing system, M/M/1

In a single server system noted by M/M/1, the utilization is given by:

$$\boldsymbol{\rho = \frac{\lambda}{\mu}} \tag{3}$$

Where **λ:** passenger's arrival rate and

μ: serving rate

In a period of time t, the systems will receive a number of passengers that is equivalent to t λ

P0, the probability of finding there is no passenger within the system.

$$\mathbf{p_0 = 1 - \rho} \tag{4}$$

Here, we note that the arrival patterns are independent one another no exact fix number can be predicted therefore this is treated as a random process and we will utilize Poisson distribution in our calculation.

A single-phase system is one in which the customer receives service from only one station and then exits the system [8]

A system is stable when the server is not busy 100% of the time. It implies that from equation 3, we must have $\rho = \frac{\boldsymbol{\lambda}}{\boldsymbol{\mu}} < 1$**,** for the queueing system stability.

Thus, in any time interval, the average number of passengers that arrive must be strictly less than the average number of passengers that the server can handle.

To fulfil the stability condition it is assumed that the number of passengers that arrive in queue are all served and no one is left. And this means that the average arrival rate is less or equal to the average of server rate in overall.

And hereby are the equations that are related to the system characteristics:

$$L = \frac{\rho}{1-\rho} = \frac{\lambda}{\mu-\lambda} \tag{5}$$

$$L_q = \frac{\rho^2}{1-\rho} = \frac{\lambda^2}{\mu(\mu-\lambda)} \tag{6}$$

$$w = \frac{L}{\lambda} = \frac{\rho}{\lambda(1-\rho)} = \frac{1}{\mu-\lambda} \tag{7}$$

$$w_q = \frac{L_q}{\lambda} = \frac{\rho}{\mu - \lambda} \quad (8)$$

It is not always absolute that the utilization of the system is equal to the fraction shown in equation 3, because some passengers may not continue to wait until they are serviced due to long waiting time or other reasons that cause the impatience as we have seen in chapter 2 such as: balking, reneged, jockey, etc.

However, to simplify calculations we assume that there is no such scenario of abandoning the system once one has entered in queue.

3.11.4 Multiserver queueing system, M/M/c

By M/M/c system, we now have a multiserver system characterized by c servers.

The number of servers is an important characteristic of a queueing system and represents a fundamental trade-off-adding servers incurs extra cost to the business, but substantially reduce delays for customers, thus, the choice of the number of servers is often a critical decision [1].

The current system/model has a Poisson arrival, with a rate of λ, with c servers where each server has independent and identically distributed exponential service –time distribution with a mean of 1/μ.

For multiserver queuing systems with c>1, the utilization is given by the average of fraction of servers that are active and thus the rate at which passengers arrival in queue system divided by the maximum rate at which the system can serve the passengers.

We have then, the related characteristics as follow:

$$p_0 = \left(\frac{r^c}{c!(1-\rho)} + \sum_{n=0}^{c-1} \frac{r^n}{n!}\right)^{-1} \quad (9)$$

Where $r = \frac{\lambda}{\mu}$ and $\rho = \frac{\lambda}{c\mu} < 1$

Here the condition for the existence of a stable system is given by $\rho = \frac{\lambda}{c\mu} < 1$.

With the above consideration, we can therefore indicate the measures of effectiveness for as M/M/c as:

$$Lq = \left(\frac{r^c \rho}{c!(1-\rho)^2}\right) p_0 \tag{10}$$

$$w_q = \frac{Lq}{\lambda} = \left(\frac{r^c}{c!c\mu(1-\rho)^2}\right) p_0 \tag{11}$$

Wq(0) shall describe the probability that a passenger has zero delay in queue before receiving service.

Equivalently, 1-Wq(0) shall be the probability that a passenger has nonzero delay in queue before receiving service. It does not indicate the real time a passenger waits in queue, but rather the probability that a passenger is not able to immediately be served.

$$w = \frac{1}{\mu} + \left(\frac{r^c}{c!c\mu(1-\rho)^2}\right) p_0 \tag{12}$$

or $$w = \frac{1}{\mu} + w_q \tag{13}$$

$$L = r + \left(\frac{r^c \rho}{c!(1-\rho)^2}\right) p_0 \tag{14}$$

L can also be obtained from Lq and thus,

$$L = Lq + r \tag{15}$$

$$Pn = \begin{cases} \frac{\lambda^n}{n!\mu^n} p_0 & (0 \leq n < c) \\ \frac{\lambda^n}{c^{n-c} c! \mu^n} p_0 & (n \geq c) \end{cases} \tag{16}$$

CHAPTER 4: SYSTEM ANALYSIS & MODELLING

4.1. Introduction

It this chapter, we present the parameters to be used for our functional model and simulation/modeling. The considerations under which the modeling is based upon, the formula or the relationships of the functional parameters to be used in the data analysis and later the modeling or design of the system to be used that optimizes the studied public transport management case.

4.2. Simulation parameters

By using the below parameters and modeling them into a mathematical function from queueing theory and systems presented in chapter 3, we calculate the parameter values and predictability of the number in the system or in queue, waiting time, number of buses to be used, the headways, etc.

Specifically, we present and analyze the key characteristics of the public transport such as; average time spent waiting in queue, average time spent waiting in system, bus utilization rate, system's headways, and average number of passengers in the system and in the queue, and lastly we maneuver some probabilities for numbers of passengers in the system.

After having data information on the queue, their relationship with the allocation of the buses to mentioned line, the analysis on each variable and their impact on time management for both passengers and transport service provider is studied.

The parameters to be used in our model are as per below listed items:

λ: Average arrival rate of passengers in queue at RFTC Kimironko bus station for CBD line

Wq: Waiting time of passengers in queue at RFTC Kimironko bus station for CBD line

Lq: Average number of passengers in queue at RFTC Kimironko bus station for CBD line

L: Average number of passengers in system at RFTC Kimironko bus station for CBD line

Po: Possibility of zero passengers existing in system at RFTC Kimironko bus station for CBD line.

Pn: Probability of n passengers existing in the system at RFTC Kimironko bus station for CBD line

W: Average waiting time of passengers in the system at RFTC Kimironko bus station for CBD line

N: Number of Buses at RFTC Kimironko bus station for CBD line

Bc: Capacity of one Bus/Seating capacity for one bus

μ: Service rate of passengers at RFTC Kimironko bus station for CBD line

***ρ*:** System utilization factor

Wh: Average headways, the time between the arrivals of two consecutive buses

Wb: Average time spent by bus waiting to be full at bus station (when passengers are less than the bus capacity)

Wa: Average time spent in alighting passengers at bus station

WB: Average time spent in boarding passengers at bus station

T: Average time spent during travel from one station/terminal to another station/ terminal.

D: Distances between two stations/ terminals

S: Average speed of bus to perform one-way trip between two stations/ terminals

Comparison of existing system parameters with proposed new parameters is done to see whether there is an improvement and adjusting parameters and hence justification of hypothesis set above in chapter one.

4.3. Conditions for modelling

The assumptions for functional model as illustrated in chapter 3, are computed and modeled with below considerations:

- Passengers' arrivals come from an infinite or very large population and follow Poisson distribution,
- Passengers' arrivals are treated on a FIFO and no balk or renege,
- Service times are constant or follow a negative exponential distribution,
- The stability condition expressed in equation (3) is followed
- Single channel such as only one queue or line is considered with single sever but with a consideration of many buses with same characteristics as per figure one in chapter 2.
- The buses are considered to be of the same capacity in the model

- One way trip is equivalent to the back trip in terms of travel consideration and initially all buses are with same headways.

4.4. Model Development

The single server or M/M/1 queue system is preferred for our model to simplify the system and other protocols that are present in boarding at station.

From the equation (3), and according to the defined parameters we can deduce that: the serving rate μ being the average number of passengers served within time period Tμ, the period here depends on Wa, WB, Wb, T and this can be expressed as

$$T_{\mu} = \mathrm{T} + \mathrm{Wa} + \mathrm{WB} + \mathrm{Wb} \tag{17}$$

μ= number of passengers served within Tμ time/ Tμ

or $\mu = \mathrm{Bc}/\mathrm{T}\mu$ (18)

It shows that the serving rate is affected by travel time between one station to another and time required to alight arrival and boarding passengers.

To simplify and make easy the case, we will consider that the alighting time (Wa) together with time spent waiting in bus (Wb) are consolidated into boarding time and hence the serving period Tμ is expressed as follow

$$T_{\mu} = \mathrm{T} + w_{B} \tag{19}$$

Given that at one time the bus serves according to its capacity, then from equation (18) and equation (19) we can deduce

$$\mu = \mathrm{Bc}/(\mathrm{T} + \mathrm{WB}) \tag{20}$$

where, Bc is the Bus seating capacity

It means that by maneuvering with T & WB; the serving rate can increase or decrease and thus the serving rate shall be one of the key parameters to work with in our analysis and interpretation.

T being the average travel time between two stations/terminals such from source to destination, then T relates to the average speed of the bus and the distance between two stations/terminals.

Thus, $T = \mathrm{D}/S$ (21)

Where D: distance between Stations/terminals and S the average speed of the bus from one station/terminal to another.

To simplify, the travel time of the bus contains also the time spent at bus stops and other aspects that may cause delays during the trip. Moreover, we can accommodate the effect of the traffic jams and other causes of the delays in the road.

As stipulated, the serving rate will be different depending on the period of the day such as during period of traffic jams or any other incident preventing or dictating the bus speed.

From equation (20), we can also find that

$$\mu = \mathrm{B} * \mathrm{S}/(\mathrm{D} + \mathrm{S} * \mathrm{w_B}) \quad (22)$$

However, the serving rate of the system is calculated with consideration of many buses in pool; this increases the system service rate by N factor, N being the number of buses in pool.

Therefore $\rho = \lambda / N\mu$ characterizing the utilization of one bus which indicates the increase of the serving rate as per the M/M/1 queue system described in previous section.

We thus deduce the relationship between serving rate μ and the Wh (headways), since all buses will not be at station and be boarded at same time, and to minimize the time that will be elapsed during the buses alignment and waiting to be full boarded before the next get started. Wh plays the role of avoiding time wastage and it then allows to keep M/M/1 but with changed serving rate with respect to number of buses and Wh shall be considered into the system.

4.5. The relationship between serving rate with various source of delays

We consider the buses identical in size and in time utilization.

The table below illustrates the relationship between μ, number of buses N and headways Wh.

Number of Buses in the pool	**Wh**	**Period of Service**	**Passengers Serviced**	**μ**
1	(T+WB)*2	Tμ +0*Wh	1*Bc	Bc/(Tμ +(0)*Wh)
2	(T+WB)	Tμ +1*Wh	2*Bc	2Bc/(Tμ +1*Wh)
3	(T+WB)*2/3	Tμ +2Wh	3*Bc	3Bc/(Tμ +2Wh)
4	(T+WB)*2/4	Tμ +3*Wh	4*Bc	4Bc/(Tμ +3*Wh)
5	(T+WB)*2/5	Tμ +4*Wh	5*Bc	5Bc/(Tμ +4*Wh)
6	(T+WB)*2/6	Tμ +5*Wh	6*Bc	6Bc/(Tμ +5*Wh)
7	(T+WB)*2/7	Tμ +6*Wh	7*Bc	7Bc/(Tμ +6Wh)
8	(T+WB)*2/8	Tμ +7*Wh	8*Bc	8Bc/(Tμ +7Wh)
……..	…………..	…….	…….	……….
N	**(T+WB)*2/N**	**Tμ +(N-1)*Wh**	**N*Bc**	**N*Bc/(Tμ +(N-1)*Wh)**

Table 1 relationship between serving rate with various source of delays

We can now generalize as per below

$$\mu = N * Bc/[T\mu + (N-1) * Wh] \text{ or } \mu = N * Bc/[T + WB + (N-1) * Wh] \qquad (23)$$

Where **N** is the number of buses in the pool,

Bc the bus seating capacity

Tμ the travel time plus boarding time as per equation (19)

By replacing T by D/S as per equation (21), we can express μ in terms of D and S, and thus

$$\mu = N * S * Bc/[D + S * WB + S(N-1) * Wh] \qquad (24)$$

At the end, with the model that we are proposing, the fleet manager can predict with the location of the bus, the time needed to serve a passenger.

From equation (24) and with stability condition stated by equation (3), we are able to predict the minimum number of buses that minimizes the system while serving the purpose and the optimum number of buses for the system for a given parameters such as: headway, number of bus, time for trip, bus seating capacity, etc.

Thus, we can at same time deduce the equivalent effectiveness parameters of the system such as: the average overall waiting time, the total waiting time for system.

After collecting data, their relationships with the allocation of the buses to mentioned line, the analysis on each variable, their impact on system performance is studied, and the findings are part of next chapter.

CHAPTER 5: RESULTS AND ANALYSIS

5.1. Introduction

In the present chapter, we discuss the data results from our data collection in survey. We present the graphics related to the current situation and whereas the optimized system is proposed, and the improved performance is achieved with new parameters such as number of buses (N), serving rate (**μ**), waiting time in the system and at queue (W, Wq respectively), the length of passengers in the system and at queue (L, Lq respectively). The probability of getting zero passenger in queue has been calculated.

As our general objective was to design a system that optimizes the waiting time on queue at the RFTC bus station (Kimironko-Town line), we have determined the number of passengers that uses Kimironko-CBD line in hour such as 3.7 person per minute equivalent to 222 person per hour and considers the peak with arrival rate of 5.7 passengers per minute.

5.2. Data analysis for existing system

Our data collection has a sample size of at least 6724 minutes as stated in chapter 3, and in field data collection we covers 8527minutes and this was collected at Kimironko bus station in the period from 17^{th} September 2021 to 1^{st} October 2021 and from 21^{st} to 22^{nd} October 2021 at Kimironko and Town bus stations.

Generally, the data survey covers the time from 5:30AM to 9:30PM; during the period, the survey was not always continuous due to different reason among others, break for the surveyors to take lunch, sometimes there was a rain, etc. Three surveyors were used, in recording passengers arrivals, buses arrival and the departure, passengers waiting time and boarding time, buses departures from Kimironko station and arrivals at town bus station known as Down Town bus station/terminal.

After the records, the collected data are treated and organized in such way that the objectives are to be analyzed and well assessed to reach the set goals from chapter one.

The summary of the data is given in below table with boarding time, headways, number of passengers served within the period, number of buses, average bus travelling time, etc.

The current system is characterized by the following parameters summarized in the below tables.

5.2.1 Passengers arrival rate

The survey results show that the arrival rate is at 3.71 passengers per minute; equivalent to 228 passengers per hour.

Day		Dates	Arrival records (number of passengers)	Time used (in Minutes)	Average Arrival rate (λ)/min
1	Friday	17/09/2022	2622	651	4.03
2	Saturday	18/09/2022	1834	595	3.08
3	Sunday	19/09/2022	1284	586	2.19
4	Monday	20/09/2022	3096	749	4.13
5	Tuesday	21/09/2022	2102	612	3.43
6	Wednesday	22/09/2022	1074	379	2.83
7	Thursday	23/09/2022	2147	656	3.27
8	Friday	24/09/2022	2771	730	3.80
9	Saturday	25/09/2022	1615	447	3.61
10	Sunday	26/09/2022	2023	786	2.57
11	Monday	27/09/2022	2922	605	4.83
12	Tuesday	28/09/2022	2968	694	4.28
13	Wednesday	29/09/2022	1411	315	4.48
14	Thursday	30/09/2022	1708	362	4.72
15	Friday	01/10/2022	2081	360	5.78
	Total		31658	8527	
	Average arrival rate per min				**3.71**

Table 2: arrival rate per minute

5.2.2 Average travelling time between Kimironko and Town Bus stations

By analyzing the bus departures and arrivals, we have found that the average travel time between Kimironko bus station to Town bus station is equivalent to 37.65 minutes. These come from a record of 234 trips counting one bus for a trip repetition as new trip, and corresponding time for travel recorded was 8809 minutes as per below table. The time was counted for one trip between two ends. These records were conducted by considering the plate number of each bus and its departure and its arrival time from one bus station to another.

Total time for trips (in minutes)	Number of trips or Buses	Average travelling time per trip in minutes
8809	234	37.65

Table 3 average travel time between Kimironko & Town Bus Terminals

5.2.3. Boarding time period at Kimironko bus station Town line

Boarding time at Kimironko station for Kimironko-Town line is at 13.92.minutes, the number comes from a record of 1302 buses that boarded within 18125 minutes.

S/N	Days	Time in Min	Number buses	Average Boarding period per day (in Minutes)
1	17/09/2021	1541	104	14.8
2	18/09/2021	1150	81	14.2
3	19/10/2021	1793	69	26.0
4	20/09/2021	1668	132	12.6
5	21/09/2021	1442	94	15.3
6	22/09/2021	969	52	18.6
7	23/09/2021	1350	86	15.7
8	24/09/2021	580	102	5.7
9	25/09/2021	1300	71	18.3
10	26/09/2021	1360	87	15.6
11	27/09/2021	1475	106	13.9
12	28/09/2021	1322	97	13.6
13	29/09/2021	835	67	12.5
14	30/09/2021	612	73	8.4
15	01/10/2021	728	81	9.0
Total		18125	1302	**13.92**
Overall Average Boarding Time (minutes)				

Table 4 Average Boading time for Kimironko-Town line

5.2.4. Average number of buses allocated to Kimironko-Town Line

Average number of buses allocated for Kimironko-Town line per day: **20.67** buses with a minimum of 14 buses and maximum of 24 buses

S/N	Days	Number of Buses per day
1	21	21
2	18	18
3	14	14
4	22	22
5	20	20
6	20	20
7	22	22
8	23	23
9	21	21
10	14	14
11	24	24
12	23	23
13	24	24
14	21	21
15	23	23
Total		310
Average number of Buses per day		**20.67**

Table 5 Average number of Buses per day

5.2.5. Average seating capacity for buses allocated to Kimironko-Town Line

Average seating bus capacity is 30.79 seats as per existing capacity.

This number is from the total number of recording from the buses categories and their respective capacity of 29 and 70 seats and their frequency of utilization or number of trips they performed. The summary is given in the below table.

Total capacity	45,907
Number of Trips	1491 (trips)
Average bus capacity	30.79 (Seats)
Average number of buses allocated	20.67 (Buses)

Table 6 Average number of buses allocated to Kimironko-Town line

5.2.6. Headways at Kimironko-Town bus line

Headway is a key parameter for the service of transportation; it is among the major characteristics of the public transportation.

From our data record and analysis, we have found that the headways range from a minimum of 4.52 minutes to a maximum of 9.83 minutes and the average headway of the system is calculated to be 6.31 minutes.

S/N	Days	Time in minutes	Number of Buses	Average Headways per day (in Minutes)
1	17/09/2021	1071	109	9.83
2	18/09/2021	665	100	6.65
3	19/10/2021	586	68	8.62
4	20/09/2021	731	143	5.11
5	21/09/2021	567	104	5.45
6	22/09/2021	419	62	6.76
7	23/09/2021	623	105	5.93
8	24/09/2021	771	139	5.55
9	25/09/2021	484	83	5.83
10	26/09/2021	665	86	7.73
11	27/09/2021	594	113	5.26
12	28/09/2021	647	116	5.58
13	29/09/2021	363	73	4.97
14	30/09/2021	357	79	4.52
15	01/10/2021	719	87	8.26
Total		9262	1467	
Overall Average headway time (in minutes)				**6.31**

Table 7 Average headway for Kimironko-Town line

5.2.7. Existing System efficiency

From equation 23 in chapter 4, the serving rate is equivalent to μ=N*Bc/[T+WB +(N-1)*Wh]

By doing all calculations we have μ=3.68 passengers per minute, and this is the serving rate.

By utilizing the formula (3), we have ρ=λ/μ, we have the utilization that is at more than 100%

which shows that existing system is congested especially when considering all factors including the bus stops in between the two bus station such as 8 bus stops and other factors.

5.3. Proposed system and its parameters

After computing the collected data and analyzing their characteristics as presented in the section 5.2, we have designed a new system basing on the needed performance according to the equation 3 and equation 23. The new system will improve the performance being in the headways, number of served passengers and waiting time at queue and at system.

5.3.1 General considerations for new system

The parameters such as arrival rate, average traveling time between two terminals are kept identical to the existing system since the way the passengers arrive does not change, rather it is independent to any factors considering normal circumstances of the public transport services same time to perform a trip.

Hence, the arrival rate for the proposed system is λ=3.71 passengers per minute and the travelling time is 37.65 minutes between Kimironko and Town stations/terminals

5.3.2 New system parameters

As we have found in the existing system, in order to improve the system, three options can be used such as:

a. Increasing the number of buses while keeping the bus seating capacity,
b. Keeping number of buses and increasing the bus seating capacity,
c. Mixing the above options, i.e; increasing the number of buses while increasing the bus seating capacity

5.3.3 New system with Increase of number of buses while keeping the bus seating capacity

With this option, we have bus capacity that is fixed and it is added to general considerations stated in previous section and such as the arrival rate and travelling time.

Parameters	**Value for existing system**	**Value for new system**
Bc (seating capacity for one bus)	30.79	30.79
T (average travelling time between two terminals in minutes)	37.65	37.65
WB(Average Boarding Time in minutes)	13.92	13.92
Tμ=T+WB (Average Boarding time & travelling time in minutes)	51.57	51.57
λ (Average passengers arrival rate)	3.71	3.71

Table 8 Constants terms for new system with varying number of buses

By varying the number of buses allocated to the line from 1 to 38, and factoring in equation 3 and 23; we have designed a system with the parameters summarized in following table.

Number of Buses in the pool	Headway (Wh)	Period of Service (Tμ)	Number of Passengers Serviced	Serving Rate (μ)	System Serving factor (ρ)
1	103.14	103.1	30.79	0.30	12.428
2	51.57	154.7	61.58	0.40	9.321
3	34.38	171.9	92.37	0.54	6.904
4	25.785	180.5	123.16	0.68	5.437
5	20.628	185.7	153.95	0.83	4.474
6	17.19	189.1	184.74	0.98	3.797
7	14.734	191.5	215.53	1.13	3.297
8	12.8925	193.4	246.32	1.27	2.913
9	11.46	194.8	277.11	1.42	2.608
10	10.314	196.0	307.9	1.57	2.361
11	9.3764	196.9	338.69	1.72	2.157
12	8.595	197.7	369.48	1.87	1.985
13	7.934	198.3	400.27	2.02	1.838
14	7.367	198.9	431.06	2.17	1.712
15	6.876	199.4	461.85	2.32	1.602
16	6.44625	199.8	492.64	2.47	1.505
17	6.067	200.2	523.43	2.61	1.419
18	5.73	200.6	554.22	2.76	1.343
19	5.428	200.9	585.01	2.91	1.274
20	5.157	201.1	615.8	3.06	1.212
21	4.9111	201.4	646.59	3.21	1.155
22	4.688	201.6	677.38	3.36	1.104
23	4.484	201.8	708.17	3.51	1.057
24	4.2975	202.0	738.96	3.66	1.014
25	4.1256	202.2	769.75	3.81	0.974
26	3.967	202.3	800.54	3.96	0.938
27	3.82	202.5	831.33	4.11	0.904
28	3.683	202.6	862.12	4.26	0.872
29	3.556	202.7	892.91	4.40	0.842
30	3.438	202.8	923.7	4.55	0.815
31	3.3271	203.0	954.49	4.70	0.789
32	3.223	203.1	985.28	4.85	0.765
33	3.1254	203.2	1016.07	5.00	0.742
34	3.0335	203.2	1046.86	5.15	0.720
35	2.946	203.3	1077.65	5.30	0.700
36	2.865	203.4	1108.44	5.45	0.681
37	2.7876	203.5	1139.23	5.60	0.663
38	2.7146	203.6	1170.02	5.75	0.645

Table 9 Developed system parameters for new system with varying number of buses

Headways in minute vs number of Buses (Wh)

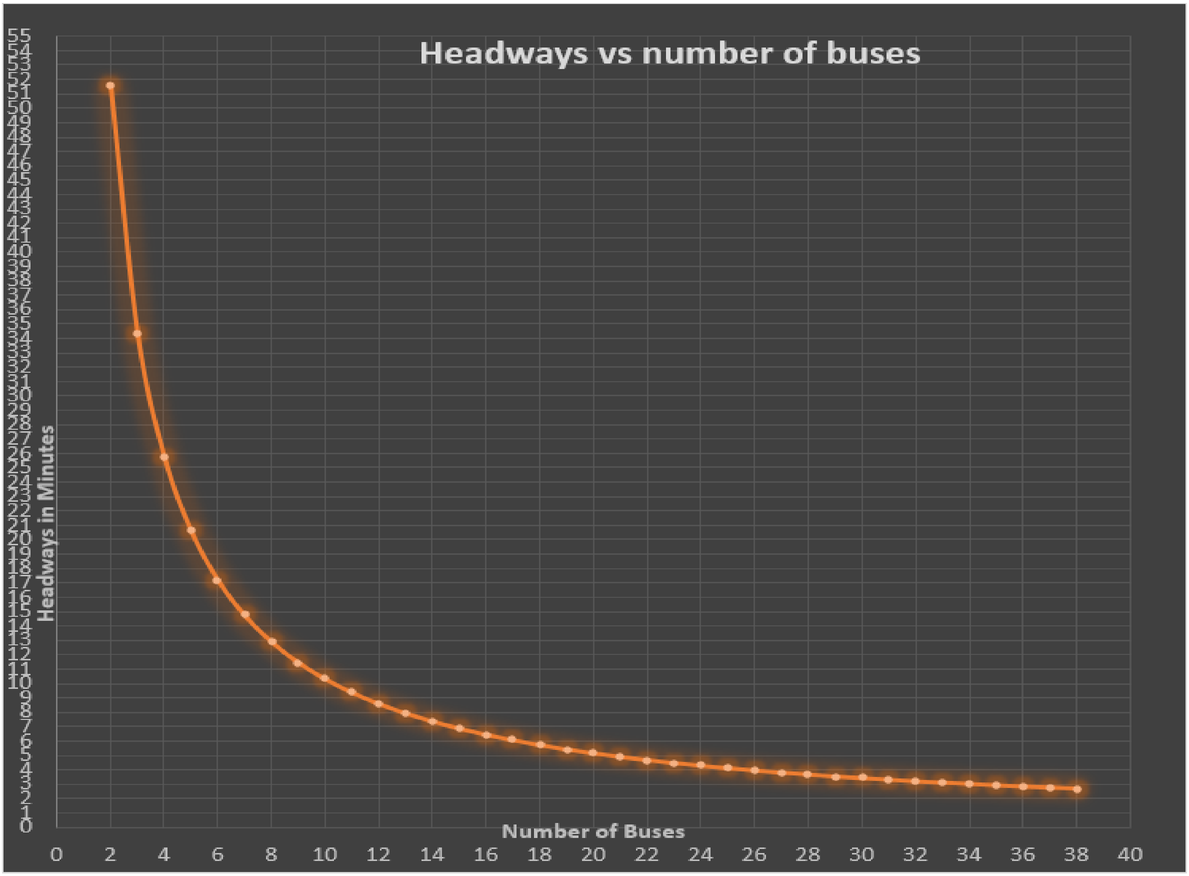


Figure 7 Headways in minute vs number of Buses (Wh) with variation of number of buses

We can see that the time between arrival of two consecutive buses decreases with the increase of the number of buses allocated to the line. The improvement is seen, since the existing system has an average headway of 6.31 minutes and the proposed system can go below as per the above figure.

For the target of any headway period, the above graph can be used to know which number of buses to allocate to the line.

Given that the targeted headways by RURA is 5min for Kimironko-Town line, we can see that the minimum number of buses to allocate would be 21 buses which corresponds to a headway of 4.91minutes.

Serving Rate (μ)

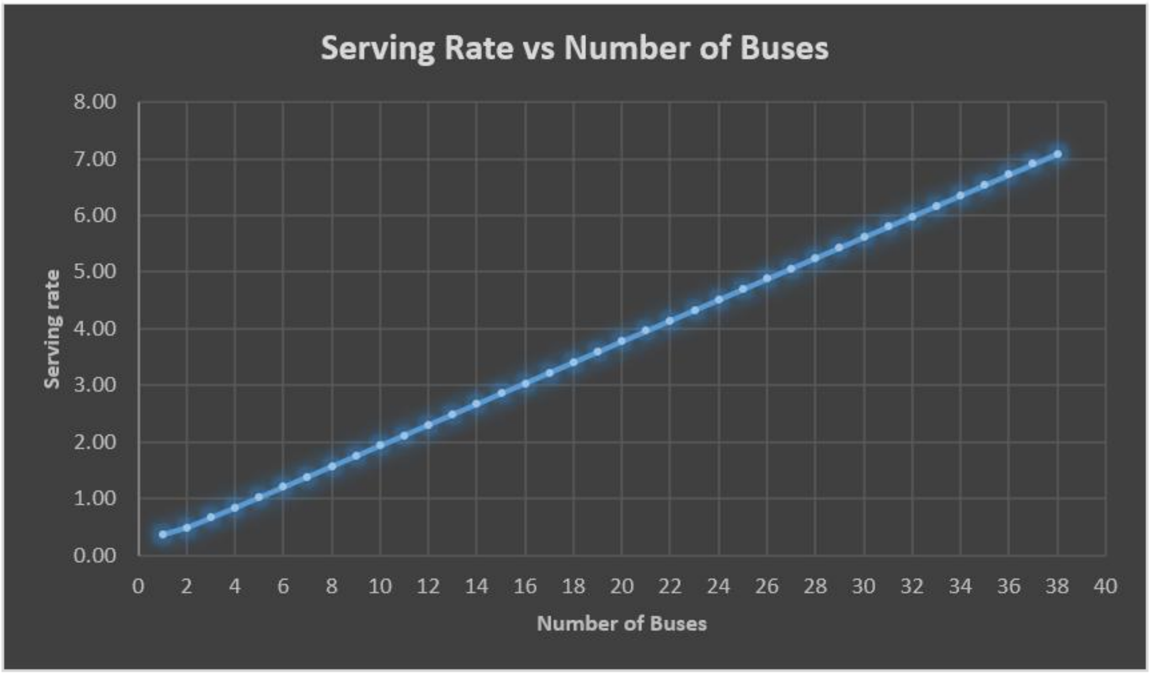


Figure 8 Serving Rate (μ) with variation of number of buses

We can observe that the serving rates and number of buses are linearly related and the higher the number of buses allocated to the line, the more the system serves. For example of 20 buses, the serving rate is at 3 person per minutes whereas for 30 buses the serving rate increases to 4.5 passengers per minute. The existing was considered to be congested with a serving rate that is less than the arrival; which led the system to be always busy.

System utilization factor (ρ)

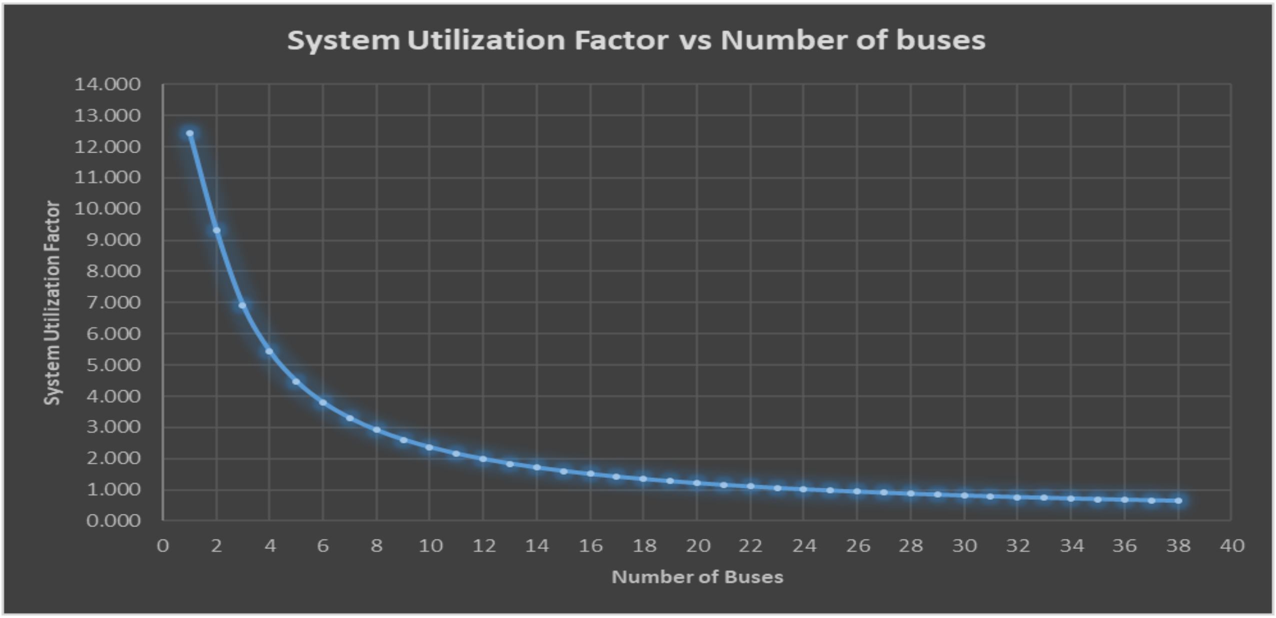


Figure 9 System utilization with variation of number of buses

The higher the number of buses allocated to the line the more the system becomes less occupied and by keeping the average seating capacity to 30.79, we can deduce that the minimum needed number of buses to be at 25 in order to meet the stability condition that ρ must be less than 1.

Average waiting time

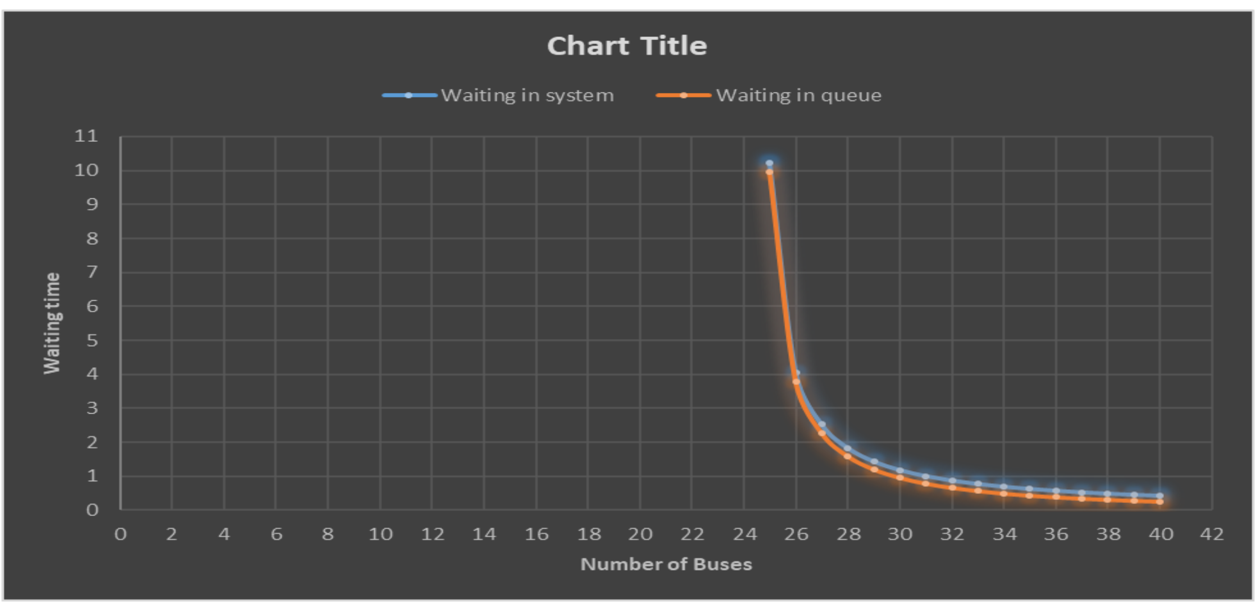


Figure 10 Average waiting time with variation of number of buses

The above graph shows that both waiting times in system and in queue decrease with increase of number of buses. For N=26, we have W=4 minutes and Wq=3.8minutes

Comparison for systems

Parameters	**Value for existing system**	**Value for new system**
Bc (seating capacity for one bus)	30.79	30.79
T (Average travelling time between two terminals in minutes)	37.65	37.65
WB(Average Boarding Time in minutes)	13.92	13.92
Tμ=T+WB (Average Boarding time &travelling time in minutes)	51.57	51.57
λ (Average passengers arrival rate)	3.71	3.71
N (number of Buses allocated to the line)	20.67	From 21 to 38
Headways (in minutes)	6.3	From 4.13 to 2.71
μ , Serving rate (number of passengers per minute)	3.68	From 3.81 to 5.75
Average waiting time (in minutes) in system	27.65	From 8.72 to 8.45
Average number of passengers in system per minute	NA	From 32.33 to 1.82
Utilization factor	Always above 100%	From 97% to 64.5%

Table 10 Comparison of system

5.3.4 New system with Increase of bus seating capacity while keeping the number of buses constant

With the option of increasing bus seating capacity while keeping the number of buses to remain constant, we have number of bus that is fixed and it is added to general considerations stated in previous section such as the arrival rate, travelling time.

N	25 buses
T	37.65 (minutes)
WB	13.92 passengers
Tμ=T+WB	51.57 minutes
λ	3.71 passengers

Table 11 constants parameters for varying bus-seating capacity

Bus Capacity (Bc)	Headways (Wh)	Serving Period	Number of passenger served	Serving rate (μ)	ρ(λ/μ)	Length in system	Length in queue (minutes)	Waiting in system	Waiting in queue	1-ρ
31	4.1	202.2	775	3.83	0.968	29.99	29.02	8.08	7.82	0.03
32	4.1	202.2	800	3.96	0.937	15.00	14.06	4.04	3.79	0.06
33	4.1	202.2	825	4.08	0.909	10.00	9.09	2.70	2.45	0.09
34	4.1	202.2	850	4.20	0.882	7.50	6.62	2.02	1.78	0.12
35	4.1	202.2	875	4.33	0.857	6.00	5.14	1.62	1.39	0.14
36	4.1	202.2	900	4.45	0.833	5.00	4.17	1.35	1.12	0.17
37	4.1	202.2	925	4.58	0.811	4.29	3.47	1.16	0.94	0.19
38	4.1	202.2	950	4.70	0.789	3.75	2.96	1.01	0.80	0.21
39	4.1	202.2	975	4.82	0.769	3.33	2.56	0.90	0.69	0.23
40	4.1	202.2	1000	4.95	0.750	3.00	2.25	0.81	0.61	0.25
41	4.1	202.2	1025	5.07	0.732	2.73	2.00	0.74	0.54	0.27
42	4.1	202.2	1050	5.19	0.714	2.50	1.79	0.67	0.48	0.29
43	4.1	202.2	1075	5.32	0.698	2.31	1.61	0.62	0.43	0.30
44	4.1	202.2	1100	5.44	0.682	2.14	1.46	0.58	0.39	0.32
45	4.1	202.2	1125	5.57	0.667	2.00	1.33	0.54	0.36	0.33
46	4.1	202.2	1150	5.69	0.652	1.87	1.22	0.51	0.33	0.35
47	4.1	202.2	1175	5.81	0.638	1.76	1.13	0.48	0.30	0.36
48	4.1	202.2	1200	5.94	0.625	1.67	1.04	0.45	0.28	0.38
49	4.1	202.2	1225	6.06	0.612	1.58	0.97	0.43	0.26	0.39
50	4.1	202.2	1250	6.18	0.600	1.50	0.90	0.40	0.24	0.40

Table 12 Modeled system parameter with N=25 while varying bus seating capacity

The table 11 shows that by keeping the number of buses constant to 25 buses, while varying the bus seating capacity from 31 to 50, both headways and period of service are constant, however the serving rate increases with seating capacity increase and the utilization factor ρ decreases which gives more room to serve passengers. The system shows also that the waiting time and passenger's length in system decease with increase of bus seating capacity, below are graphs related.

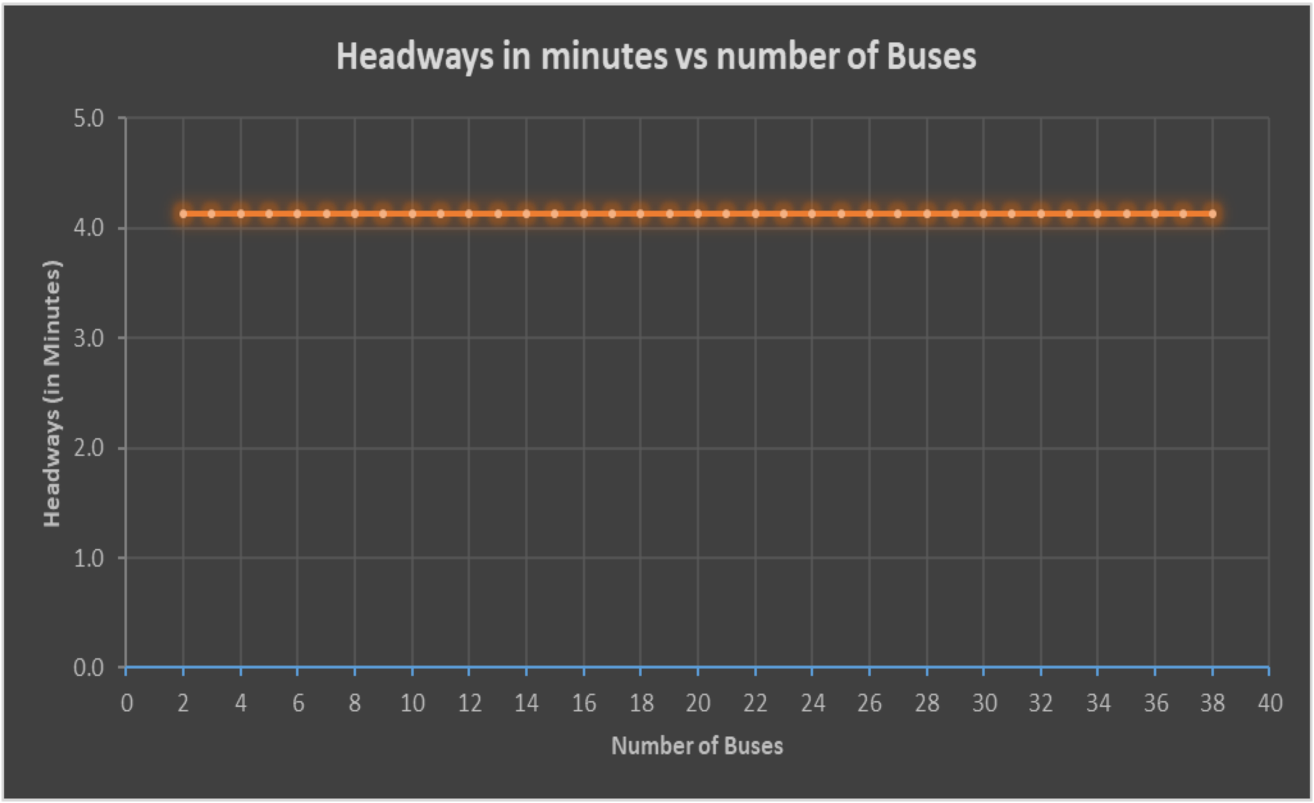


Figure 11 Headways in minutes with fixed number of buses at 25.

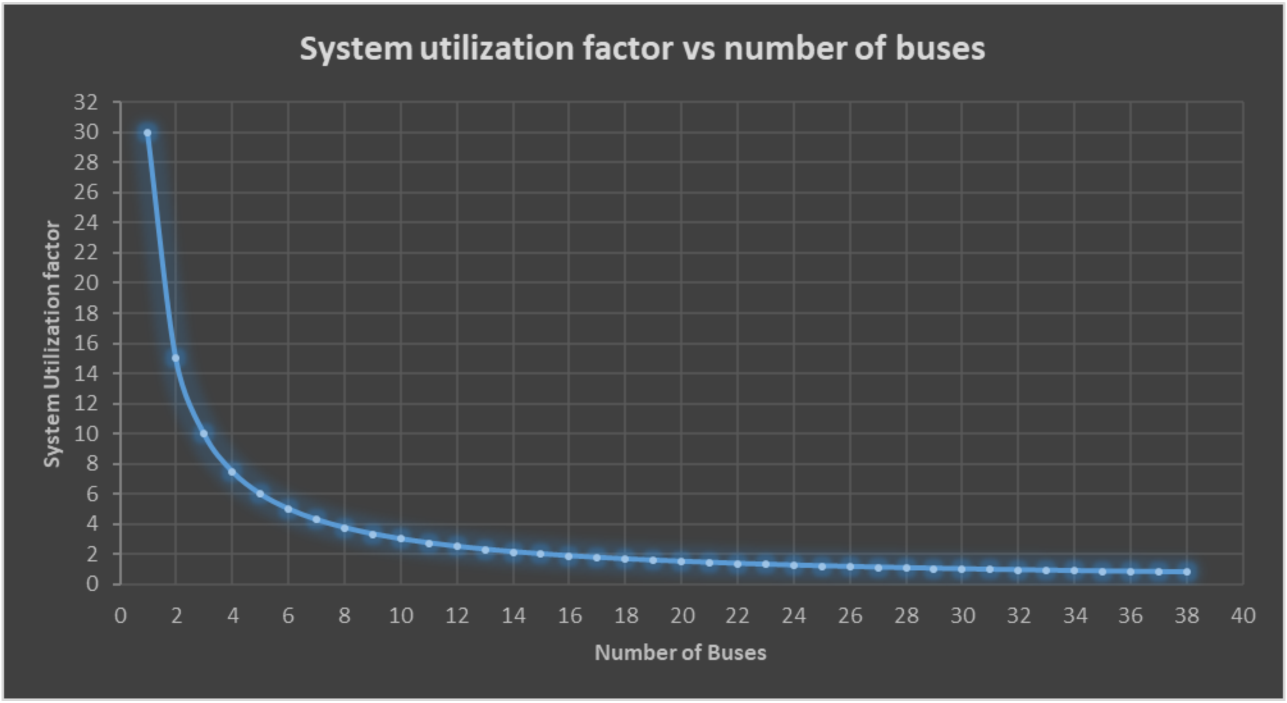


Figure 12 System utilization factor with fixed number of buses to 25

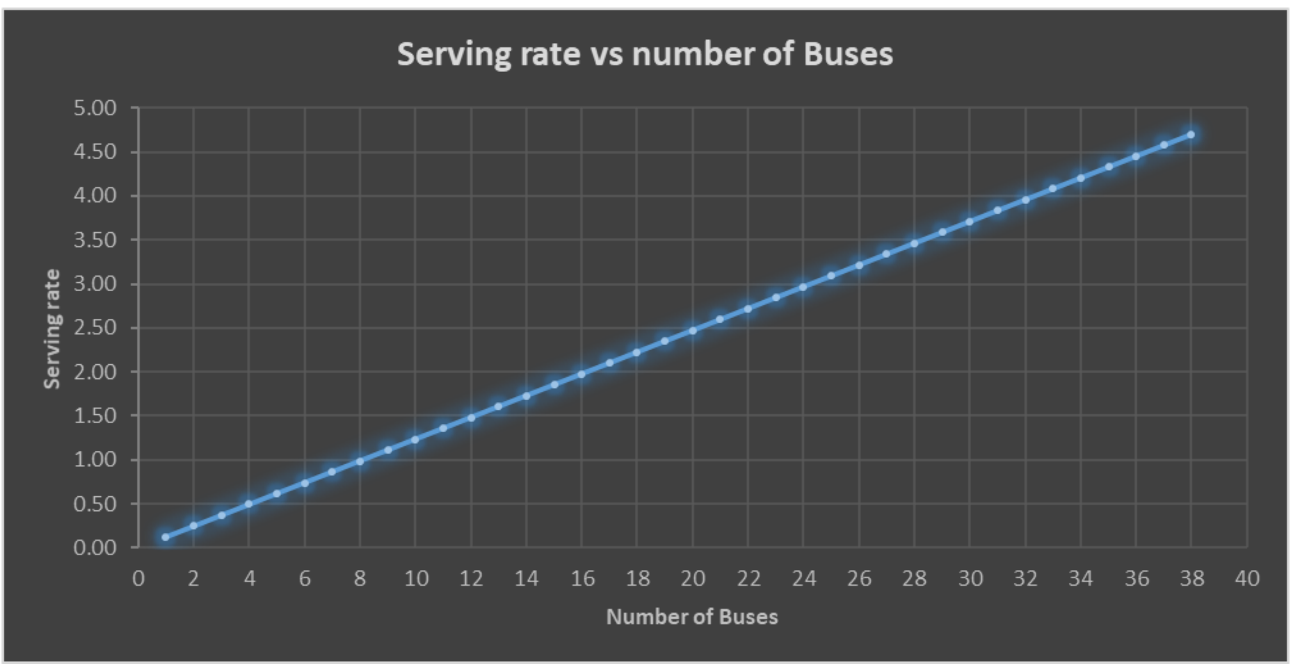


Figure 13 Serving rate with fixed number buses to 25

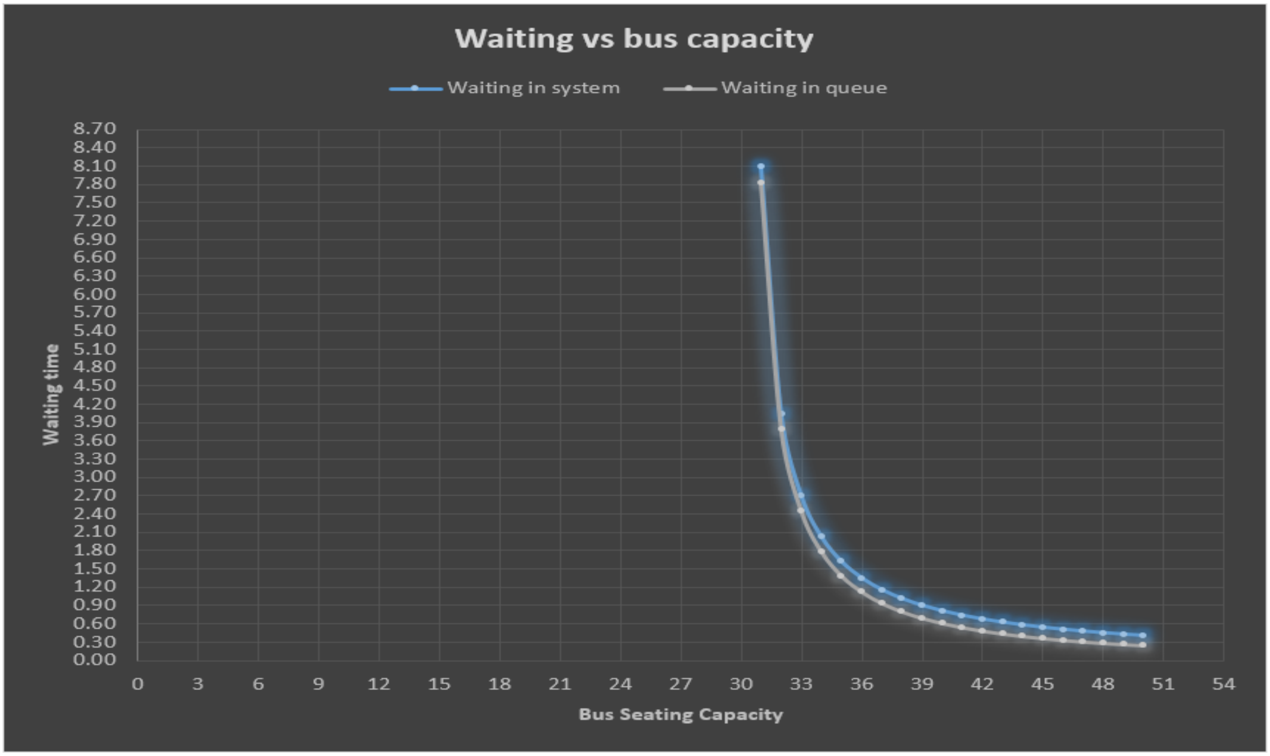


Figure 14 Average waiting in the system and in queue with fixed number buses to 25

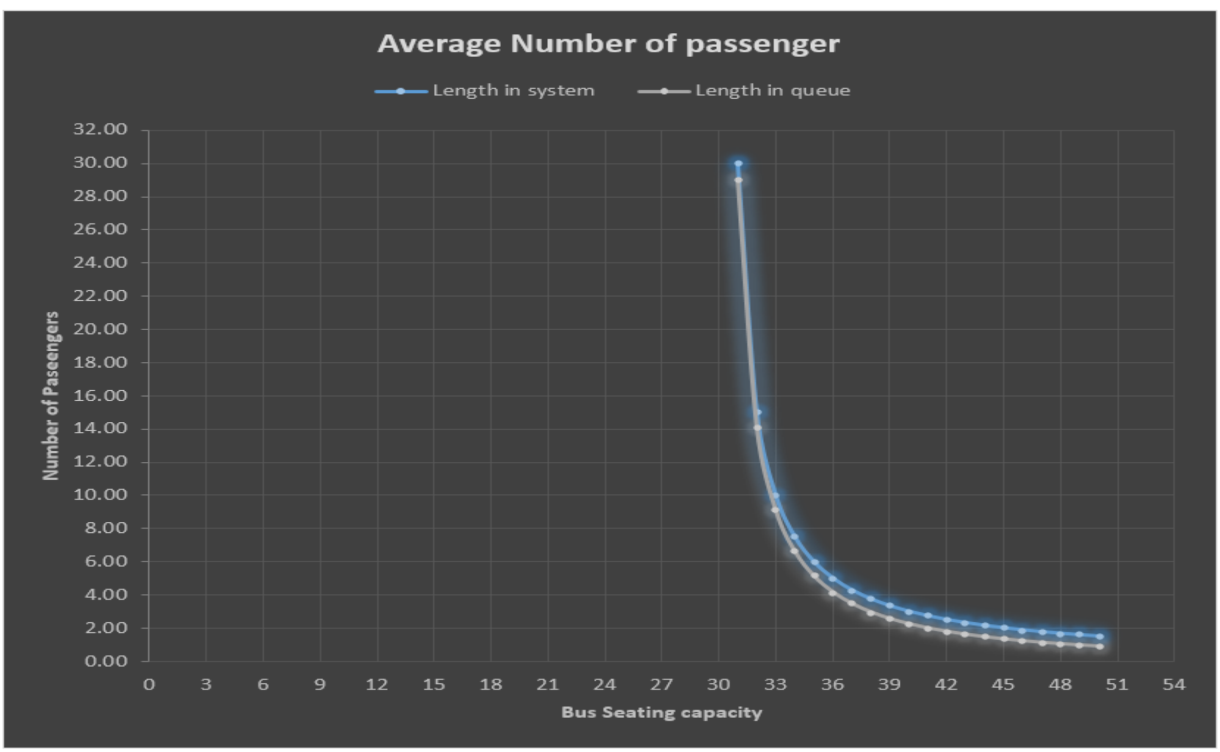


Figure 15 Average passenger length in the system and in queue with fixed number buses to 25

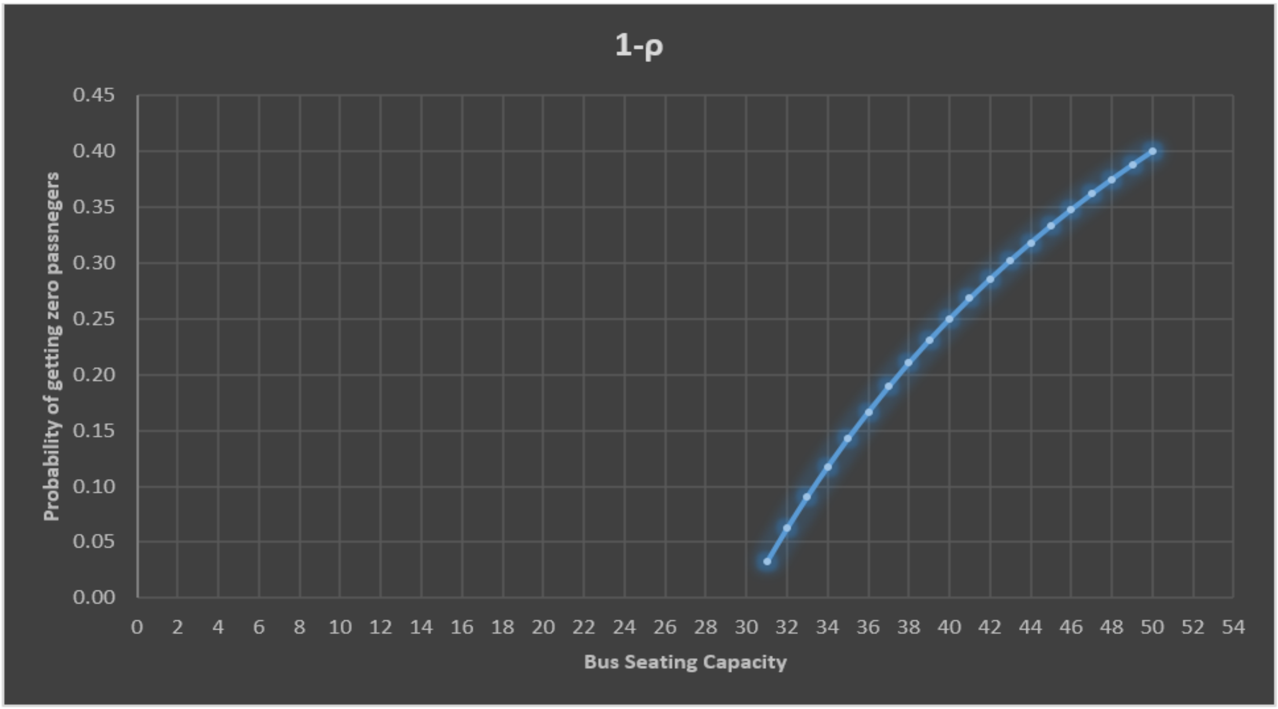


Figure 16 Probability of getting zero passengers in the system.

The higher the number of seating capacity per bus the higher the probability to have zero passengers in the system. It means that with 25 buses, with arrival rate of 3.71 passengers per minute with traveling time and other delays considered constants, a system with seating capacity of 30 seats will have 0% of getting the system non-occupied whereas it is varying to, 25%, 30% and 40% when increases to 40, 43, 50 seats respectively.

Comparison of the systems.

Parameters	Value for existing system	Value for new system
Bc (seating capacity for one bus)	30.79	From 31 to 37
T (average travelling time between two terminals in minutes)	37.65	37.65
WB(Average Boarding Time in minutes)	13.92	13.92
Tμ=T+WB (Average Boarding time &travelling time in minutes)	51.57	51.57
λ (average passengers arrival rate)	3.71	3.71
N (number of Buses allocated to the line)	20.67	25
Headways (in minutes)	6.3	From 4.13 to 2.71
μ , Serving rate (number of passengers per minute)	3.68	From 3.81 to 4.58
Average waiting time (in minutes) in system	27.65	From 8 to 1.2
Average number of passengers in system per minute		from 29.99 to 4.29
Utilization factor	Always above 100%	From 97% to 64.5%

Table 13: Comparison of the systems

5.3.3 New system efficiency description

The system efficiency is the condition of the stability and this must be less than 1or 100% to have the system that functions in a better way.

The higher the system utilization the higher waiting in another word the service rate becomes very low and hence the congestion.

Though, we have not studied the financial impact of the system, by limiting the new system to perform in a range of 80% to 97% for average utilization factor, the average seating capacity ranges from 31 seats to 37 seats while the number of buses is 25.

Bc	Wh	Period of Servic e	Number Served Passenger s	µ	P	Lengt h in system	Lengt h in queue	Waitin g in system	Waitin g in queue	1-ρ
31	4.1	202.2	775	3.83	0.968	29.99	29.02	8.08	7.82	0.03
32	4.1	202.2	800	3.96	0.937	15.00	14.06	4.04	3.79	0.06
33	4.1	202.2	825	4.08	0.909	10.00	9.09	2.70	2.45	0.09
34	4.1	202.2	850	4.20	0.882	7.50	6.62	2.02	1.78	0.12
35	4.1	202.2	875	4.33	0.857	6.00	5.14	1.62	1.39	0.14
36	4.1	202.2	900	4.45	0.833	5.00	4.17	1.35	1.12	0.17
37	4.1	202.2	925	4.58	0.811	4.29	3.47	1.16	0.94	0.19

Table 14 Optimized system for PTS at Kimironko-Town line

The average waiting time ranges from 8 to 1.2 minutes and 7.8 minutes to 0.94 minutes for system and queue respectively.

The average number of passengers ranges from 29.02 to 3.47 in queue and from 29.99 to 4.29 in the system.

We have determined that the serving rate (µ) is between 3.83 and 4.58 passengers per minute, which is greater than arrival rate of (λ) 3.71 passengers per minute.

The probability of having no passenger at queue (Po) in existing system is 3% while for the new system, this range from 3% to 19%.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

In our research, we have assessed the arrival rate and waiting time for the passengers attending Kimironko-Town line.

Considering all factors stated in this research project; among others including, FIFO, bus seating capacities of 29 and 70 as recorded during field data collection, etc; the finding showed that the existing system has a serving rate that is less than the passengers arrival rate. The later leads to system congestion or causing to have always presence of passengers on the queue.

We have observed that the serving rates and number of buses are related and the higher the number of buses allocated to the line the more the system serves.

Given that our project's main aim was to propose, based on the queue theory an algorithm that optimizes the waiting time at Kimironko-Town line; we have come up with a new system with the serving rate from 3.83 to 4.58 passengers per minute with average bus seating capacity from 31 to 37 seats. The headways for new system is constant of 4.11 minutes and the average waiting time and length of passengers have improved compared to the existing system. Which leads to the conclusion of rejecting our null hypothesis and therefore confirming the alternative hypothesis stating that the proposed system optimizes the waiting time and number passengers on queue for Kimironko-Town line.

RECOMMENDATIONS

- To the CoK, RURA and PTSP to introduce a bus rapid service that will optimize the time spent at bus stop in order to reduce the travelling time between terminals.
- To CoK & RURA to introduce dedicated public transport lanes in near future so that the time spent in traffic jam may be reduced hence the waiting time in return as well.
- To PTSP, to increase or adjust the big buses and coasters to have the number as per the suggested new system.
- To future researchers, the present research has not consider the case of pricing system, we recommend other researchers to conduct a research in the fare pricing model that can be associated to the new system in order to balance on the service cost and PTSP requirements patterning in.

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