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ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**



**IMPROVING ADDIS ABABA LIGHT RAILWAY TRANSIT SERVICE
USING QUEUE THEORY AND MONTE-CARLO SIMULATION
MODELS: CASE OF TORHAILOCH AND LIDETA STATIONS**

**BY
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Fulfillment of the Requirements for the Degree of Master of
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Declaration

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ABSTRACT

One of the main problems of Addis Ababa light railway transit service is the congestion and extended waiting line. The waiting time of passengers took on average 17 minutes, greatly reducing the satisfaction of customers. This is the reason why the study set the main objective to develop an optimization model for improving the service of AALRT station. As part of the approach to achieve this objective, the study first developed the characteristics of the data to investigate the congestion problem. second, an optimization model developed on the selected station. And finally, the researcher designed an alternative model through comparing the performance and cost-effectiveness against the existing model.

The study adopted case study research methodology by taking the Torhailoch and Lideta metro station using combined Queuing Theory and Monte-Carlo simulation method. Moreover, the case studies were selected for the most congested station in the morning's and afternoon's peak hours. Based on this, primary data were collected from each station and secondary data were conducted from document and through interview.

The best fit probability distributions of the passengers were found to be uniform, binomial and negative binomial. These indicates that the congestion problem cannot be solved through Queue Theory and Markov Chain. Hence, the researcher optimized the problem by combining Queuing Theory and Monte Carlo simulation. The models output indicates that the congestion rate of AALRT in Torhailoch and Lideta are 109.13% - 115.76% and 116.18% -131.06%, respectively.

Therefore, it was found that adding two single tramcars could reduce the waiting time by seven minutes and the congestion by 95%. As well, the new model improved the profit by \$4,152.25 and \$3,623.22 per hour in the morning and afternoon, respectively.

Key Words: - Optimization, Queue Theory, Markov Chain, Monte Carlo Simulation, Waiting Time.

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LIST OF ABBREVIATIONS

AALRT - Addis Ababa Light Railway Transit
AAU - Addis Ababa University
AS - Accident Saving
ATM - Automated Teller Machine
BBC – British Broadcasting Corporation
CBD - Central Business District
CDE - Chemin de Fer Djibouti- Ethiopien
CDF/PDF - Cumulative or Probability Distribution Function
CPM – Critical Path Method
CREC - China Railway Engineering Corporation
ERC - Ethiopian Railway Corporation
FCFS - First Come First Served
FIFO - First In First Out
GIS - Geographic Information System
GTP - Growth and Transformation Plan
JMP - Joint Management Plan
K-S - Kolmogorov-Smirnov
KSI - Killing and Serious Injuries
LCFS - Last Come First Served
LIFO - Last-In, First-Out
LRT - Light Railway Transit
LRTPWC - Light Railway Transit Passenger Waiting Time Cost
MATLAB - Matrix Laboratory
MLIT - Ministry of Land, Infrastructure, Transport and Tourism of Japan
MRT – Mass Rapid Transit
OCC – Operation Control Center
PERT- Program Evaluation and Review Technique
RR - Round Robin
RT- Revenue from Tariff
SAS - Statistical Analysis System
SIRO - Service In Random Order
SSJ - Stochastic Simulation in Java
WWII - Second World War
VOT - Value Of saving Time
VSL - Value of a Statistical Life

CHAPTER ONE - INTRODUCTION

1.1 The Research Background

Addis Ababa is one of the metropolitans in Africa at the horn of the continent. The geographical coordinates the city is 9°1'48" North and 38°44'24" East and an average elevation of 2355m above sea level. The total area of the city is about 530.14 Km² and a population of 2,738, 248 according to the last census of 2007 and the population growth rate of 3.8% (Wondwossen 2011). However, according to United Nation population projection the current population of Addis Ababa is 4,794,000. The city is divided into ten administrative sub-cities and 99 Kebeles. Addis Ababa takes most of the economy and social development of Ethiopia. This economic and social development with population growth has created a significant demand for vehicles which is causing traffic congestions and costed about 5-8 million Birr per year (Wondwossen 2011).

This traffic congestion happened due to different modes of transport. The most common modes of transport are road transport, animal-powered transport, human-powered transport and recently the Ethiopian government-built light rail transit.

However, the increasing demand for Addis Ababa transportation has created long queues like vehicle traffic. This queue or congestion creates different problems. According to, Wondwossen (2011) states that traffic congestion is an ever-growing chronic problem in the transportation system soon after the invention and mass production of automobiles. All major cities, both in developed and developing countries, are faced problem of increasing travel demand due to economic and population growth. Traffic congestion directly affects commuters with increased travel time, excessive delay in a queue, increased fuel cost, delay for necessary appointment and job, loss in productive hours; and it indirectly affects the living standard and the environment as well. Hence, traffic congestion causes road users and cities to incur a significant amount of money for both economic and social costs.

The Ethiopian government decided to address the congested roads of the capital, Addis Ababa by commissioning a new urban metro, largely funded, constructed and run by Chinese institution. This Light rail transit (LRT) system is a lightweight mass transport system that uses rail-based technology, run on steel by electric city, that serve especially in urban area. LRT has opened up a new market for public transport users in Addis Ababa. It covers the transport demand untapped by other modes through solving the high traffic congestion. It is used as a means for solving existing public transport problems. At present LRT has become main transport in the city during peak hours and people are associating their life around the system (Abdlemalik 2017).

This AALRT serves an average of 97,002 passengers per day and the average waiting time is 17 minutes. The AALRT administration has long- and short-term plans to decrease the average waiting time to 10-12 minutes (Mesfin 2018). According to, Stoilova and Stoev (2016), Umanah and Undoh (2017) and Dickson et al. (2018), railway network companies often need to model and simulate to minimize the waiting time of their passengers. This need usually arise with the expansion or maintenance of infrastructure, or the addition of new tramcars on the existing rail.

Mala and Varma (2016) showed that queuing theory can be applied to determine optimum service by balancing the waiting time and the service cost. According to the best of the knowledge of the researcher, limited research has been done to clarify the AALRT service condition. However, the studies focused on the factors that led to the AALRT congestion, as well as the mismatch of service and demand. This gap has prompted the researcher to perform in-depth studies to analyze the optimization of service and cost in AALRT project using combined Queue Theory and Monte Carlo simulation methods.

1.2 Statement of the problem

Addis Ababa is one of the most congested cities with low quality of transportation service in Ethiopia. The waiting times of AALRT, Anbessa Bus, Sheger Bus and Higher Bus is 17, 86, 24, 20, 14 minutes respectively.

The cause of this traffic congestion in the city is due to the increasing mobility demand, economic activity and rapid urbanization (Mesfin 2018). As the capital city and major economic hub of the country, the annual population growth is estimated at 3.8% which has increased the demand for both public transport and private vehicles (Wondwossen 2011). The same study indicates that the high travel demand is expected to increase with an average of 0.87% per annum with 6.63% travel demand for 16 years starting from 2004 up to 2020.

AALRT entered service in 2015 and is severely overcrowded, making the trip uncomfortable and leading to long queues (Clélie 2018). The long queues are an indication of a mismatch between the available supply and demand.

During peak hours, it is impossible to enter and depart the train with ease and passengers complain of missing their stops (Meseret and Sebawit 2018). Such problems are particularly visible during peak hours but as the use of the AALRT becomes more common, the issues are starting to occur during off-peak hours (Wondwossen 2011). The queues associated with the AALRT during peak hours is illustrated in Figure 1 below.



Figure 1 Photo of passenger waiting line in Addis Ababa LRT

This mismatch of supply and demand is a typical example of congestion or queue problem (Anindita and Parimal 2015). With the increasing population, this problem is bound to get worse without intervention based on scientific analysis. In this research, quantitative methods will be used to prove that there is a congestion

problem in the AALRT and optimization models will be used to suggest improvements to the current service.

1.3 The objective of the study

1.3.1 General Objective

To develop an optimization model for improving the service of Addis Ababa light railway transit on Torhailoch and Lideta metro station.

1.3.2 The specific objectives of the study are:

- To characterize the collected data at Torhailoch and Lideta metro station of AALRT.
- To investigate the congestion problem in the boarding and alighting doors of AALRT at Torhailoch and Lideta station.
- To develop an optimization model for Torhailoch and Lideta metro station of AALRT based on the proved data.
- To analyze the existing and new optimization model by comparing their performance and cost-effectiveness at Torhailoch and Lideta station of AALRT on the west-east corridor.

Hence, the research should address the following questions

- What are the characteristics of the passengers, tramcar arrival of AALRT at the boarding and alighting doors of Torhailoch and Lideta station?
- Are the doors of Addis Ababa LRT is congested at Torhailoch and Lideta station?
- What is the optimum service for the Addis Ababa LRT at Torhailoch and Lideta station?
- What is the alternative model for the Torhailoch and Lideta station?

1.4 Scope and Limitation of the study

1.4.1 Scope of the study

The study will focus on improving the service of AALRT using optimization methods or techniques at Torhailoch and Lideta station. The main scope of the research is: -

- To develop an optimization model in Torhailoch and Lideta station based on direct data collection on each metro station.

- To consider the Torhailoch and Lideta metro station of the west-east corridor as a prototype for the application of the remaining station.
- This research studies only Torhailoch and Lideta station on the direction of Torhailoch to Lideta Route of west-east corridor. It did not undertake on the other direction of Lideta to Torhailoch stations due to non-availability of data.

1.4.2 Limitations of the Study

The limitations of the study include:

- Due to time constraint, the data collection was conducted only for two months,
- Only two critical stations have observed during peak operation hours.
- Due to the non-digital ticketing system of AALRT, and use of only two stations limit the application of discrete event simulation.
- The assumption of the study is to solve the two critical stations for the whole stretch.
- The cost analysis is undertaken only on the research period.

1.5 Research Significance

This research is mainly contributed to initiate researchers on the optimization of the service sector by establishing the foundation to explore the possibility of using and refining a realistic simulation model. This simulation model used for the synchronizations of complex, unstructured and evolving operations of simple service up to so many continuous production and service. The study can be used as an input for further research development to the optimization of the service and production sectors, especially in AALRT. Furthermore, the following are the main contribution of this research paper:

- I) It is expected to solve the congestion problem in the specified case study.
- II) The model can be used as a prototype for the development of optimization models for the rest of the section.
- III) It initiates further study by opening the data and essential information for future researchers.

1.6 Research Organization

The organization of this thesis is divided into five chapters as follows

Chapter One (Introduction): - This chapter gives an introduction to the optimization of the queuing problem in LRT. It states the research background, statement of the problem, research objective or aim of the study and research questions. Furthermore, it puts the scope of the study, research significance and contribution to the body of knowledge.

Chapter Two (Literature review): - This chapter consists of literature on the critical review of queuing problem-solving model with the type of transportation/ mode of transport, history, and type of railways transport, AALRT, literature survey on the application of optimization method, theoretical review and simulation tools and application in the optimization model.

Chapter Three (Research design and methods): - This chapter discusses the research material and methods of the study. It included data sampling, data collection methods, model development, and data analysis. It also clarifies how the objective of the research would be achieved.

Chapter Four (Analysis and discussion): - It discusses the result based on the input data, the perimeters, and software outputs. It also discusses a simulation model. Finally, the interpretation and summarization of the results or findings in graphical and tabular form will be presented.

Chapter Five (Conclusion and Recommendation): - This chapter states the conclusion based on the findings of the study and recommendations for further research based on the conclusions.

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

A literature review is a systematic identification, location, and analysis of documents containing information related to the research problem (Amin 2005). Hence, this chapter provides a critical review of the literature on the optimization model. It includes the theories to be used as well as the critical concepts of the study and their interrelationships.

According to Wondwossen (2011) traffic congestion is a travel time delay occur when the traffic demand for the road space exceeds the capacity. It also stated that road traffic congestion is an ever-growing problem and the global phenomenon of significant cities. Throughout the world, it was getting worse during the last decades, mainly due to the increasing population number and the growing economy of nations. This growing traffic accident resulted in detrimental effects on the performance of the road network, the traffic flow, the society, the national economy, and the environment.

In addition, the adverse effects of traffic congestion are considerable loss of travel time, higher fuel consumption, more vehicle emission and associated environmental and health impact, increased accident risk, stress and frustration on commuters and higher transportation cost. The Ethiopian government launched the Addis Ababa Light Rail Transport to address this problem, (Abdlemalik 2017).

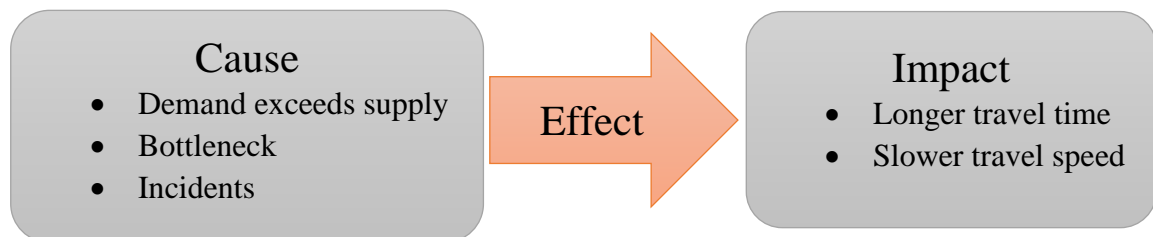


Figure 2 Conceptual framework of congestion's cause and impact

2.2 Transport

Transport is defined as the movement of people and goods from one place to another (Transport 2019).

2.2.1 Type of transportation (mode of transport)

According to Etim (2018), transports can be broadly classified into the following categories:

1. *Road transport* exists in all parts of the world, and this involves the use of motor vehicles (cars, Lorries, buses, bicycles, and trucks). Road transport is more flexible and relatively cheaper and faster. It carries goods over short distances.
2. *Railway transport* developed during the period of the industrial revolution in the 19th century for political as well as economic reasons. In many countries, they were built to penetrate isolated regions and to promote political unity. The significant advantage of railway transport includes the provision of reliable services to convey heavy and bulky goods. It is also very cheap, safe and comfortable for passengers over a long distance.
3. *Water transport* is the cheapest way of transporting bulky goods over a long distance by inland and ocean water transport. Inland water transport is the transport system through rivers, lakes and human-made canals. However, Ocean waterways transport is transport through ocean waterways from one country to another at the cheapest cost.
4. *Air transport* was introduced in 1903 but developed into full means in the 1930s and the Second World War (WWII). It used for both domestic and international flights.
5. *Pipeline transport* is the use of hollow pipes in the transportation of water, crude oil, (petroleum) and gas. It is safer and more efficient than tankers or trailers in liquids transportation.
6. *Other modes of transportation* are Animal-powered transport, Human-powered transport, Cable transport, and Space flight.

2.2.2 Railway transport

I. History of railway in the world

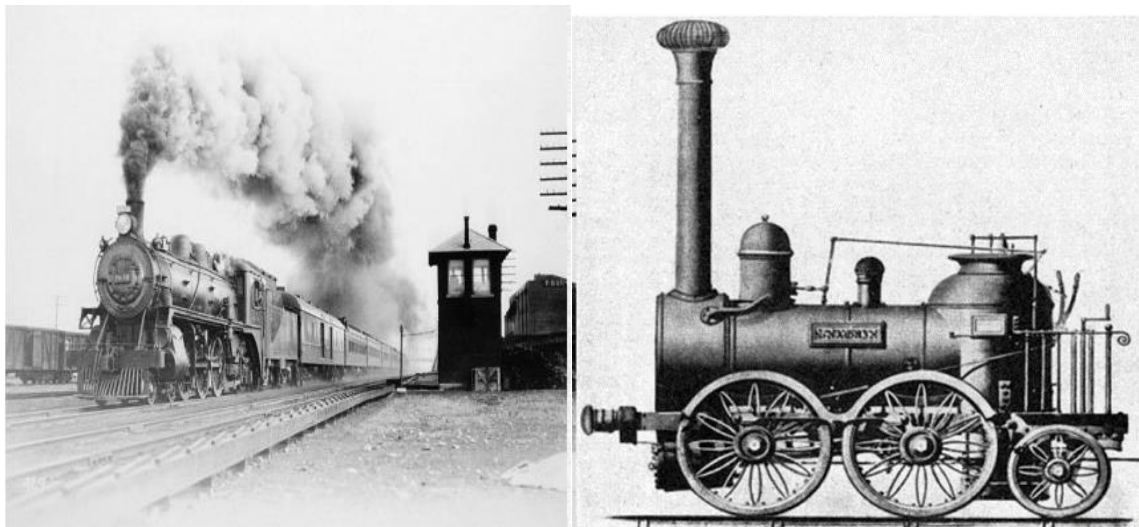
Lewis's define "railway is a prepared track which so guides the wheels of the vehicles running on it that they cannot leave the track". The history of Railways that fit the above definition existed as far back as the 6th century BC. It indicates,

the idea of a special track for hauling goods dates back about 2000 years. For example, Greek Diolkos was 6km stone made track across the Peloponnese, used for transporting ships until the 9th century AC (Coulls, 1999).

The modern railway started in England revolution in the 1830s by steam locomotives. The opening of the 48km (30 miles) double track line of metal rails of Liverpool-Manchester Railway in 1830 the world's first true and the prototype of the 'modern railway' (Coulls, 1999). It was a combination of track for the conveyance of passengers as well as freight, mechanical traction, and some measure of public control. It was constructed when the canal is not accessible, latter it became common when steam and rail technology became improved. This reality and development, the railway became the primary means of transportation of goods and labors (History of rail transport 2019).

In the second half of the 19th century, due to the arose of the industrial states with their contest for strategic advantage, economic fortune and imperial expansion, railways became a means to great power and status. The colonial railways in Africa, Asia and South America were thus an essential part of the spread around the world of the economic processes, ideas, and institutions of the European powers (Coulls, 1999). According to the story of Africa (2019), Railways in Africa was started in 1852 in Alexandria, Egypt and continued until the 1960s. The 1920s completed most of the main lines. They were hugely expensive to build, both in lives lost and financial cost. Most of them were government-owned and run.

Electric locomotive ware developed after more efficient steam power railways as compared to diesel, were available in the 1850s. In 1964, Japan introduced high-speed railways between Tokyo and Osaka with speed around 300km/h then it became common in Europe, North America, and Asia. Now a day, high-speed transport like Mass Rapid Transit (MRT) and Light Rail Transit became common in major cities of the world (History of rail transport 2019).



(a)

(b)

Figure 3 Railway transportation of the early 19th century (a) freight train (b) steam locomotive (Amen,2015)



(a)

(b)

Figure 4 World's recent (a) cargo and (b) high speed trains (Amen,2015)

II. History of railway in Ethiopia

Under the initiative of emperor Menelik II, Ethiopia became the second African country to build railway infrastructure at the beginning of the early 20th century with the help of France. This railway line extends from Addis Ababa to the red sea of Djibouti with a total length of 784 km. It is called Franco-Ethiopian railway, about 691 km is found in Ethiopia and the rest in Djibouti (Dawit 2014). According to CDE (2007), this rail line run from Djibouti to Addis Ababa through Harar, and then

to the White Nile, via Kaffa. It was believed that the rail would realize the access of foreign markets for gold, coffee, and ivory from the western part of Ethiopia. The construction of the railway started at Djibouti in 1887 and the track reached Dire Dawa in 1902. However, it was not extended to Addis Ababa until 1917.

First, the management was in the hand of France. However, in 1981, a treaty between the Ethiopia and Djibouti governments replaced the previous organization via the Chemin de Fer Djibouti- Ethiopien (CDE). The CDE track provided freight and passenger. It has been 100 years old one-meter gauge single track railway. And it was owned by the government of Ethiopia and Djibouti. It was representing the principal means of transportation between Addis Ababa and the port of Djibouti. Passenger traffic had been steadily increasing from 367,000 passengers in 1972 to 1,269,000 passengers in 1982/1983. However, freight traffic declined from 405,000 tons in 1972 to 237,000 tons in 1982/1983 (CDE 2007).



Figure 5 Ethio-Djibouti railway line (CDE 2007)

This Ethio – Djibouti Railway had the maximum permitted speed of passenger trains was 85 km/hr. However, for Freight and standard passenger trains, it was

50km/hr. The maximum axle loading on 20kg/m rail was 14metric tons and for 30kg/m was 18 metric tons. The Track was designed to accommodate a 14-ton axle load, even if loading characteristics varies with the gradients along the way. It also designed for the maximum bridge loading of 17 tons and maximum gradient of 2.7%. It had 996 curves out of which 79 were very sharp with radius of less than 200m. There are also 416 turnouts at station. Running repair and service facilities exist at Addis Ababa and Djibouti workshops, but most mechanical maintenance was undertaken at Dire Dawa.

The new modern standard gauge railway was launched in the five year 'Growth and Transformation plan' of Ethiopia in September 2010. It is a modern, high capacity, high speed standard gauge with electric traction railway system. It was a 5,000 km national railway network with 8 routes. The primary aim was to link the capital, Addis Ababa, to various regions of the country. The priority corridor of the GTP was the construction of a new standard gauge railway line from Addis Ababa (Sebeta) to Djibouti (Doraleh Ports) to replace the existing dysfunctional line. The estimated length was 756 km (656 km inside Ethiopia and 100 km inside the territory of Djibouti) (Amen 2015).

2.2.3 Type of railway transportation

There are three types of railway transportation system

- a. Conventional Rail Transit: - It is a railway system based on conventional or narrow-gauge trucks and trains. It is typically powered by diesel or electric city. It is the most common in developing countries (History of rail transport 2019).
- b. Mass Rapid Transit: - It is rapid transit, subway, metro, elevated or underground railway system. It used in an urban area with grade separation of the other traffic (History of rail transport 2019).
- c. Light Rail Transit: - It is a mass transport system that uses rail-based technology and typically operates in urban area. Vehicles are usually relatively lightweight, run on steel rails, and driven by overhead electrical wires (Abdlemalik 2017).

2.3 Addis Ababa Light Rail Transit (AALRT)

Addis Ababa is unsafe and hazardous city. This was mainly due to the expansion of the city, the increasing of average trip length of buses, the increased congestion on roads, aged fleet, and the chaotic movement of minibuses and taxis. In this case, the Federal Government of Ethiopia decided to develop a mass transport system. This mass transport would provide an alternative mode of transport to the passengers. Then on March 2008, Ethiopian Railway Corporation (ERC) took charge of LRT to launch the in the city. On March 2009, Minister of Transport signed with China Railway Engineering Corporation (CREC). After that, on July 2009, CREC presented the conceptual design and cost estimates. The loan agreement was signed with China Export-Import Bank in June 2011 and the contract for the construction was signed on September 2009 (Mohapatra 2015).

2.3.1 The main characteristic of AALRT

Based on the above classification, AALRT is a Light Rail Transit used to transport city passengers with minimum cost. It was constructed in the two main corridors of Addis Ababa.

AALRT is composed of two corridors. The first corridor is 17.26 Km from Torhailoch to Ayat of the east-west direction and the second one is 16.246 Km in the north-south direction from Menelik II Square to Kaliti. The total length is about 34.25 km and 2.662 km of mutual line.

It has 39 stations with a standard double-track gauge of 1.435 meters composed of tunnels, bridges and ground level. The minimum curve radius of AALRT is 50m for mainlines, 30m for a parking garage for horizontal curve and 1000m for vertical curve radius. It has up to 50‰ steep gradient and sharp curves. All the main and auxiliary tracks, including the depots, use 50kg/m steel rails with a cut-length of 25m (Tekle 2017).

The operational speed range is between 20 and 80 km/h with the maximum regression speed of a passenger train is 10km/h. It can serve up to 16 hours per day at 6 minutes' headway that can be reduced up to 90 seconds. AALRT's fare system is passenger-km, and it is operating to adopt manned visual driving. The

sleeper arrangement for the inside and outside the garages of rolling stock is 1,440 pairs/km but 1,600 pairs/km for main tracks (Tekle 2017).

The average acceleration for a startup would be at 1m/s^2 . In addition, the average deceleration for standard braking with rated load (including control response time) is more than or equal to 1.0m/s^2 . The emergency braking with rated load (including control response time) is more than or equal 1.5m/s^2 . The AALRT is environmentally friendly due to the fully electrified railway system. In addition to that, it has a battery with the capacity of support of a failed train for at least 30 minutes especially for the operation of the door, the emergency lights, the onboard equipment, and the communication system. The Map of rail lines and stations of the AALRT is shown below (Tekle 2017).

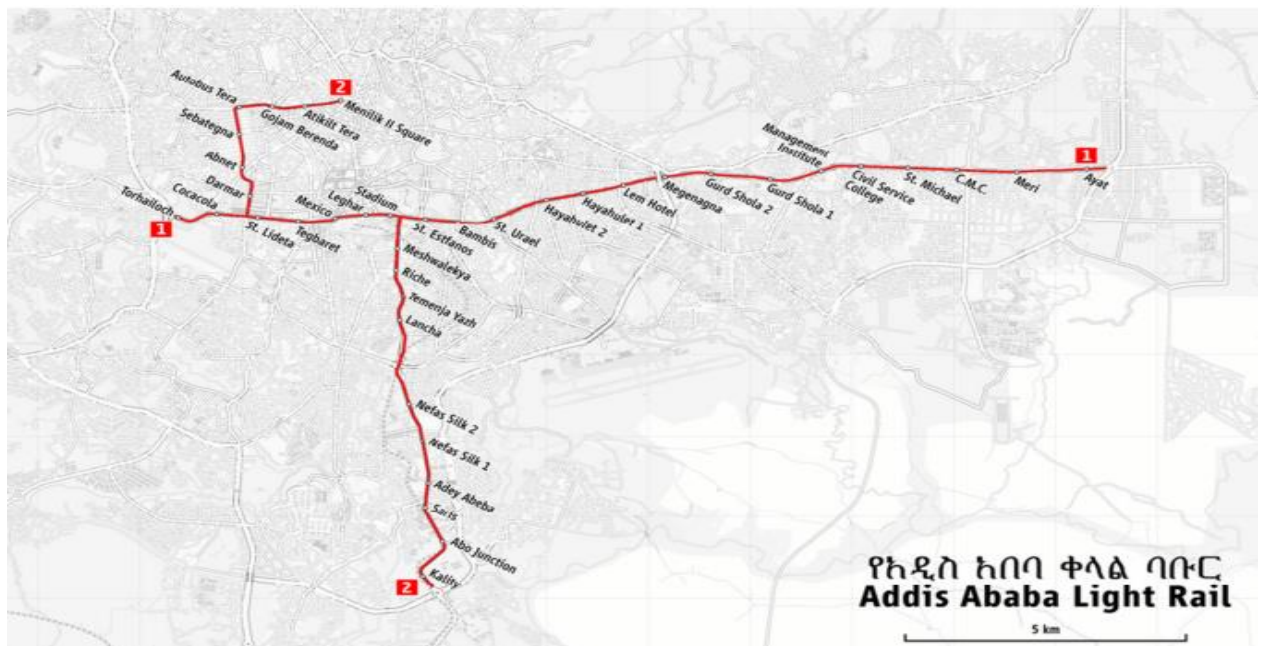


Figure 6 Map of rail lines and stations of the AALRT

2.3.2 Benefit of AALRT

In addition to mass transport for Addis Ababa dwellers, AALRT has the potential to open up a new market for public transport travel in Addis Ababa, which has largely remained untapped. Where demand can justify the volumes of patrons would naturally progression from a bus-based system to LRT (modal shift) may occur on defined line haul routes. Moreover, LRT is meant for solving existing

public transport system problems, if significant modal shifts towards urban public transport achieve.

The success of light railway along defined corridors is attributing to its modern, reliability and effectiveness in moving commuters, especially during peak periods to the central business district (CBD). Most commuters in the study area live in the suburbs due to the high cost of living in the CBD but need to transport to the CBD to work daily. The LRT system encourages people to plan their lives around the system with confidence, which ensures them with transport choices based on their availability. It also encourages businesses to develop along the routes, which in turn concentrates development, so that it become more effective serves by public transport and more user of the new technology.

2.3.3 Future of AALRT

Based on the statement of the problem, Queue is the main problem of AALRT especially at peak hours (Clélie 2018, Meseret and Sebawit 2018). This queuing is similar to the queue or waiting time occurs in heavy vehicle traffic, a busy grocery, ATMs, multistage production line performance, public hospital, supermarket checkout point, telephone traffic, business industry and so on (Anindita & Parimal 2015). The congestion creates the following problems in AALRT:

- large waiting time,
- low satisfaction of customers due to mismatch between the demand and the service,
- slower speed,
- longer trip time and so on.

2.4 Theoretical review

Theory is a conceptual framework for organizing knowledge and providing a blueprint for understanding and action. Discussion of some theoretical elements related to the study.

2.4.1 Model

According to Models and Modeling (2019), a model is a system that abstracts the reality or a representation of a real object or situation with more simplification. Modeling allows the user to understand the problem better and presents a means for manipulating the situation. This used to analyze the results of various inputs ("what if" analysis) by changing the set of assumptions. Modeling chosen due to the system does not exist physically, building a system is expensive, and the measuring is time-consuming. As per the book of AbouRizk, Hague & Ekyalimpa (2016), the accuracy of a model is depending on how well the model represents reality and the number of variables that dictates the outcome of the operation and the details of the process. This model applied on collection of entities called system. This system act and interact together toward the accomplishment of some logical end asper (Models and Modeling 2019, Law & Kelton 1991) and it can be graphical expressed as follow.

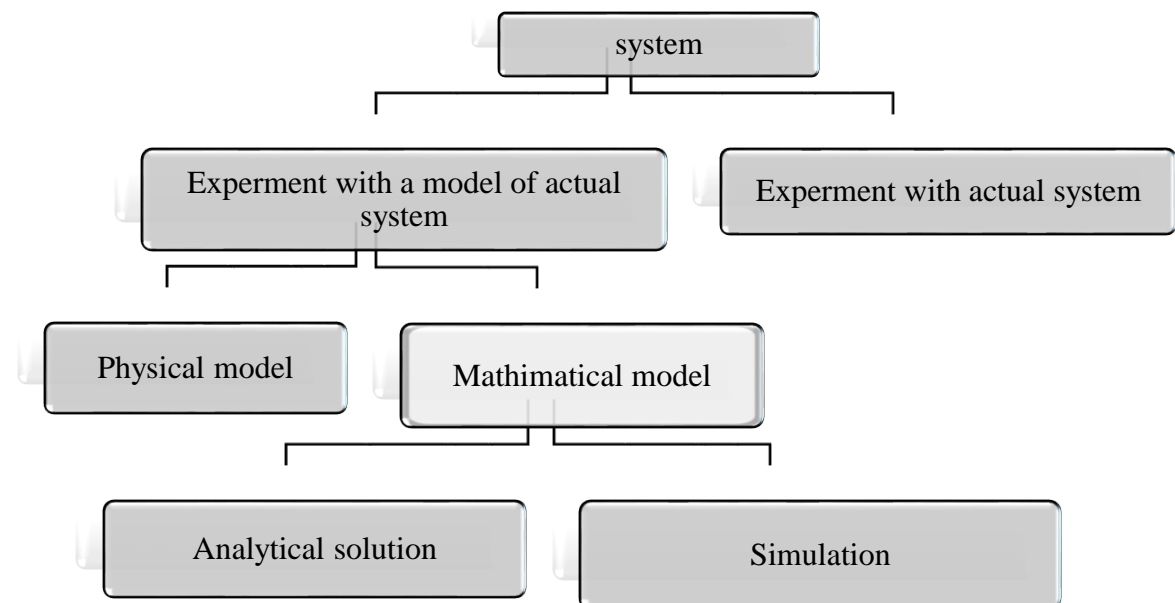


Figure 7 Systematic ways of approaching problem

The types of models are Physical model, Schematic model, Verbal model, and Mathematical model. Physical Model is a prototype of the finished object they represent. Schematic Models is the pictorial representations of conceptual relationships. Verbal Models use words to represent some object or situation that exists or could exist, in reality. Mathematical models are built using numbers and

symbols that transformed into functions, equations, and formulas. It can be description or optimization, deterministic or stochastic, and specific or general (Models and Modeling 2019). Mathematical model can also be static or dynamic when time is a significant variable and continuous or discrete when the system state evolves continuously or at discrete points in time (Law & Kelton 1991).

2.4.2 Simulation

Simulation is the imitating the performance of real-life in a controlled environment to estimate what would be the actual performance (Shanmugasundaram & Banumathi, 2016). Similarly, Ayichiluhum (2018) defines simulation as a representation of a real-world situation that provides a framework within which a given situation can be investigated and analyzed. It can be interpreted according to certain rules, provide information for the decision-making process and reflects the real world.

Banks et al (2001), A simulation is the imitation of the operation of a real-world process or system over time. It can be done by hand or computer to generate an artificial history of a system. It used to draw implications concerning the operating characteristics of the real system by using different “what if” questions. Simulation can also be used to study systems in the design stage. Thus, simulation modeling can be used both as analysis and design tool for predicting the effect of changes to existing systems and the performance of new systems under different scenarios respectively.

Simulation is numerically exercising the inputs of the model to see how they affect the output or performance. After a detailed design developed, a prototype model can be built and tested in actual flight to fine-tune the final design. Simulation typically used when the stochastic system involved is too complex to be analyzed through a mathematical model called queue models (Law & Kelton 1991 and Nafees 2017). Lastly, according to AbouRizk et al. (2016) simulation model is defined as the composition of objects that represent an abstraction of the system. The abstraction is generally in the form of concepts that describe the elements of the system. This systems' behavior determined by the modeler.

Generally, Law & Kelton (1991) stated that, to simulate a complex system, a detailed simulation model needs to be formulated to describe the operation. So, based on the study of Hillier & Lieberman (2001), this simulation model need to include several basic building blocks: like definition of the state of the system, identify the possible events that would change the state of the system, a provision for a simulation clock, a method for randomly generating the events, and formula form for identifying state transitions that are generated by the various kinds of events.

a) Type of simulations

Simulation divided in to two broad categories called discrete-event and continuous simulations (Hillier & Lieberman 2001).

- Discrete-event simulations used when the state of the system changes instantaneously at random points over time due to discrete events like LRT.
- Continuous simulation used when the system changes continuously over time like air plane flight.

b) Advantage and disadvantage of simulation

The advantage of simulation stated as follows (Banks et al 2001, and Oloufa 1992).

- It used to study the internal interactions of a complex system or subsystem
- It uses to simulate and observe different scenarios of information, organization, and environmental changes to provide alternate solutions to a problem of study and compare.
- It used to gain knowledge during the designing of a simulation model that gives the investigator an insight and enhances the comprehensibility of the system considered. This used to suggest improvement of the system under investigation.
- It used to change simulation inputs and to observe the outputs to know which variables are the most important and how variables interact. This enables the investigator to study an existing or planned system when subjected to different set of “what if” conditions before implementation.

-
- It used as an academic device to reinforce analytic solution methodologies especially for training make learning possible without the cost and disruption of on-the-job instruction.
 - It used to study too complex system that cannot be described in an analytical model like modern system (factory, wafer fabrication plant, service organization, etc.) to treat inter interactions.
 - It used to insight in to the interaction and importance of variables to the performance of the system.
 - It used to analysis bottleneck to discover where work in process, information, materials, and so on are being delayed excessively.
 - It helps to understanding how the system operates rather than how individuals think the operating system.

Disadvantage of Simulation is similarly stated as follows (Banks et al 2001).

- It is an art that is learned over time and through experience. Since reliable simulation modeling and analysis can be time consuming and expensive.
- The large amount of data produced after simulation may give misleading information about the simulation model's performance and validity. It can be difficult to interpret due to the randomness of most simulation variables.
- It requires a large number of simulations runs. Since simulation generally portrays the system's performance for a given set of conditions.
- It helps in selecting the best alternative from the standpoint of the model and its constraints, which is not necessarily to the optimum.

c) Application area of simulation

Oloufa (1992) state simulation is applicable to solve any problem. Similarly, Kelton et al (2002) stated, the main reason for popularity simulations application is its ability to deal with to complex system that made simulation versatile and powerful tool to the improvement in performance, flexibility, quick and valid decision-making tools". So according to Banks et al (2001) and Law and Kelton1 (991) simulation is applicable to the following area.

- To designing and analyzing manufacturing systems like semiconductor manufacturing
- For construction engineering and project management.
- To evaluating a new military weapons system or tactic.

- For designing and operating transportation facilities such as freeways, airports, subways, or ports.
- For Logistic, Supply Chain, Distribution of business process and determining ordering policies for an inventory system,
- For evaluating hardware and software requirements for a computer system
- For designing communications systems and message protocols.

2.4.3 Queuing Theory

Queuing theory is the art of solving a queuing problem through the probabilistic and stochastic model. It used to analyses the waiting time in real life like optimizing the clerks of railway ticket office (Umanah & Undoh 2017 and Dickson et al. 2018). A queuing problem can happen due to imperfect matches between the customers and service facilities like AALRT, (Meseret & Sebawit 2018). It compromises a decision to minimize the sum of the cost of waiting customers and idle facilities.

I. History of queuing theory

Erlang (1917), a Danish mathematician, developed queuing theory in telephone network congestion problems. He determines the probability of the different numbers of calls waiting with the waiting time, which assumed Poisson inputs from unlimited sources and exponential holding times. His work stimulus and formed the basis for the subsequent development of queuing theory (Queueing Theory 2019, Sztrik 2010).

II. Terminology in the waiting line system/queuing models

Input sources: - it is the calling population, that became potential customers to the system. Its size can be finite or infinite. The process of modeling the queue became easier if the calling population is finite. Most queuing models assume that the impute source as infinite (Hillier & Lieberman 2001). Input process is the random arrivals of customers. It represents the number of customers arrival during a time interval (Sztrik 2010). Therefore, based on the above two study input process is the arrival of customers in to the service area.

Queue: - The queue is a line that customers form to wait before being served. It characterizes by the maximum permissible number of customers. Queues are

called infinite or finite based on the customers is infinite or finite. The assumption of an infinite queue is the standard one for most queuing models, even if dealing with such population is a complicated factor in the analysis (Hillier & Lieberman 2001). However, for queuing systems where this upper bound is small enough it becomes necessary to assume a finite queue. Queues are part of everyday life like

- Waiting of people, machines, or other objects for service or products.
- Trucks waiting to unload or load, like excavator and loaders wait for the dump truck.
- Workers waiting for parts like mechanics wait to receive tools.
- Broken equipment waiting to fixed
- Labors at construction site queue for lunch, payment, etc.

Queue length: - It is the number of customers in the queue. It can be limited or unlimited customers (Taha 2007). Queue length states the serviceability of the server. Since, large queue indicates poor service facility and small queue indicates excess of service facilities (Shanmugasundaram and Banumathi 2016).

Arrival Process: - The arrival process or the inter-arrival times are how customers arrive in server. It is the input processes of a queuing system (Hillier & Lieberman 2001). It is the inter-arrivals of customers (Taha 2007). It can be stationary (deterministic /scheduled), independence (random) and orderliness. The stationery customers arrival happens when the probability of customers arrivals within a specific time interval like Doctor's office visits. Independence customer's arrivals happen when the arrival of one customer does not influence the arrival of another. The third one is orderliness customers' arrival is when one customer, at most, will arrive during any time interval. In many situations, customers arrive according to a Poisson probability distribution (i.e., exponential inter-arrival times).

The customer arrival processes concerning number and behaviors of customers

- One by one customer's arrival is the arrival of customers at the service center one by one.
- Batches customer's arrivals is the arrival of several customers simultaneously to the server to have simultaneous service

- Time-dependent customers' arrivals happen when the arrival rate varies according to the time of the day like AALRT passengers.

The arrival processes also have the following property for several customers allowed in the system.

Limited/finite population arrival happens when the service is unable to accommodate more than the required number of customers at a time. In this case, no further customers are permitted to enter until space became available to accommodate new customers (Taha 2007, Hillier & Lieberman 2001).

Unlimited/infinite customer arrivals are occurring when the service system can accommodate any number of customers at a time. For example, in the sales department, the receiving of customer's order has no restriction on the number that comes to the service area (Taha 2007, Hillier & Lieberman 2001).

The Behaviors of arriving customers: - the arrived customers in the services area could have the following attitude to the queue faced at the service area (Taha 2007).

- Patient customers are the customers who have the endurance to stay in the queue until served with no limitation.
- Impatient customers have the limited endurance to wait in the queue and live the system without gating the services.
- Balking is the behavior of customers who decide not to join the queue by observing the number of customers already in the system. They deciding to leave the queue before joining by the queue.
- Reneging is customers' behavior that leaves the queue, feeling that they are tired of waiting in the queue.
- Jockeying is another behavior of customers who re-join the queue which they had left earlier either by balking or by reneging.

Service mechanism: - also called service pattern is the way that customers receive service once selected from the front of the queue (Hillier & Lieberman 2001, Sztrik 2010). The service mechanisms have served customers in single or one by one or batch (Parimala 2008).

- Single or one by one service is the way server serves one customer at a time. See Figure 8 of single-channel and single-phase system
- Batch service; it serves several customers simultaneously.

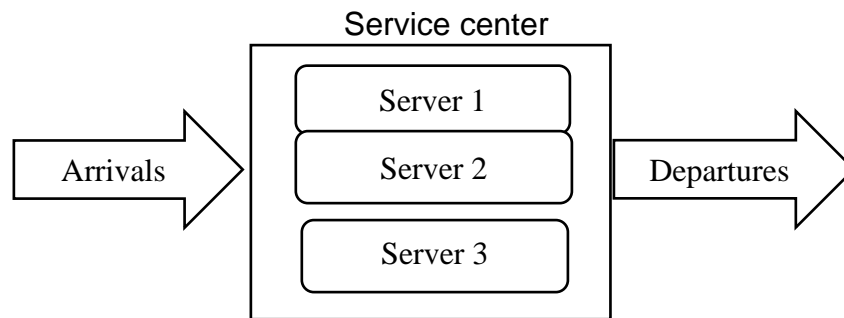


Figure 8 Batch servers.

- Service times: - it is the time taken by the server to serve the customers who join a queue (Taha 2007, Ghimire, Thapa & Ghimire 2017).

A particular queuing system has a probability distribution of service times for each server, although it is common to assume the same distribution for all servers. In most common case it assumed is the exponential distribution. Other principal service-time distributions are the degenerate distribution and the Erlang distribution. The Service times can be occurring as dependent on the queue length. For example, the processing rates of the machines in a production system can be increased once the number of jobs waiting to be processed becomes larger (Hillier & Lieberman 2001).

The Service Discipline: -the order of service given to customers. It can be First Come First Served (FCFS), Last Come First Served (LCFS), Service In Random Order (SIRO) and Priority Service. Some of the service facilities are as follows (Ghimire, Thapa & Ghimire 2017).

- First Come First Served (FCFS) also called "First In First Out (FIFO)". The server provides the service in the order of arrival. Generally, this method applied in the supermarket, billing counters, and many other queuing systems.
- Last Come First Served (LCFS) also called "Last-In, First-Out (LIFO)". In this case the last customers get service at first. It applied in the production line where the products are kept one over the other. Since the top item sold at first thought it is placed.

- Service In Random Order (SIRO) provide the service without any fixed rule like security checkpoints. The service provider collects data randomly for statistical studies.
- Priority Service is the way to serve some customers who need the service immediately for many reasons. Like the emergency in hospital and VIP.
- Processor Sharing is primarily applied in the communication system where computers divide their processing power equally over all the other computers like customers can get access to the internet from a single router.
- Round Robin (RR): - This method can be seen mainly in the cyclic queuing system in which either server or the customers move in a cycle. It experienced a revolving dining table where customers are stationary, but the server moves to carry different menu on the table (Ghimire, Thapa & Ghimire 2017).

The Service Capacity: - It is the amount of service provided at a time (Sztrik 2010). Channels are the paths or ways to go through the system after getting in the queue. To have excellent overall services, the combination of the arrival rate and service rate is critical. It used to determine the number of service channels and the design of the service mechanism determines the arrangement of the services (Hillier & Lieberman 2001). It has the following arrangement forms (Parimala 2008).

- Parallel channels are the arrangement of several channels providing identical service facilities to serve several customers simultaneously. It is a multi-server model since it has many parallel channels having one server for each channel.
- Series channels are also the arrangement of channels for customers to go through successive ordered channels before the services completed.
- The exceptional to those stated above is a single-server model that occurred when the system has only one server.

Phases are the number of stops a customer must make after getting in line. Single-phase when only one stop for service. Multi-phase when more than one stop for service line like order, pay and pick-up in different places.

III. Characteristics of the queuing system

The characteristics of queuing theory express by customer's arrival rates and service rates. The Arrival rate is the average number of customers arrives per time, and the service rate is the average number of customers that can serve during a period. Server can be a group of persons like a repair crew and it need not even be people. But it may be a machine, a vehicle, an electronic device, etc. In the same way, the customers may not be people rather it may be items waiting for a particular operation by a given type of machine, or they may be cars waiting in front of a tollbooth. The arrival population is not necessary to form a physical waiting line in front of a physical structure that constitutes the service facility rather it may scatter throughout an area like machines waiting to repair, bank service waiting through ticket number. The only essential requirement for queuing theory to be applicable is that changes in the number of customers waiting for a given service (Hillier & Lieberman 2001).

The service rate governs the capacity of the service system. When fluctuation in arrival and service patterns happened, it causes wait in the queuing system. The assumption in waiting line characters are (Taha 2007)

- customers arrive described by Poisson probability distribution, which specifies the probability that a certain number of customers will arrive in a given period
- Service times are described by an exponential distribution, which describes the service times as the probability that particular service time will be less than or equal to a given amount of time.

Customer's arrival process can be one of the following

- Stationary: for a given frame of time, the probability of arrivals within a specific time interval is the same for all time intervals of equal length.
- Independence: the arrival of one customer does not influence the arrival of another.
- Orderliness: one customer, at most, will arrive during any time interval.

IV. Combination of channel and phases

It is the arrangement of service facility either in parallel, in serious and in the combination of the two. This combination would form in the form of a single queue single server, single queue multiple servers with the arrangement of in parallel, in serious or in mixed services facility.

- a) Single channel-single phase is one way through the system and one-stop for the service.

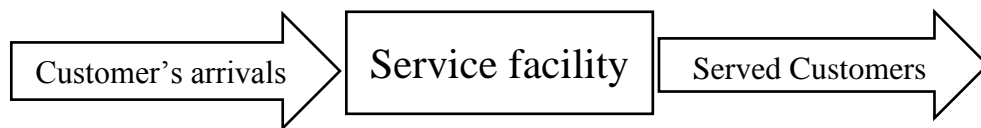


Figure 9 Single-channel and Single-phase system

- b) More than one single-channel and single-phase system. It has a different queue line but having a single-phase in line for each channel.

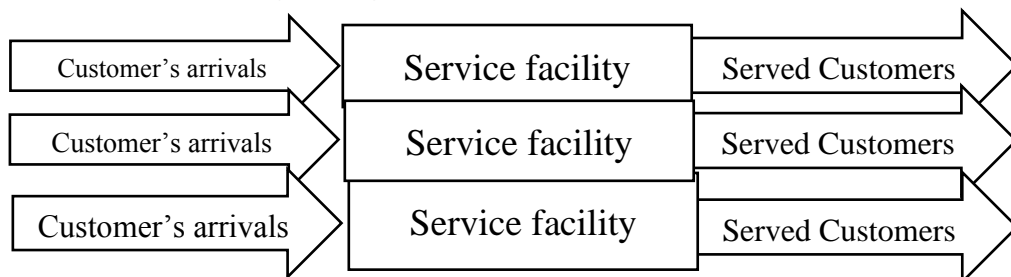


Figure 10 More than one single-channel and single-phase Systems

- c) Multi-channel but Single-Phase it has a single-phase but multi-channel with in the phases. So, in this case, once in line, customers have many possible paths through the system with one stop.

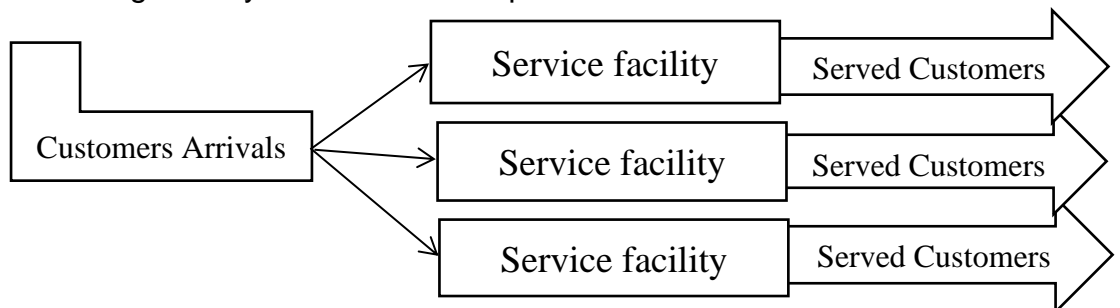


Figure 11 Multi-channel, Single-phase system.

- d) Multi-channel, Multi-phase it has more than one channeled, and if customers became once in line, they have at least two choices with at least two stops (phases).

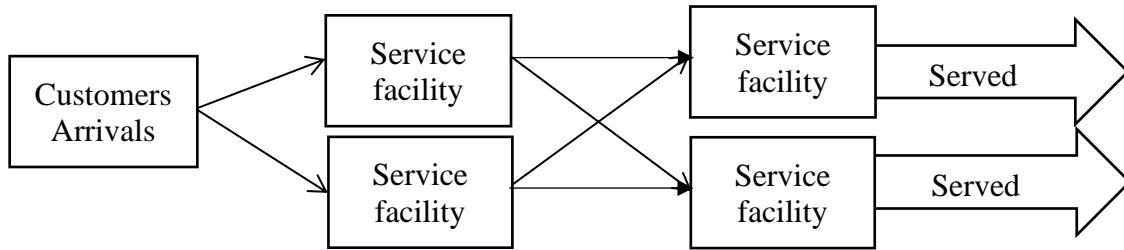


Figure 12 Multi-channel, Multi-phase system.

V. Queue model and its mathematical expression of performance measurement

As stated in the above model is the representation of the real object, situation, or system. Hillier & Lieberman (2001) stated that a queuing model is a mathematical description of a queuing system which makes some specific assumptions about the probabilistic nature of the variables' variable are the arrival and service processes, the number and type of servers, and the queue discipline and organization. There are countless possible variations, but some queuing models widely used. For these models, there are mathematical expressions that enable the fast calculation of various performance measures. These expressions help to design a new service system or improve an existing one.

So, the queue model is the mathematical representation of the queue problem in a specific area. In addition to that, the queuing model is an optimization model for different service stations and production systems to minimize the cost and to maximize the profit using limited resources (Ghimire et al. 2017). All in all, queuing models can be advantageous in identifying appropriate levels of staff, equipment, and beds as well as in making decisions about resource allocation and the design of new services. This queue model measure at the steady-state condition.

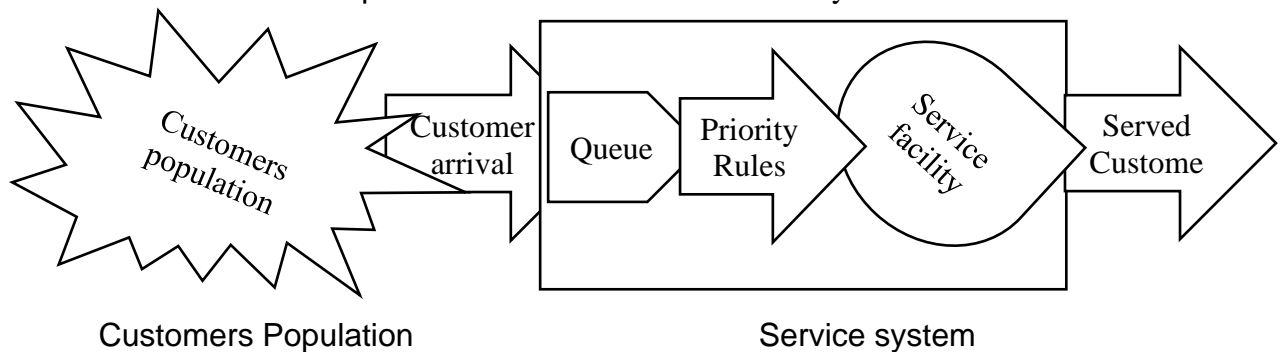


Figure 13 Queue model.

Queuing models is analyzing queuing systems by an understanding of the appropriate service measurement. This model includes customers who are waiting plus and the customers in the service. This model can be static when it controlled by the arrival rate of customers and dynamic if both the service facility and customers control it. Most of the queue models assume that all inter-arrival times and service times are independent and identically distributed (Hillier & Lieberman 2001). Such models conventionally are labeled as follows:

$$(a/b/c): (d/e)$$

Where,

a = arrivals distribution. (If Poisson arrivals or exponential service time = M).

b = service time distribution. (Exponential = M)

c = number of servers

d = maximum number of customers allowed in the system

e = queue discipline

Where: -

M (Markovian) = Poisson arrivals or exponential distribution,

D (Deterministic) = degenerate distribution (constant times) of arrival rate or service time,

E_k (Erlang) = Erlang distribution (shape parameter = k),

G (General) = general distribution for arrivals or service time,

Performance measures of the queuing system are the measure of the serviceability of the system as a whole, and it can be express by the customers in queue and customers in the system. In addition, the performance measures are the measurement of the system in a steady state.

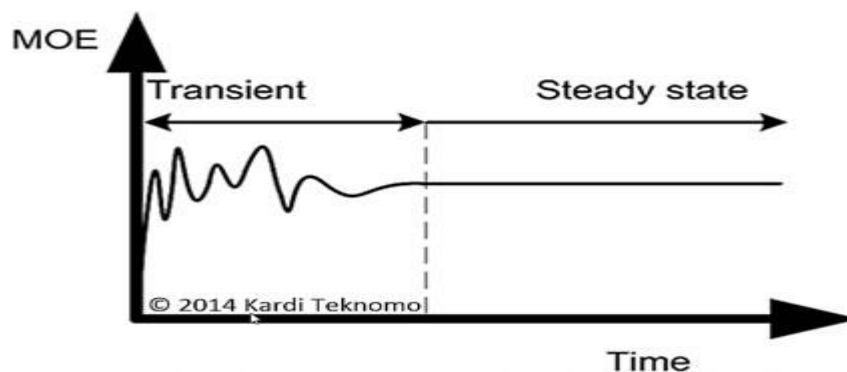


Figure 14 The graph of performance measurement of a queue system (kardi 2019)

From the above graph of performance measure for the queue system, the transient period occurs at the initial time of operation. This initial transient behavior is not indicative of long-run performance. However, long-run performance measures can be calculated for the system when it is in a steady-state since queuing performance is the measure of effectiveness in operation research. The steady-state condition occurs when the probability distribution of the state of the system remains the same (the steady-state or stationary distribution) over time. So, in the steady-state, the valid arrival rate (λ) must be less than the sum of the useful service rates (μ) (Hillier & Lieberman 2001).

Terminology and Notation

State of system = number of customers in the queuing system.

Queue length = number of customers waiting for service to begin (state of system minus number of customers served).

$N(t)$ = number of customers in queuing system at time t ($t = 0$).

$P_n(t)$ = probability of exactly n customers in the queuing system at time t given a number at $t = 0$.

S = number of servers (parallel service channels) in the queuing system.

λ_n = mean arrival rate (expected number of arrivals per unit time) of new customers when n customers are in the system ($1/\lambda$ = Mean inter-arrival time).

μ_n = mean service rate for the overall system (expected number of customers completing service per unit time) when n customers are in the system ($1/\mu$ = Mean service time).

P_n = probability of exactly n customers in the queuing system.

L = expected number of customers in the queuing system.

L_q = expected queue length (excludes customers served).

W = waiting time in system (includes service time) for each customer.

W_q = waiting time in queue (excludes service time) for each customer.

ρ = Traffic intensity = Mean rate of arrival (λ) / mean rate of service (μ). It is the probability of arriving customers must wait for the service

Relationships between L , W , L_q , and W_q and interpretation of Traffic intensity

Through rigorous work of Little on Operations Research published in 1961, the following relationship developed for the above steady-state performance measurement.

- $L = \lambda W$
- $L_q = \lambda W_q$
- $W = W_q + \frac{1}{\mu}$
- If $\rho > 1$ system is overloaded (queues form) and if $\rho < 1$ system not overloaded (no queues).

Queuing models based on the birth-and-death process

The birth-and-death process is the assumption of the inputs (arriving customers) as “birth” and outputs (leaving customers) as the “death” of the queuing system. It means in the context of queuing theory, the term “birth” refers to the arrival of a new customer into the queuing system, and “death” refers to the departure of a served customer. It also assumed that individual births and deaths occur randomly, where their mean occurrence rates depend only upon the current state of the system. The main content of the birth-and-death process is the rate in and rate out are equal. It means for any state of the system n ($n = 0, 1, 2, \dots$), mean entering the rate and mean leaving rate are balanced. These models are said to have a Poisson input and exponential service times, and it has four essential types of queuing systems, as stated below (Hillier & Lieberman 2001).

M/M/s Model

In this model, it assumed that all inter-arrival times are independently and identically distributed according to an exponential distribution (i.e., the input process is Poisson), that all service times are independent and identically distributed according to another exponential distribution, and that the number of servers is s (any positive integer). Consequently, this model is the particular case of the birth-and-death process where the queuing systems mean arrival rate and

mean service rate per busy server are constant (λ and μ , respectively) regardless of the state of the system.

When the maximum mean service rate $s\mu$ exceeds the mean arrival rate λ that is when $\rho = \frac{\lambda}{s\mu} < 1$, a queuing system fitting this model will eventually reach a steady-state condition. In this situation, the steady-state results derived for the general birth-and-death process are directly applicable for each case stated below for steady-state performance measurement.

Case 1: - Single server (M/M/1)

It is a simple model of birth and death process with the following interpretation on the notation with their order.

- Poisson distribution of arrivals with a mean arrival rate of (λ).
- Single server with an exponential distribution of service time (μ).
- Single server.

The performance measurement of this system would be express as follows...

$$\begin{aligned}
 & \color{red}{+} P_0 = 1 - \frac{\lambda}{\mu} \dots\dots \text{and} \dots\dots P_n = [1 - \frac{\lambda}{\mu}] (\frac{\lambda}{\mu})^n \\
 & \color{red}{+} w = \frac{1}{(\mu - \lambda)} \dots\dots \text{and} \dots\dots w_q = \frac{\lambda}{\mu(\mu - \lambda)} \\
 & \color{red}{+} L = \frac{\lambda}{(\mu - \lambda)} = \lambda w \dots\dots \text{and} \dots\dots L_q = L w_q
 \end{aligned}$$

Case 2: - Multiple-server (M/M/k)

It is the same as case 1, but the number of servers (s) is more than one, ($s > 1$) and their corresponding performance measurement of this system would be express as follows...

$$\begin{aligned}
 & \color{red}{+} p_0 = \frac{1}{\sum_{s=0}^s \frac{1}{s!} (\frac{\lambda}{\mu})^s + \frac{1}{s!} (\frac{\lambda}{\mu})^s (\frac{s\mu}{s\mu - \lambda})} \dots \text{and} \dots P_n = \frac{(\lambda/\mu)^n}{n!} P_0 \text{ for } n \leq s \text{ but } P_n = \frac{(\lambda/\mu)^n}{s! s^{n-s}} P_0 \\
 & \text{for } n > s \\
 & \color{red}{+} W = \frac{(\lambda/\mu)^n}{(s-1)!(s\mu - \lambda)^2} P_0 + \frac{1}{\mu} \dots\dots \text{and} \dots\dots W_q = \frac{(k\rho)^s}{s!(1-\rho)^2 s\mu} P_0 \\
 & \color{red}{+} P_w = \frac{1}{s!} (\frac{\lambda}{\mu})^s (\frac{s\mu}{s\mu - \lambda}) P_0 \dots\dots \text{and} \dots\dots \rho = \frac{\lambda}{s\mu}
 \end{aligned}$$

$$L = \frac{\rho(s\rho)^s \mu}{s!(1-\rho)^2} P_0 + \frac{\lambda}{\mu} \dots \dots \dots \text{and} \dots \dots \dots L_q = \frac{\rho(s\rho)^s \mu}{s!(1-\rho)^2} P_0$$

M/M/s/K model with finite queue variation

It is the particular case of the M/M/s queue model of the birth and death process. In this case, any customer that arrives while the queue is "full" is refused entry into the system and so leaves forever. That means the mean impute rate of any customers became zero at this time when the total number of customers' reach k value.

Mathematically it is express as $\lambda_n = \begin{cases} \lambda, & \text{for } n = 0, 1, 2, \dots, k - 1 \\ 0, & \text{for } n \geq k \end{cases}$ this means after

k customers there is no arrival of the customer in the queue.

The other case Birth-and-death process assumption of queue model is Single server with a finite population (M/M/1/k), Multiple-Server with finite population (M/M/s/k) when (s>1), Single server with finite calling population variation (M/M/1), Multiple-server with finite calling population variation (M/M/s) with s > 1, Single-server with state-dependent service rate and/or arrival rate (M/M/1) and Multi-server with state-dependent service rate and/or arrival rate (M/M/s) with s > 1. In addition to that when the queuing models involving non-exponential distributions, the model became M/G/1 Model, M/D/s Model, M/E_k/s Model, Models without a Poisson Input and Priority-discipline queuing model (Hillier & Lieberman 2001).

Queuing networks are networks of service facilities where customers must receive service at some of or all these facilities. It is mandatory to study the entire network to obtain the expected total waiting time, the expected number of customers in the entire system, and so forth. Under equivalence, the property is that if the customers must then go to another service facility for further service, this second facility also will have a Poisson input (Hillier & Lieberman 2001). The two types of queue networks are;

- a) Infinite queues in series; it is the arrangements of more than one server in serious, and all phases of server have an infinite queue of customers.
- b) Jackson networks; it used when customers in arranged in serious, and the customers on servers can be both from the previous servers and the outside sources according to a Poisson distribution process. The

characteristics of a Jackson network are the same as the infinite queue in series for the system of infinite queues in series, except now the customers visit the facilities in different orders (and may not visit them all).

A Jackson network is a system of service facilities where the facility has

- an infinite queue
- customers arriving from outside the system according to a Poisson input process
- servers with an exponential service-time distribution

VI. Cost of queuing system

The Cost of a queuing system express as the costs of waiting time in line in one hand and the cost of providing service in hand (Mala and Verma 2016). The cost of waiting line should be paying idle employees while they are in line waiting for something they need (waiting for parts, supplies, deliveries, etc.), nonproductive equipment awaiting repairs and losing customers because of long lines, etc. However, the cost of providing service expressed as paying people to service the customers in line and the cost of offering the services (Hillier & Lieberman 2001).

Therefore; based on the above literature, queuing problems is a compromise decision to minimize the sum of the cost of waiting customers and idle facilities. It means queuing problems is a compromise in the cost of offering the services and costs incurred due to delay in offering services or customer is waiting time cost. So, according to Hillier & Lieberman (2001), the objective of queuing theory is minimizing cost of service and waiting time for service. Thus, the mathematical statement of the objective is to minimize $E(TC) = E(SC) + E(WC)$.

Where: -

- WC denotes waiting for cost,
- SC denotes service cost, and
- TC denotes total cost.

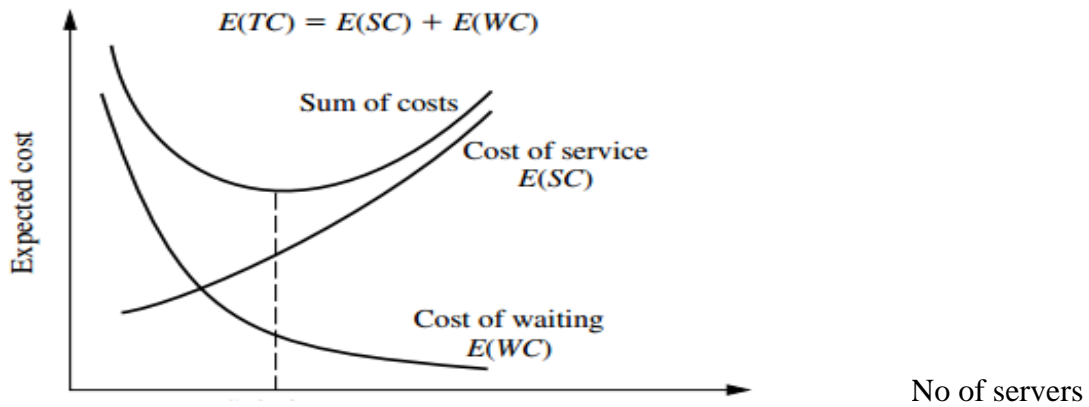


Figure 15 Sum of cost of service and cost of the waiting line

2.4.4 Markov chain

The Markov chain, like queue theory is used for decision making in the face of uncertainty about future events. However, Markov chain used to make decisions of future events. It became the choices for this broader context and also for the processes that evolve probabilistic manner called stochastic processes (Hillier & Lieberman 2001).

Markov chains have the unique property. Its solution to the future depends only on the present state of the process, and so are independent of past (Taha 2007). In other words, Markov chain should have Markovian property with the conditional probability of any future “event,” given any past “event” and the present state $X_t = i$, is independent of the past event and depends only upon the present state. The main drawback of this optimization model, the data should be Poisson arrivals distribution and binomial service distribution (Taha 2007, Hillier & Lieberman 2001).

2.4.5 Monte Carlo simulation

Many quantitative problems in science, engineering, and economics are nowadays solved via statistical sampling on a computer through Monte Carlo methods. It can use in three different ways like to generate random objects and processes to observe their behavior, to estimate numerical quantities by repeated sampling, and to solve complicated optimization problems through randomized algorithms. When the mathematical complexity faced optimization problems,

Monte Carlo simulation became the usual method of examination for frameworks including line disciplines other than first-come-first-served, (Choi & Radharamanan 2017).

i. Generating Random number

The heart of any Monte Carlo method is a uniform random number generator procedure that produces an infinite stream U_1, U_2, \dots of random variables that are independent and identically distributed in the interval $(0, 1)$. Since such random numbers usually produced via deterministic algorithms, they are not genuinely random; instead, it is pseudorandom numbers. However, for most applications, all that is required is that such pseudo-random numbers are statistically indistinguishable from genuine random numbers, which are uniformly distributed on the interval $(0, 1)$ and are independent of each other. In addition to that, it repeatedly runs to obtain the distribution of an unknown probabilistic entity (Bihani 2014).

The number of data or the appropriate sample size used to conduct the specific research will determine the certainty of the study. Thus, the accuracy of the solution depends on the number of random data or representative data used. Otherwise it creates 'Statistical errors' that can be reduce by longer simulation (Landau 2004). Monte Carlo simulation is typical in most computer languages to contain a built-in random number generator like excel applications, MATLAB, VSL, SAS, and the simulation packages SSJ, Arena, and Automod.

ii. Properties of a good random number generator

According to Kroese, Taimre & Botev (2011) some desirable or essential properties of a good uniform random number generator are as follows.

- It should pass statistical tests to detect deviations from uniformity and independence of the uniform random numbers.
- It depends on sound mathematical principles. The random numbers are reproducible that can be essential for testing and variance reduction techniques.
- The fast and efficient manner with a little storage in the computer memory that should be cheap and not require expensive external equipment.

- The long period would be required to avoid problems with duplication and dependence on random numbers.
 - It should have easy provisions for multiple independent random streams in parallel without producing 0 or 1 to avoid division by 0 or other numerical complications.
- iii. Choosing a good random number generator

According to Kroese et al. (2011), choosing a good random generator based on the purpose of random numbers generated, for example, for Monte Carlo simulation the distributional properties of random generators are paramount, whereas in coding and cryptography unpredictability is crucial. Suitable classes of generators that have overall good performances are Combined multiple recursive generators and Twisted general feedback shift register generators. Combined multiple recursive generators is a random number generator with excellent statistical properties, simple, extensive period, support multiple streams, and are relatively fast. Whereas Twisted general feedback shift register generators, is a random number generator with excellent equi-distribution properties, the fastest generators available and can have extremely long periods.

In general, a good random number generator has overall excellent performance, in terms of the criteria mentioned above, but is not usually the top performer in overall criteria. So, in choosing an appropriate generator that must remember faster generators are not necessarily better, a small period is in general bad as the larger period is not necessarily better and good equi-distribution is a requirement for a good generator but not a sufficient requirement.

iv. Generators based on linear recurrences

It is the most common method for generating pseudorandom sequences that use simple linear recurrence relations.

- a) Linear congruential generators are a random number with the output stream U_1, U_2, \dots is of the form $U_t = X_t/m$, where the state X_t satisfies the linear recursion. It means it is undertaking a single call $X_t = (aX_{t-1} + c) \bmod m$, $t = 1, 2, \dots$. Where, the integers m , a and c called the modulus, the multiplier, and the increment respectively. It is applying the modulo- m

operator in the above means that $aX_{t-1} + c$ divide by m , and the remainder taken as the value for X_t .

- b) A multiple-recursive generator of order k is a random number generator defined by a k -dimensional vector $X_t = (X_{t-k+1}, \dots, X_t)^T$, whose components satisfy the linear recurrence. $X_t = (a_1X_{t-1} + \dots + a_kX_{t-k}) \bmod m$, $t = k, k + 1, \dots$ for some modulus m and multipliers $\{a_i, i = 1, \dots, k\}$.
 - c) The other generators are Matrix congruential generators which interpreted and implemented as a matrix multiplicative congruential generator; modulo 2 linear generators have a huge state space as compare to the above two.
- v. Combined generators

A significant leap forward in the development of random number generators made with the introduction of combined generators. Here the output of several generators, which individually may be of poor quality, is combined, for example by shuffling, adding, and/or selecting, to make a superior quality generator.

vi. Tests for random number generators

The quality of random number generators assessed in two ways. The first test is through a spectral test to test the theoretical properties of the random number generator that based on the theoretical of algorithmic structure and parameters that does not require the actual output of the generator. Such properties like the period length of the generator and various measures of uniformity and independence. This test feasible if the generators have a sufficiently simple structure like linear congruential and multiple-recursive methods and combined versions thereof.

The other test is empirical tests based on the application of a battery of statistical tests to the output. It intended to detect deviations from uniformity and independence. The empirical test would be Equi-distribution (or Frequency) tests, Serial tests, nearest pair's tests, Gap tests, Poker or Partition tests, Coupon collector's tests, Permutation tests, Run tests, Maximum-of- d tests, Collision tests, Rank of binary matrix tests and Birthday spacing tests.

In general, using the Monte Carlo simulation method, the inverse random number shall be generated. This number is the exact Monte Carlo random number within

the probability distribution. It is obtained from the primary data that based on the inverse-transform method. The other random number generators are the alias method, the composition method, and the acceptance-rejection method (Kroese et al. 2011).

2.4.6 Combined simulation - optimization

Combined optimization simulation methods are the optimization of a certain scenarios or problems using a combination of different theories. The researcher uses the following example to certify the combination of different theory used in optimization problem.

Stoilova and Stoev (2016) used ARENA software simulation modeling to determine the fundamental frequency of train for passengers and linear optimization models to optimize the route and the number of trains in the metro under a combined simulation-optimization model for the selection of metro trains to scheme transport. The above researchers go through the following four steps to achieve their objectives. In the first step, the train movement has been simulated using ARENA software to study the interval between the trains based on incoming passenger flows at the stations. The results were validated through experimental observations. The second step is the correlation of the observed parameters - the incoming passengers and the interval between trains - has been studied using the results obtained from first step. The third step defines the variant schemes of transportation. The fourth step presents the optimal choice of transportation of trains in metros based on linear optimization model.

Klemen et al. (2018) applied the heuristic optimization algorithm and Monte Carlo simulation to have optimal bus stops allocation as follows. First road data points and pupils' addresses points are collected using GIS. In the next step, an initial road data reduction is carried out by a heuristic rule, which are not too close to the nearest neighboring road data points. Further, it was applied the Monte Carlo procedure to reduce or to optimize road data points to have optimal iteration. The next step is a clustering of the remaining to have optimal iteration and randomly pick from each cluster based on the inner radius of the inner circle of the point in the clusters and finally save all-important points. In general, the researcher

combined clustering-Monte-Carlo heuristic algorithm on 3D GIS data of a problematic dynamic rural terrain and dispersed pupils' addresses.

Shanmugasundaram and Banumathi (2016) analyze the future behavior of railway systems under the M/M/1 queuing system using Monte Carlo simulation. It used for optimizing the number of counters to reduce the waiting time of customers in the queue. The unique future of this study is the researcher takes the railway junction that has multiple channels to know which channels need the additional server and which need to be merged through the Monte Carlo simulation method.

All in all, Stoilova and Stoev (2016) combined ARENA software and Linear optimization methods to develop methodology of Transport Scheme Selection for Metro Trains. Klemen et al. (2018) develop heuristic optimization algorithm and Monte Carlo simulation to have optimal bus stops allocation. Shanmugasundaram and Banumathi (2016) combined queue theory and Monte Carlo simulation to analyze the future behavior of railway systems. These three literatures indicate the possibility of combining different theories to the optimization problems.

2.5 Optimization techniques used in service sector

Optimization is the process of finding the conditions that give the minimum or maximum value of a function, where the function represents the effort required or the desired benefit.

2.5.1 Technical terms of optimization through simulation

In the following statement, an introduction to the basic concepts of modeling and simulation is given (Vangheluwe 2001).

Object is some entity in the real world with widely different behavior depending on the context and behavior in which it studied.

Base Model is a theoretical representation of the object's properties.

System is a well-defined object in the real World under specific conditions.

Experimental Frame is a description of the real-world objectives for analysis.

Model gives an accurate description of a system within the context of a given experimental frame.

Experimentation is the act of carrying out an experiment that may interfere with system operation (influence its input and parameters) or it may not.

Simulation is a fast and accurate way of representing the real world, and it allows us to answer real-world questions about the system.

Verification is the process of checking the consistency of a simulation program of lumped model. It means the correct transformation of conceptual model to the program code or simulation model by ensuring the exactly reflection of the conceptual model (Vangheluwe 2001).

Validation is the process of comparing experiment measurements with simulation results.

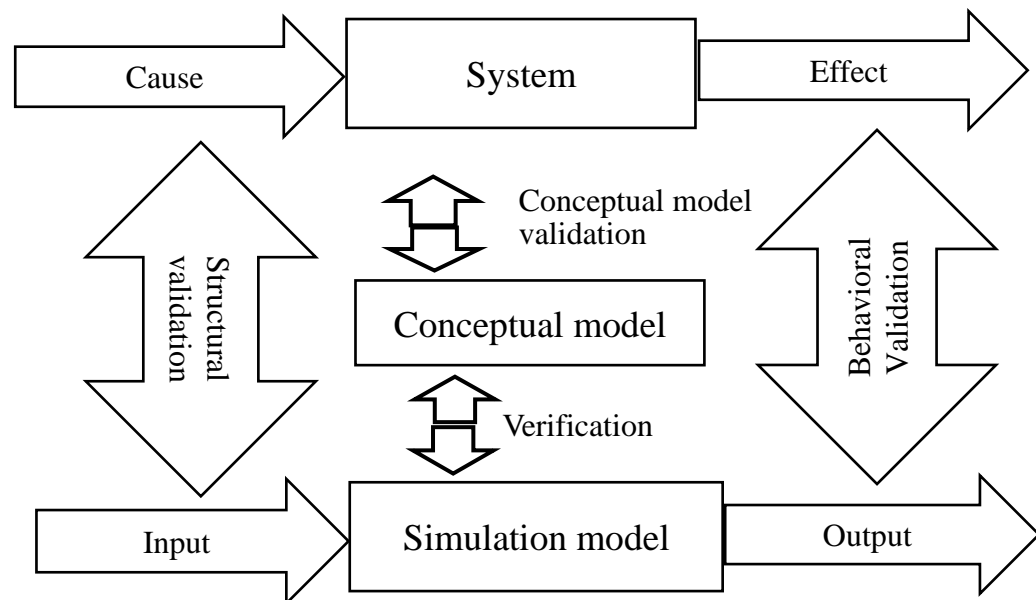


Figure 16 Verification and validation activities

2.5.2 Pro and cons of optimization method

Queueing Theory and Markov chain used to optimize a problem at a steady-state. These are simple mathematical expressions to solve congestion problems either using excel or software's. However, Markova chain used for decisions that needs to account uncertainty about many future events in broader context (Ghimire et al. 2017, Hillier & Lieberman 2001). The main drawback of Queueing theory, it assumed Poisson inputs from unlimited sources and exponential holding times (Queueing Theory 2019; Sztrik 2010). Similarly, Markov chain also base on Poisson probability distribution for customer arrival and service mechanism is based on binomial probability distribution (Hillier & Lieberman 2001). The above

two requirements limit the application of Queue Theory and Markov chain only to those properties of data and the condition of the system.

Monte Carlo methods used to generate random objects and processes to observe their behavior, to estimate numerical quantities by repeated sampling, and to solve complicated optimization problems through randomized algorithms. It is used when the optimizations face mathematical complexity and line disciplines other than first-come-first-served, (Choi & Radharamanan 2017). It repeatedly runs to obtain the distribution of an unknown probabilistic entity (Bihani 2014). The main drawback of Monte Carlo method is the random numbers produced via deterministic algorithms, they are numbers within the interval (0, 1) (Kroese et al. 2011). The other drawback is the accuracy of the solution depends on (Landa 2004).

- the size of sampled data used called Statistical value
- the efficiency of the algorithm to describe the physics properly
- the computer time and memory.

Combined optimization-simulation methods are the optimization of a certain scenarios or problems using a combination of different theories like queue theory, Monte Carlo simulation, Markov chain and linear optimization. It is used to face all problems but it is complicated. Examples of combination of methods for optimization problem are; Stoilova and Stoev (2016) combined ARENA software and Linear optimization methods to develop methodology of Transport Scheme Selection for Metro Trains. Klemen et al. (2018) develop heuristic optimization algorithm and Monte Carlo simulation to have optimal bus stops allocation. Shanmugasundaram and Banumathi (2016) combined Queue Theory and Monte Carlo simulation to analyze the future behavior of railway systems. The above studies indicate the complexity of the method by using two different theories.

2.5.3 Simulation-optimization software

In real world, the interaction of entities are complex and mathematical models like queuing systems can be applied to a limited number of special cases. In construction, output from one operation tends to be the input to the following operation. This creates chains of work tasks as well as situations in which many

units are delayed at processors. Such chained or linked situations are too complex to be modelled using classical queuing models (Ayichiluhum, 2018). Development of a simulation-based model can be “tedious and expert knowledge on simulation technique is required and can also be time consuming”. Then to simplify the simulation-based modeling process in construction, computer simulation was developed. This simulation requires the knowledge of a special language that allows the programmer to simulate the system. So, some methodologies called computer software were developed to simulate the complex real-world situations (Moussa et al, 2014). For this research the researcher stated the most popular simulation software used in construction (Ayichiluhum, 2018).

- **ARENA simulation** is working simulation tool for simulation environment consisting of module templates, built around SIMAN language constructs and other facilities, and augmented by a visual front end (Altiok and Melamed, 2007).
- **CYCLONE/ Micro CYCLONE Simulation** is a simulation model applied to the modeling of concrete batch plant operations to study different combinations of resources that originally developed by Halpin in 1973 to model and simulate concrete batch plant operations (Ayichiluhum, 2018). It used to gear toward modelling the construction process not the entire system (AbouRizk et al. 2016).
- **DISCO Simulation** is a prototype program developed to implement the DISCO approach by using Microsoft Visual Basic language and runs under the Windows operating environment (Ayichiluhum, 2018).
- **SIMPHONY Simulation** provided many extra features to CYCLONE modeling systems such as the possibility of the user writing their own programming code to manipulate the model and its components for more accurate modeling (Ayichiluhum, 2018. Symphony as a new development from CYCLONE for modeling construction operations and the concept was presented as a special purpose simulation (SPS) for domain specific modeling (Moussa et al, 2014).

2.5.4 Performance of a model

The performance measures of a queue system are the evaluation of the performance of a queue system at a steady state. In systems theory, a system or a process is in a steady state if the variables of the system or the process are unchanging in time. In continuous-time, for those properties p , the partial derivative with respect to time is zero and remains so. However, in discrete-time the first difference of each property is zero and remains so. In stochastic systems, the probabilities of various states will repeat or will remain constant. Steady-State achieved after the system started called the transient state, warm-up period to approaches asymptotically. An unstable system is one that diverges from the steady-state (Steady state 2019).

So, the performance of a system is the evaluation of the system at a steady-state. It shows how the queue system performance with respect to the customers and cost. It can be the probability of there are no or "n" customers in the system, the average number of customers in the queue or system, the average time a customer spends in the queue or system and the probability that an arriving customer must wait for service. So based on the Monte Carlo simulation, the following findings can be determined from the random number simulation table.

- The Average waiting time = $\frac{\text{Total time customers wait in the queue (minutes)}}{\text{Total number of customers}}$
- Probability of customers waiting = $\frac{\text{Numbers of customers who want}}{\text{the total number of customers}}$
- Probability of getting server idle = $\frac{\text{Total idle time of the server(minutes)}}{\text{Total run time of simulation(minutes)}}$
- percentage of time that the server became idle is the percentage of the amount of space that are not serviceable
- Average service time = $\frac{\text{Total service time(minutes)}}{\text{Total numbers of customers(minutes)}}$
- The expected service times
- The average waiting time of those who wait is the average waiting time that a customer's wait is the system to have the service.
- The average time customers spend in the queue as well as in the system.

2.6 The probability distribution of the arrival and service of customers

In optimization, it is mandatory to know the probability distribution of the arrival and service of customers, and there is plenty of software used for the intended purpose. Among different distribution software, the researcher's review and uses @RISK probability distribution fitting software. As information, the following software is available in the market like EasyFit 5.6 Professional, JMP statistical software, Arena, etc. (Mehrannia & Pakgohar 2014, Altiok and Melamed, 2007).

@RISK (Risk Analysis and Simulation Add-In for Microsoft Excel) software

@RISK software is an Excel add-in application of the most used risk analysis tools, and it is a helpful modeling tool used to analyze under uncertain and risky conditions. In addition, it allows risk analyzers' ability to make more productive and insightful business decisions. It also uses simulation to combine uncertainties and risks and allow easy graphical analysis (Modeling with @RISK 2016).

The necessary steps to using @RISK to define a stochastic variable are as follows

- Open Excel from the start menu
- Select the @RISK tab from the top right corner of Excel
- Click the define distribution button
- Select the distribution type
- Define the parameters of the distribution

Fitting distributions to data

It is choosing appropriate probability distributions for uncertain inputs. It is done through narrow the choice by assessments as the quantity must be between 0 and 100. It has only a few discrete values or the distribution of the quantity skewed to the right. However, the other approach is to fit possible distributions to historical data on the quantity. Since historical data are not always available, at this time @RISK's distribution fitting tool can be used. This tool automatically ranks candidate distributions on their goodness-of-fit to the data, and then it can make the ultimate choice of the distribution that wants to use (Palisade Corporation

2011). The goodness of fit test is comparing the fitted distribution to the empirical distribution to assessing the quality of the fit after parameterizing distribution. It should be check by using the Chi-Square test, Kolmogorov-Smirnov (K-S) test, and Visual assessment of the quality of the fit.

Chi-Square test evaluates the data based on the measurement of the discrepancy between the histogram of the sample and the fitted probability density function. Kolmogorov-Smirnov (K-S) test measured the discrepancy between the empirical CDF and fitted CDF. Visual assessment of the quality of the fit of the simple for visual comparisons of the plot of the empirical and fitted CDFs to see how well the fitted CDF tracks the empirical one. In this case, one can compare how well the shape of the sample histogram compares to that of the theoretical PDF. For this research, the researcher prefers a Chi-Square test to know the probability distribution of a peak hour passenger flows of Addis Ababa light railway transit. Since it used to test discrete data sample while Kolmogorov-Smirnov test mainly used for continuous data samples. Karl Pearson follows the following steps to check the goodness of fit test by Chi-Square test.

1. Determine the number of intervals k.

- Heuristic Approach;

$$k = \begin{cases} \text{round to the nearest integer } \frac{n}{5}, \text{ where } n < 35. \\ \text{the largest integer below } 1.88 * n^{\frac{2}{5}} \text{ where } n \geq 35 \end{cases}$$

- Manning and Wald (1942) approach for (n >= 200):

$$k = 4 * \sqrt[5]{\frac{2(n-1)^2}{Z^2_{1-\alpha}}}, \text{ Where; the n-total number of data points and } Z_{1-\alpha} \text{ is the standard normal Z value corresponding to probability } 1-\alpha.$$

2. Through the following equation, compute the interval boundaries (a_i).

$$a_i = F_x\left(\frac{i}{k}\right), i = 1, \dots, k \text{ and } F_x \text{ is the inverse CDF of the fitted distribution}$$

3. Calculate the following for each bin/cell

- $p_j = 1/k$.
- Find out the expected number of observations (np_j) and the actual number of observations (N_j) in each cell.

4. Calculate Chi-Square statistic χ^2 through the following formula

$$\chi^2 = \sum_{j=1}^k \frac{(N_j - nP_j)^2}{nP_j} \text{ where } n \text{ is the total number of observations.}$$

- Compare the value of χ^2 to that of the Chi-Square tables and reject the distribution if $\chi^2 \text{ computed} > \chi^2_{1-\alpha, (k-q-1)}$ where $k-q-1$ is the degree of freedom.

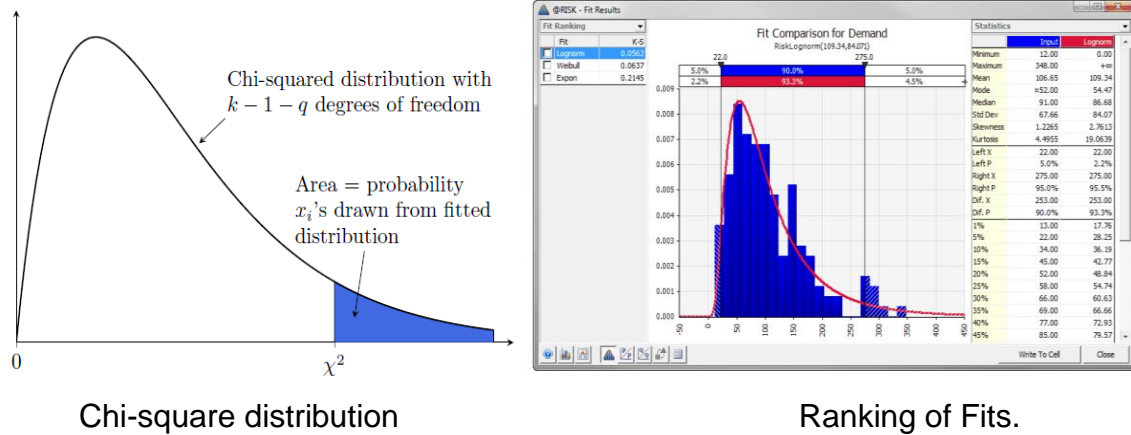


Figure 17 Chi-square distribution and Ranking of Fits.

2.7 Empirical literature survey of optimization methods

2.7.1 General application of optimization methods

Sharma and Barue (2015) optimized the small enterprise based on the arrival and service rate. They take M/M/1 and M/M/2 queue models to select the best performance through compare the cost of an alternative and existing model. Mehendiratta (2011) attempt to analysis healthcare problem through queuing theory. Moreover, he states the instance of using queue theory in the health care organization around the world with the benefit acquired for the same. Sztrik (2010) discuss the queuing theory and some mathematical models of queuing systems that can be used in a real-life situation. Nafees (2007) analyzed the sales checkout operation of ICA supermarket. Under this study, the parameters are computed using the confidence interval to estimate the service and arrival rate. It checks the performance of the system. The main drawback of this research is, the data collected is questionnaire and the probability distribution and queue theory property are an assumption not based on real data.

Arthur et al. (2016) optimize call center staffing of workers to answer 80% of calls within 30 seconds via the Monte Carlo simulation method in the following ways. First, they organize the data by call type and day of the week and standardize by the conventional method of standardization to collect the histogram according to call type and day. Then the probability distribution is fitted to generate random data from the fitted distribution. This random number was used to optimize call center staffing workers. Similarly, Prakash et al. (2016) optimized the transportation of sugar cane to mills in Fiji to optimized cane delivery schedule. It focused on minimizing mill idle time and lorry queue time to optimized the schedule. This study incorporated required travel times to the mills, the processing time of mills, and the time taken to cut cane and load lorries.

Manuel (2014) uses combined Queuing theory with Monte Carlo simulation in ATM to determine, control, and manages the level of congestion. Marsudi and Shafeek (2019) carry out queuing analysis to examine multi-stage production line performance to facilitate more realistic resource planning. This researcher passes through the following ways. They select a production line to be studied, collect data for each workstation to analyze through Chi-Squared goodness test. Then they made validation of the task time value resulted to have 93.80% accuracy.

2.7.2 Application of optimization in constructions sectors

Sheikh, Lakshmipathy and Prakash (2016) developed a queuing model for the optimization of concreting and earth moving activities to minimize the cost. The researchers take concrete truck as a server while concrete pumps and placement crew as a customer. Similarly, Hardjito, Antoni & Muljati (2012) numerically optimize concreting and earth moving activity. In concreting activity, crane and bucket considered as a server and concrete mixer as the customer.

Hasan, Jhe, and Ghosh (2018) developed queue model through Microsoft excel to determine the optimum numbers of pumps and the arrivals rates of truck mixtures. This improved concerting equipment at the construction site. Gunawardena (1990) develop mathematical models for maintenance optimization and replacement analysis of construction equipment. The maintenance model simulates the equipment repair crew system of the equipment company to

optimize the repair crew. The replacement model optimizes the replacement strategy of equipment using Integer Linear Programming.

2.7.3 Application of optimization methods in Light Railway Transit

Queuing theory applied for the optimization of subway station capacity. It implemented on Beijing subway line 2 by combining the analytical queuing network modeling and Least-squares regression (Xu, Liu & Li 2014). Umanah and Undoh (2017) applied queue theory at ticket windows of Lagos railway station to improve the waiting time of passengers. In this research, the data was primary, and the queue model was $M/M/C/\infty/FCFS$. The researcher's assumption of the data property is the main drawback. Similarly, Dickson et al. (2018) applied queue theory at Salem railway ticket counters to have optimum clerks of 4.

Shanmugasundaram and Banumathi (2016) analyze the future behavior of railway systems under the $M/M/1$ queuing system and Monte Carlo simulation to optimize the number of counters. The researcher takes multiple channeled railway junction to optimize the servers. The main drawback of this study is, it needs to be completed. Klemen et al. (2018) applied the heuristic optimization algorithm and Monte Carlo simulation to have optimal bus stops allocation. This combination optimizes 503 pupils' addresses to 37 bus stops with acceptable walking distance of 1962m. It satisfies 94.6% pupils. This study is comparable with the current AALRT design.

Stoilova and Stoev (2016) used ARENA software to determine the fundamental frequency of services. In addition, linear optimization models to optimize the route and the number of trains. They combined simulation-optimization model for the selection of metro trains to scheme transport. Tekle (2017) investigates the performance of AALRT train timetable using ARENA software. And the researcher conclude that the 7.5 minutes train timetable can be used for all speed.

2.8 Summary of the literature review

A literature review is a systematic identification, location, and analysis of documents containing information related to the study area. Traffic congestion happens when the traffic demand for road space exceeds the capacity. Among

the different modes of transport, Railway transportation is the primary concern of this research, specifically the AALRT. It is an LRT that transport the passengers from one corridor to the other with minimum cost. It was constructed in the two main corridors of the city, with about 34.25 km besides a 2.662 km mutual line. It has 39 stations with the operational speed range between 20 and 80 km/h. It can serve up to 16 hours per day at 6 minutes' headway that can be reduced up to 90 seconds. It is a fully electrified that opens other means of public transport at peak hours, and most of the time, it is congested.

Among different literature reviewed in this study area, the optimization in a small enterprise, call center and transportation of sugar cane to mills, healthcare, supermarket checkout, ATM, subway station, ticket windows, multi-stage production line and construction was done through queuing theory. The combination of Monte Carlo simulation with Queueing theory and simulation-optimization was used to analysis railway systems. The heuristic optimization algorithm and Monte Carlo simulation applied to have optimal bus stops allocation.

The literature review also indicated that solving queuing problem broad concept that consists of many theories. This theory can be select based on the property of the data, queuing problem, and customers' behaviors. Queueing theory and Markov chain use to solve the congestion problem. Queue theory has Poisson and exponential distribution for arrival and service rate, respectively. In addition, Markov chain has Poisson arrivals and binomial service distribution. However, the property is differed from the above distribution, discrete or continuous event simulation, and Monte-Carlo simulation can be used. These methods use to solve the congestion problem without the restriction of the property. In the monte-carol simulation, a set of a random number will generate based on the probability distribution. The property of data fixed by @RISK software.

2.9 Research Gaps

According to the best knowledge of the researcher, there is limited research on the optimization of the service sectors in Ethiopia. Previously, the optimization in a small enterprise through characterizing the data (Sharma and Barue 2015) and the call center staffing and sugar cane to mills via the Monte Carlo simulation

method (Arthur et al, 2016), in healthcare problem (Mehandiratta 2011), in supermarket (Nafees 2007) was done. The main drawback of this research is that either the data questionnaire, the probability distribution is assumed and all in all it applied in another sectors.

In LRT, the property of data used to optimization subway station capacity (Xu, Liu & Li 2014), and ticket windows (Umanah and Undoh 2017) is assumed. The combined M/M/1 queuing system and Monte Carlo simulation of railway systems is no completed (Shanmugasundaram and Banumathi 2016). ARENA and linear models optimize the route and the number of trains (Stoilova and Stoev 2016). Tekle (2017) investigated the performance on the AALRT train timetable for optimal use of the available resources.

So, from above literature the train scheduling for passenger, optimization in the ticket window, the sub-way capacity, train timetable was done on LRT. However, the fundamental parameter was assumed, and some of them were not completed. For the congestion problem in AALRT, only the performance of the train timetable studied. In addition, this performance was not based on passengers' arrival and service. So, this research used to fill the gap of train optimization based on passengers' arrival and service on AALRT.

CHAPTER THREE - RESEARCH DESIGN AND METHODS

3.1 Introduction

The research defines as a careful, systematic investigation in a specific field of knowledge, undertaken to establish facts or principles or to find answers to a problem. According to Kerlinger (1986), "scientific research is a systematic, controlled, empirical and critical investigation of propositions about the presumed relationships of various phenomenon. Kumar (2011) stated that research design is a plan, structure, and strategy of the investigation so conceived as to obtain answers to research questions or problems. It includes an outline of what the investigator will do from writing the hypotheses and their operational implications to the final analysis of data.

The research method is a way of systematically solving a research problem. The research process is the steps that the researcher goes through to find out answers to the research questions or the path that the researcher passes through to achieve the research objectives (Kumar 2011). So, this section describes the research methodology and process used in the data collection and data analysis at different stages of the research. This research methodology and process involves various steps that were followed by the researcher during the study.

3.2 Description of the case study

This case study was conducted on Torhailoch and Lideta station of the west-east corridor of AA-LTR. It starts at Torhailoch metro station, which is the beginning point of the west-east corridor. It is at grade station parallel with the traffic flow. It has the most significant customer's arrival and departures like that of Megenagna and Ayat station. All of the customers are from outside sources, and it is the begging or last station where all the passengers and customers alight or depart.

Lideta is the third station of the west-east corridor from Torhailoch, and it finds in the transition section of west-east and north-south corridor of AALRT with 1.7 Km from Torhailoch. It used for both north-south and east-west passengers. Both the

outside passengers and from the tramcar arrivals can served hear. Lideta metro station is an overpass structure with a single staircase and elevators on the left side and two lift shafts on either side of the LRT route. The left side lift shaft of Lideta station embedded in the Awash International bank's building. Two types of tramcar pass through this station. The green tramcar passes through on the east-west corridor whereas the blue tramcar passes through on the north-south corridor.

3.3 Research design and organization

The main objective of this research is to identify and develop an optimization model for Torhailoch and Lideta station of AALRT. Thus, it is required to assess to what extent the congestion of passengers exists. Beside that to apply practices and tools of the congestion problem-solving model and computer-aided simulation software are solve the problem. Optimum service is one of the most critical activities in the service sector under the operation. For this purpose, it is necessary to develop a model to ensure effective management of the metro station. This used to guide the planners and estimators to maximize transit service; and forecast activity durations. Finally, it used to lower cost and optimize the waiting time.

In the development of an optimum model for this research paper, the system is treated as passengers pass from ticket window to platform then to tramcar in Torhailoch. However, in Lideta station with the addition of passenger flow from tramcar to tramcar is included. The server is the tramcar that transit passengers from one station to the other through the stretches as mentioned earlier. The objective of this research paper is achieved through the following step and process.

1. Statement of the problem used to find out for problem identification, significance of the research and also to identify the congestion problem happens during rush hour.
2. Stating general and specific objectives that used to develop a framework of the study and the findings.
3. Literature review,

- To identify the knowledge area of the subject-matter through critical review.
 - To identify processes and practices to be included in the planning and modeling process of the current study.
 - To know the way and the content of the current study by going through the subject area.
 - To study and identify the state-of-the-art, importance, and way of simulation implementation in the service industry with more emphasize on light railway optimization.
4. Case study used to model the existing transportation process and to develop the optimum solution through computer-aided simulation software.
 5. Data collection was conducted through direct counting as primary data and from reading documents as secondary data to develop the optimum model of the passenger congestion.
 6. Data analysis and discussion
 - To analyze the collected data using simulation and spreadsheets to attain the objective.
 - To determine the relative importance of the optimization model simulation in the LRT passenger's congestion.
 - To develop a useful supporting tool in the transportation service of AALRT at a specified station.
 7. Finally, using the developed model efficiency assessment, the conclusion and recommendation have developed. Figure 21 demonstrates the process of Research Methodology.

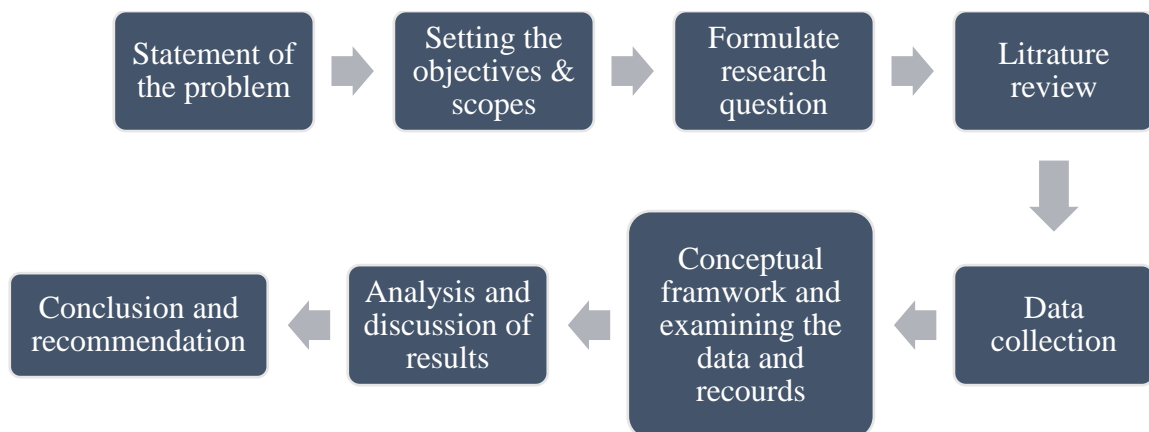


Figure 18 Flow chart of research methodology

3.4 Research Method

This study schedule to the find the independent variable for the collected and developed of the dependent variable, including the optimization model. The dependent variable used to undertake the performance evaluation. The elements of the independent variables are the arrival characteristics and waiting line characteristics. Arrival characteristics are concerns on the size of arrival population, behavior of arrivals, and statistical distribution of arrivals. The probability distribution obtained by fitting @RISK software to check the behavior of the probability distribution of the inter-arrival and service time. In the same way, the waiting line characteristics concerned with limited or unlimited queue population and queue discipline.

The dependent variable included in the optimization model and performance evaluation. The optimization model based on the arrival rate, service rate and queue model of the independent variables. Performance evaluation is the performance measurement and cost comparison of the existing with the new model. The aggregate work of the study starts from finding the optimum waiting time for the passenger in the AALRT of Torhailoch and Lideta station. This solution is based on the consideration of optimum service and cost of customer and ERC respectively. So, to have the independent variable the researcher goes through the following.

3.4.1 Data Sampling and collection

In this research, both quantitative and qualitative data required. According to Bridget and Darko (2018), qualitative research methodology is a systematic data collection, organization and interpretation of textual information (also images/video). It is the inductive approach when the phenomena are difficult to quantify. Quantitative methods are those that deal with measurable data. Therefore, in this study, the research is based on both qualitative and quantitative research methodology of data collection for qualitative description and exploratory explanation.

a) Primary data

This data collection would be undertaken to get primary data of both qualitative and quantitative. The qualitative data used to find the satisfaction of the customer in Addis Ababa LRT. It is obtained by literature review. However, quantitative data obtained from direct counting of the total number of the customer at the boarding and alighting of the tramcar. Besides that, the arrival characteristics of a tramcar for the selected metro station is collected in the specified direction. This primary data collection at Lideta, and Torhailoch metro station along the route of Torhailoch to Ayat was conducted using stop-watch for two months at the rush hours.

b) Secondary data

The secondary data for the description of customer satisfaction obtained from a desk study of various works of literature. In the same way, some quantitative data obtained from the desk study of various documents of AALRT.

3.4.2 Data analysis and modeling methodology

In this part of the research, the researcher would show every step that the research goes through to achieve the research objective. The specific objective has to be obtained using data analysis and modeling to attain the main objective as follows.

a) Data Analysis

In part of the research, the researcher solves the first, second, and fourth specific objectives as follows. The first objective will solve by determining the probability distribution of the data collected. This justification will undertake by using distribution fitting software like @RISK. The second objective will address by collecting and comparing data at Torhailoch and Lideta station on the west-east direction of passenger flows. The fourth objective will address by comparing the cost and benefit of the existing server with the new model.

b) Optimization model

The third specific objective will address by developing a new model based on the data collected and the probability distribution. In this case, the researcher would choose the theory for developing the optimization model based on the characteristics of data.

3.5 Flow chart of the research

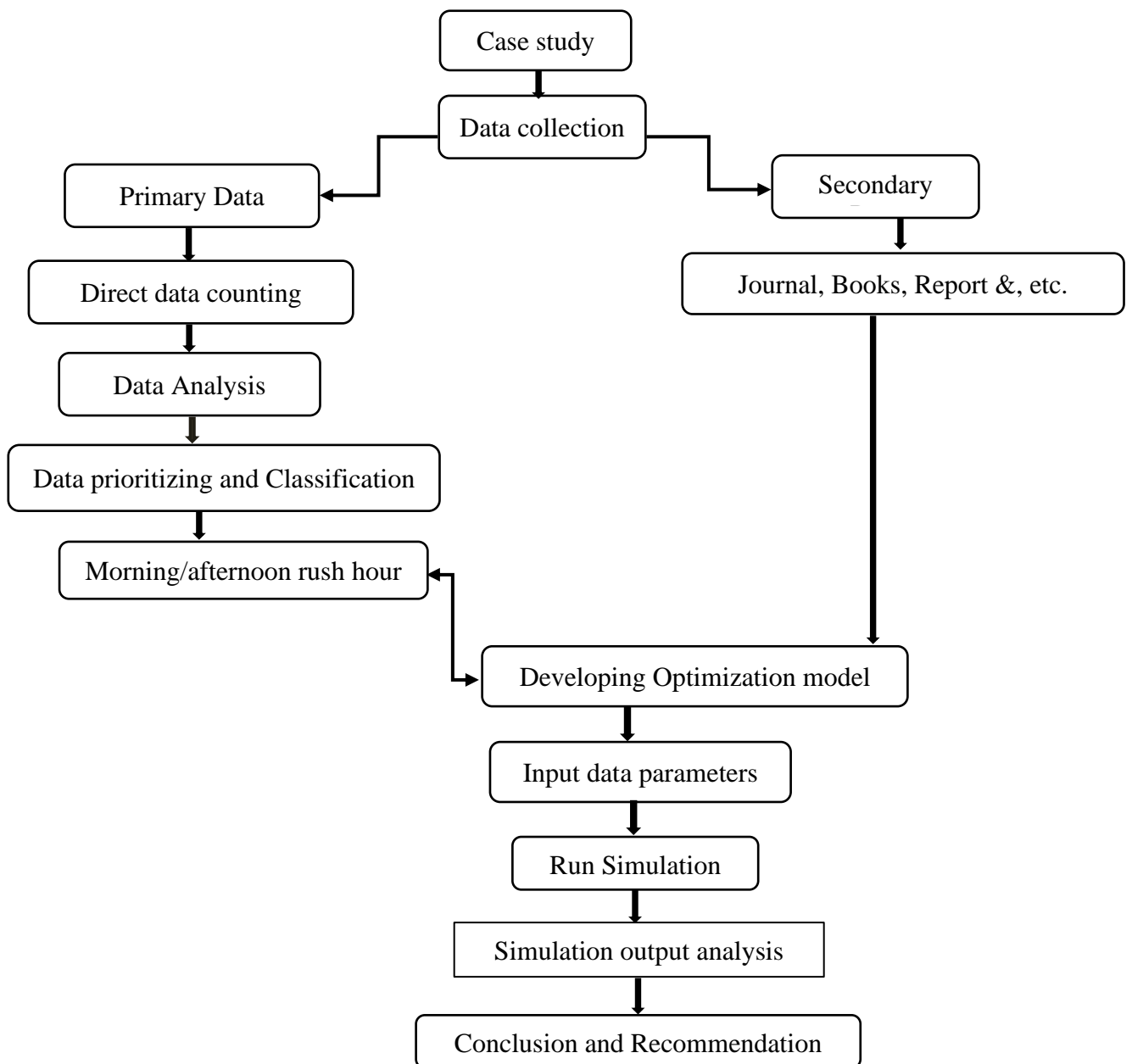


Figure 19 Process of data collection, model development, and finalization of the research

CHAPTER FOUR - ANALYSIS AND DISCUSSION

4.1 Introduction

In this chapter, step by step data analysis was undertaken for the formation of a new model. It is achieved through answering of each specific objective of the main objective. The probability distribution of each station was determined using @RISK software. In the new model development, the congestion of each station checked. This data is further analyzed to obtain a new model by answering the third specific objective. The new model was developed by considering waiting for the time and cost of providing service. For these steps, the researcher uses Monte Carlo simulation for the direct optimization of waiting time.

Addis Ababa Light railway transit constructed on east-west and north-south corridors, and as per the interview of AALRT operation control center worker, the east-west corridor is congested as compared to north-south corridors. In addition to that, Megenagna, Torhailoch, and Ayat are the most congested in AALRT of the west-east corridor. Here also, based on the interview of the OCC worker of AALRT, Torhailoch and Lideta station is the second congested station after Ayat and Stadium station, respectively. AALRT serves for 16 hours in two shifts called the morning and the afternoon. The morning shift is from 6:00 AM up to 2:00 PM, and the afternoon shift is from 2:00 PM up to 10:00 PM. Its peak hours are from 7 - 9 AM and 10 - 12 PM in the morning and afternoon, respectively, as per the interview of OCC worker and ticket sellers of AALRT workers.

The primary data collected for this research is a passenger and tramcar arrival in Torhailoch with the additional departure of passengers at Lideta station. This data was collected for the peak hours from January 14, 2019, up to March 03, 2019 by excluding public holidays. In the first month, Torhailoch data was collected. In the second month the data collection undertook at Lideta station. The discussion and analyzing of the result were done by summarizing the and calculation of the collected data. It answered the followings

- Average passenger rate of arrival and inter-arrival time

-
- Service rate
 - The probability distribution of passenger and tramcar arrival and discussion
 - An optimum model of AALRT
 - Cost comparison of the existing AALRT model with a new.

4.2 Data collection and validation

The congestion problem is solved through different models like Queue Theory, Markova chain, Monte Carlo simulation, and the likes. However, to stick on one theory, the researcher found the probability distribution by @RISK software.

4.2.1 Data collection and summary of data

As stated above, two-month data was collected in Lideta and Torhailoch metro station in the morning and afternoon peak hours. The morning peck hours are starting from 7 AM up to 9 AM out of 6 AM up to 2 PM. The afternoon peck hours are starting from 4 PM up to 6 PM out of 2 PM up to 10 PM. The summary of the data stated in table 1&2 below for both Torhailoch and Lideta metro station in the morning and afternoon shifts.

The table 1 below shows the summary of statistical distribution of morning and afternoon peak hour of Torhailoch station. It summarizes the statically distribution of tramcar arrival, passengers' arrival and the tramcar capacity. *Tramcar capacity* is the multiple of tramcars arrival with its design capacity; 286 passengers. Table 2 shows the summary of the statistical distribution of morning and afternoon peak hours of Lideta station. However, the passenger arrival in Torhailoch is replaced by boarding and alighting of passengers' arrivals in Lideta. Intermediates station passenger arrival can be boarding passenger arrival from the street and the previous station. Here, the data of Torhailoch and Lideta was collected in serious not in parallel.

Table 1 The statistical distribution of peak hours at Torhailoch station

Peck hours	7 - 8 AM			8 - 9 AM			4 - 5 PM			5 - 6 PM		
Statically description	Tramcar arrival	Passengers arrival	Tramcar capacity	Tramcar arrival	Passengers arrival	Tramcar capacity	Tramcar arrival	Passengers arrival	Tramcar capacity	Tramcar arrival	Passengers arrival	Tramcar capacity
Minimum	2.00	980.00	858.00	2.00	842.00	858.00	3.00	711.00	1,144.00	2.00	660.00	858.00
Maximum	5.00	1,348.00	2,002.00	5.00	1,266.00	2,288.00	5.00	1,409.00	2,288.00	5.00	1,284.00	2,288.00
Mean	3.64	1,184.14	1,521.93	4.07	1,118.11	1,756.86	4.29	913.43	1,838.57	4.21	912.21	1,797.71
Mode	3.00	1,123.00	1,716.00	5.00	1,196.00	2,288.00	5.00	711.00	2,002.00	5.00	660.00	1,716.00
Median	3.50	1,201.00	1,573.00	4.00	1,148.00	1,716.00	4.00	905.00	1,859.00	4.00	916.00	1,716.00
Std. Deviation	0.83	104.87	339.77	0.90	116.48	465.18	0.76	152.98	295.67	0.88	139.20	372.14
Skewness	0.36	(0.53)	(0.11)	(0.48)	(1.01)	(0.36)	(0.55)	1.42	(0.34)	(0.81)	0.55	(0.69)
Kurtosis	2.28	2.37	1.84	2.16	3.45	1.79	1.97	5.97	2.76	2.77	3.85	3.26

Table 2 The statistical distribution of peak hours at Lideta metro station

Peck hours	7 - 8 AM				8 - 9 AM				4 - 5 PM				5 - 6 PM			
Stastical discription	Tramcar arrival	Boarding Passenger	Alighting Passenger	Tramcar capacity	Tramcar arrival	Boarding Passenger	Alighting Passenger	Tramcar capacity	Tramcar arrival	Boarding Passenger	Alighting Passenger	Tramcar capacity	Tramcar arrival	Boarding Passenger	Alighting Passenger	Tramcar capacity
Minimum	1.00	83.00	5.00	572.00	2.00	94.00	25.00	572.00	2.00	95.00	11.00	858.00	2.00	101.00	13.00	572.00
Maximum	5.00	195.00	34.00	2,002.00	6.00	179.00	60.00	2,574.00	5.00	217.00	49.00	2,288.00	5.00	222.00	60.00	2,288.00
Mean	3.41	151.06	21.41	1,463.65	4.06	134.65	37.47	1,783.29	4.24	160.29	28.06	1,833.76	4.12	162.12	34.82	1,783.29
Mode	4.00	160.00	34.00	1,716.00	5.00	140.00	33.00	1,716.00	4.00	193.00	22.00	2,002.00	4.00	201.00	30.00	1,716.00
Median	4.00	160.00	21.00	1,430.00	4.00	140.00	36.00	1,716.00	4.00	168.00	27.00	2,002.00	4.00	171.00	33.00	1,716.00
Std. Deviation	1.00	36.16	8.99	376.75	1.14	25.57	9.29	576.71	0.83	39.52	8.84	405.21	0.78	39.17	12.61	371.93
Skewness	(0.99)	(0.79)	(0.13)	(0.61)	(0.41)	0.13	0.79	(0.47)	(1.24)	(0.63)	0.54	(0.84)	(1.11)	(0.18)	0.43	(2.23)
Kurtosis	3.77	2.25	2.06	3.31	2.46	2.18	3.67	2.91	5.01	1.95	3.99	3.36	5.38	1.77	3.09	10.05

Note: The data of Torhailoch and Lideta was collected in serious time not in parallel.

4.2.2 The probability distribution of Torhailoch and Lideta station

Summary of the probability distribution of passenger arrival of Torhailoch and Lideta station as follows

Table 3 the probability distribution of passenger arrival, tramcar arrival, and tramcar capacity at Torhailoch and Lideta metro station.

Station	Data collected	Peak hours	Probability Distribution
Torhailoch Metro station	Passenger arrival	7 - 8 AM	Uniform
		8 - 9 AM	Uniform
		4 - 5 PM	Negative Binomial
		5 - 6 PM	Negative Binomial
	Tramcar arrival	7 - 8 AM	Binomial
		8 - 9 AM	Binomial
		4 - 5 PM	Binomial
		5 - 6 PM	Binomial
	Tramcar Capacity	7 - 8 AM	Uniform
		8 - 9 AM	Uniform
		4 - 5 PM	Negative Binomial
		5 - 6 PM	Negative Binomial
Lideta Metro station	Passenger arrival (Boarding passengers)	7 - 8 AM	Uniform
		8 - 9 AM	Negative Binomial
		4 - 5 PM	Uniform
		5 - 6 PM	Uniform
	Passenger arrival (Alighting passengers)	7 - 8 AM	Uniform
		8 - 9 AM	Negative Binomial
		4 - 5 PM	Negative Binomial
		5 - 6 PM	Negative Binomial
	Tramcar arrival	7 - 8 AM	Binomial
		8 - 9 AM	Binomial
		4 - 5 PM	Binomial
		5 - 6 PM	Binomial
	Tramcar Capacity	7 - 8 AM	Negative Binomial
		8 - 9 AM	Uniform
		4 - 5 PM	Negative Binomial
		5 - 6 PM	Negative Binomial

The above table indicate, the result of goodness of fitting is uniform, the binomial, and negative binomial distribution. Uniform distribution happened when the data are uniformly distributed within a specific interval. The binomial distribution represents the probability for x successes in n trials, given a success probability p for each trial. It is a discrete distribution. The negative binomial distribution is a discrete probability distribution of the number of successes in a sequence of independent and identically distributed before a specified (non-random) number, r failures occur-sample graphical probability distribution each station at the peak hour of AALRT as shown bellows.

a Torhailoch station.

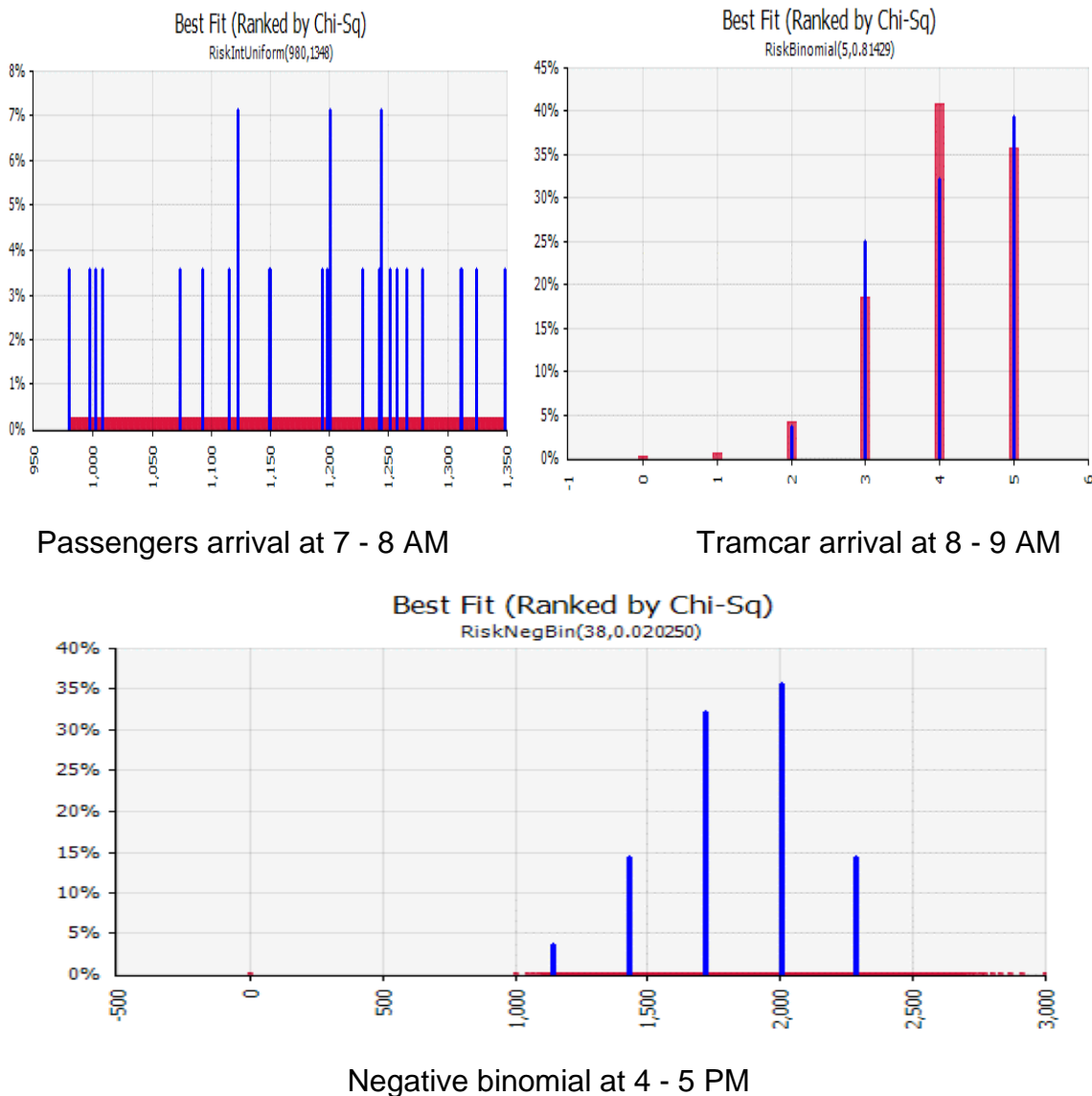


Figure 20 The probability distribution for peak hours at Torhailoch station using @RISK

b Lideta station.

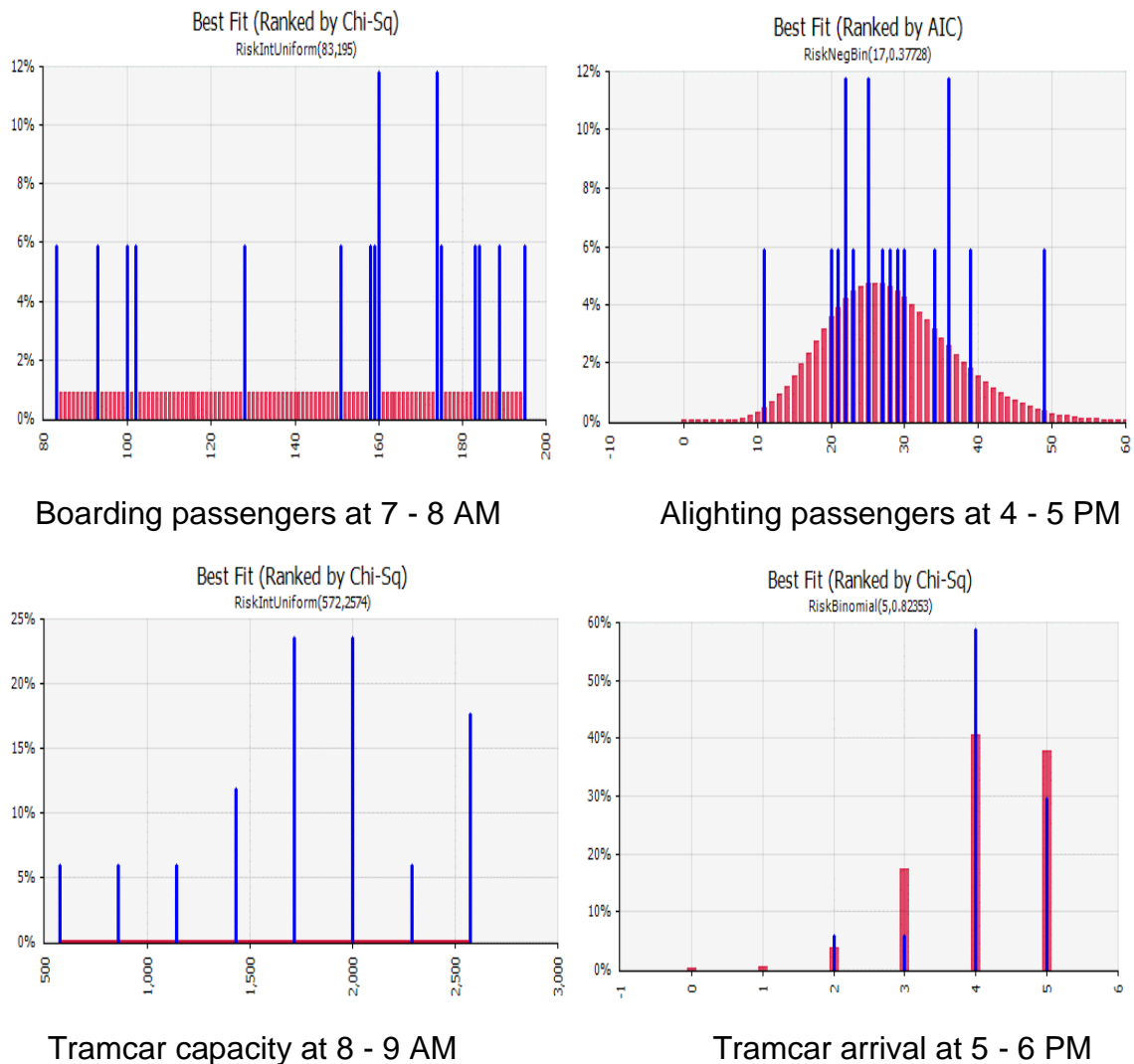


Figure 21 The probability distribution for peak hours at Lideta metro station using @RISK

4.2.3 Discussion and Conclusion

The discrete probability distribution of each station with their corresponding peak hours using @RISK is Uniform, Binomial, or Negative binomial. From all data collected, only tramcar arrival has the same probability distribution. The probability distributions of passenger arrival, tramcar capacity, boarding, and alighting of passengers have either uniform distribution or the Negative binomial distribution. Therefore, based on the two months' passenger arrival, tramcar arrival, tramcar capacity, boarding and alighting of passengers of both Torhailoch and Lideta

station would be either uniform distribution, binomial or negative binomial probability distribution as it can be seen from table 3 and figure 20 & 21.

4.3 Investigation of congestion of AALRT at Torhailoch and Lideta station

Congestion defines as too blocked or crowded and causing difficulties. Besides, congested roads and towns have too much traffic, and movement is painful. It happens when “users share a service system with limited capacity” (Lakshmi & Bindu 2011). According to ‘Your Door to Japan’ (2018) the congestion rate calculated by averaging the level of crowdedness during a train line's busiest hour. MLIT defines a 100% level as a situation where "all the seats in the train taken and the standing passengers can find a strap to hold on to." The congestion also calculated through traffic intensity, ρ , and it can happen when $\rho > 1$, the LRT is overloaded, and a queue formed but when $\rho < 1$, the LRT is not overloaded (no queues formed) (Hillier & Lieberman 2001). The calculation is done through

$$\checkmark \text{ Percentage of Overcrowded} = \frac{\text{additional passenger}}{\text{capacity of tramcar}} = \text{Traffic intensity}(\rho) - 1$$

$$\checkmark \text{ Percentage of extra tramcar required.} =$$

$$\frac{\text{no of additional passenger occurred}}{\text{total number of random number generated}}$$

The percentage of extra tramcar required is the indication of the amount of time overcrowded occurs in a particular interval. Therefore, from Monte Carlo simulation random number generation, the congestion rate or crowdedness during a train line’s busiest hour in each station calculated and summarized as follows;

Table 4 The percentage of overcrowded and extra train required at Torhailoch and Lideta station.

station	Peak hours	Percentage of the extra capacity of tramcar required	Percentage of Overcrowded
Torhailoch	7 - 8 AM	65%	109%
	8 - 9 AM	51%	109%
	4 - 5 PM	49%	111%
	5 - 6 PM	60%	116%
Lideta	7 - 8 AM	87%	116%
	8 - 9 AM	85%	131%
	4 - 5 PM	63%	119%
	5 - 6 PM	71%	131%

The average train congestion rate in AALRT at Torhailoch and Lideta metro station

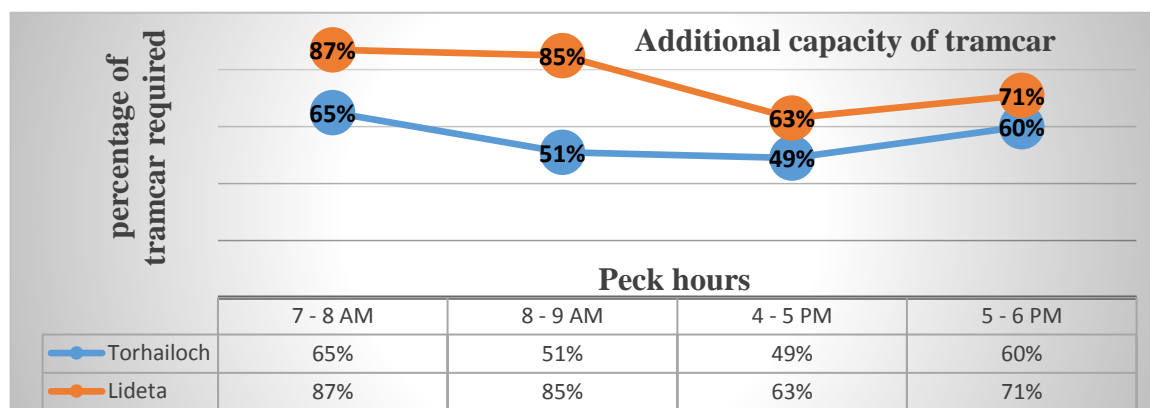


Figure 22 Percentage of additional tramcar required at Trohailoch and Lideta station.

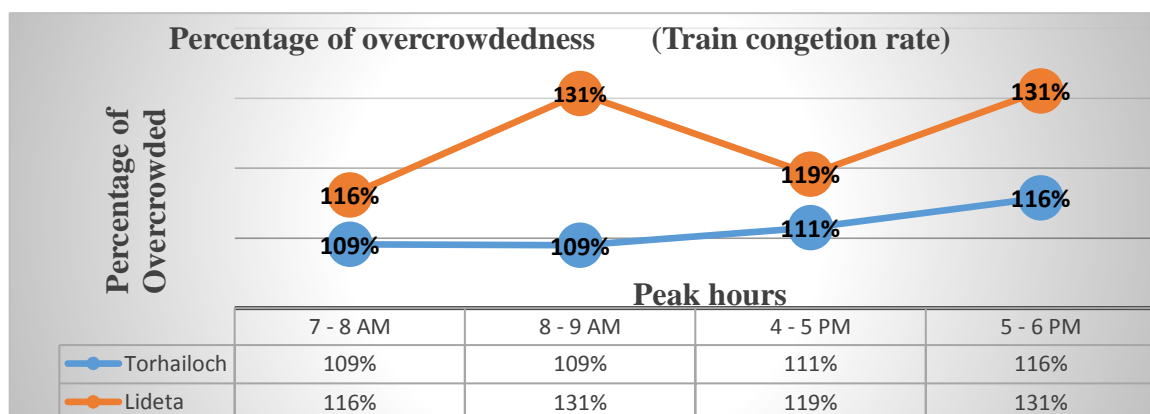


Figure 23 Percentage of over crowdedness at Torhailoch and Lideta station.

From the above table and additional tramcar graph, 49 - 65 percent of additional tramcar is required at Torhailoch, similarly 63 - 87 percent of extra tramcar is required at Lideta metro station. In addition, the congestion/overcrowded rate of AALRT is from 109.13 up to 115.76 percent in Torhailoch and 116.18 up to 131.06 percent at Lideta station, as shown above. Therefore, **Addis Ababa LRT is congested.**

4.4 Optimization of AALRT on Torhailoch and Lideta Metro station

If congestion has happened and the data are characterized to the specific probability distribution, the next step should be finding a solution to the congestion problem. For the current condition, the solution would be to develop a new model based on the actual data. This queue model would be to optimize by increasing the service and decreasing the cost. In this research optimizing the service means decreasing the waiting time or queuing line of customers on the platform of AALRT through increasing the number of arrivals of tramcars with consideration of service cost.

Depending on the output of @RISK, it is impossible to pick one probability distribution for all hours. In addition, it is impossible to choose either Queue Theory or Markov chain for queue model development, since Queue Theory based on Poisson distribution for arrival of customers and exponential distribution for service rate. Similarly, the Markov chain also base on Poisson probability distribution for customer arrival but service mechanism is binomial probability distribution. This is different from the output of @RISK. The other option to develop this queuing model is to use a random number between the minimum and maximum based on the probability distribution. This random number can be created through Monte Carlo simulation to optimize the LRT service in each station.

4.4.1 Optimization of AALRT service by Monte Carlo simulation

Optimization can be done through the Monte Carlo simulation method by generating many random numbers for each peak hour. This random number generated with the consideration of their corresponding probability distribution of each peak hour

- a) Statically summary of passenger arrival, tramcar arrival, and capacity of the tramcar.

Through the statically summary of passenger arrival, tramcar arrival and capacity of tramcar sited, 100 random numbers were generated by considering the probability distribution to find additional tramcar capacity required. This additional passenger would be used to find the additional tramcar capacity for solving the passenger congestion as stated bellows.

Table 5 Statically summary of passenger arrival at Torhailoch station

Distribution Statistics	Peak hours			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
Minimum	980	842	-	-
Maximum	1,348	1,266	+Infinity	+Infinity
Mean	1,164	1,054	913.43	912.21
Mode	980	842	892	893
Median	1,164	1,054	906	906
Std. Deviation	106.52	122.69	142.54	135.09
Skewness	-	-	0.31	0.29
Kurtosis	1.8	1.8	3.14	3.13
Distribution Type	Uniform		Negative Binomial	

- ❖ The above satirical distribution is based on the probability distribution of their corresponding peak hours.

Table 6 Statically summary of passenger arrival at Lideta station

Distribution Statistics	Peak hours of boarding passengers at Lideta station				Peak hours of alighting passengers at Lideta station			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
Minimum	83.00	94	95	101	5	25	11	13
Maximum	95.00	179	217	222	34.00	60.00	49.00	60.00
Mean	39.00	134.65	156	161.5	19.50	37.47	28.06	34.82
Mode	83.00	131.00	95	101	5.00	36	26	31
Median	139.00	133	156	161	19.00	37.00	27.00	34.00
Std. Deviation	32.62	24.99	35.51	35.22	8.66	8.88	8.62	12.50
Skewness	-	0.33	0	0	0	0.361	0.50	0.64
Kurtosis	1.80	3.16	1.7998	1.7998	1.7973	3.1892	3.37	3.61
Distribution	Uniform	Negative Binomial	Uniform		Uniform	Negative Binomial		

❖ The above satirical distribution is based on the probability distribution of their corresponding peak hours.

Table 7 Statically summary of the capacity of tramcar at Torhailoch station

Distribution Statistics	Peak Hours at Torhailoch station				Peak Hours at Lideta station			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
Minimum	858	858	1,144.00	858	572	572	858	572
Maximum	2,002	2,288	2,288	2,288	2,002	2,574	2,288	2,288
Mean	1,430.00	1,573.00	1,838.57	1,797.71	1,463.65	1,573.00	1,833.76	1,783.29
Mode	858.00	858.00	1790	1,712.00	1,351.00	572	1731	1664
Median	1,430.00	1,573.00	1,822.00	1,769.00	1,426.00	1,573.00	1,800.00	1,744.00
Std Dev	330.53	413.09	301.32	394.57	407.74	578.216	434.34	462.38
Skewness	0	0	0.3245	0.4364	0.5547	0	0.4714	0.5164
Kurtosis	1.8	1.8	3.1579	3.2857	3.4615	1.8	3.3333	3.4
Distribution Type	Uniform		Negative Binomial		Uniform	Negative Binomial		

❖ The above satirical distribution is based on the probability distribution of their corresponding peak hours.

Table 8 Statically summary of tramcar arrival at Lideta station

Distribution Statistics	Peak Hours at Torhailoch station				Peak Hours at Lideta station			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
Minimum	2.00	2.00	3.00	2.00	1.00	2.00	2.00	2.00
Maximum	5.00	5.00	5.00	5.00	5.00	6.00	5.00	5.00
Mean	3.64	4.07	4.29	4.21	3.41	4.06	4.24	4.12
Mode	4.00	4.00	5.00	5.00	4.00	4.00	5.00	4.00
Median	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00
Std. Deviation	0.99	0.87	0.78	0.81	1.04	1.15	0.80	0.85
Skewness	4.00	-0.72	-0.91	-0.84	-0.35	-0.31	-0.86	-0.76
Kurtosis	0.82	3.12	3.43	3.31	2.72	2.76	3.34	3.18
Distribution Type	Binomial				Binomial			

- ❖ The above satirical distribution is based on the probability distribution of their corresponding peak hours.

b) Assumption and summary of how the model developed

The assumption made in the development of Monte Carlo simulation

- None peak hours or out of 7-9 AM and 4-6 PM is normal operation by assuming the rate in and out are equal in each station.
- 9-10 AM and 6-7 PM arrivals and the previous peak hours transferred to these hours are manageable through the existing system.
- 3 - 4 PM and 6 - 7 AM are manageable through the existing operation, and there are no passengers transferred to the next station.
- Out of peak hours, the tramcar collects a large number of passengers from the intermediates station, and it became fully utilized.

The model developed as follows

- Data collected from Torhailoch and Lideta station
- The goodness of fit was checked through MS-Excel add in @RISK software to get the probability distribution.
- Since probability distribution was unfit to queue theory and Markov chain, Monte Carlo simulation was selected to generate random numbers.

- One hundred random numbers generated from each probability distribution for passenger and tramcar arrival in Torhailoch and Lideta station. Alighting and boarding passenger arrival at Lideta station are also included.
- The average capacity of the passenger calculated from randomly generated average tramcar arrivals
- The extra passenger that can be transferred to the next hour with first come first served principle. But the Monte Carlo random number generation with extra passenger addressed by adding extra tramcars.
- Calculation tramcar capacity for an additional passenger was conducted based on the extra passengers of each peak hours.
- Summary of optimization and comparison of the actual and ideal solution conducted.

The Monte Carlo random number generated for passenger arrival at Torhailoch and boarding with alighting at Lideta, the extra passenger and average arrival of tramcar attached in Appendix. In this section, only the extra passengers created at Torhailoch and Lideta station on their corresponding peak hours for their random number generated are stated below.

c) Extra passenger of each peck hours at Torhailoch station

Table 9 Extra passenger of each peck hours at Torhailoch station

Total Passengers more the tramcar capacity os the simulation hours				Total passengers more than the sum of the tramcar capacity and a single tramcar			
7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
102.23	55.85	224.21	224.21	-	-	-	-
106.37	211.57	-	-	-	-	-	-
171.25	196.54	-	-	-	-	-	-
-	-	-	-	-	-	-	-
116.83	-	-	-	-	-	-	-
-	-	-	13.05	-	-	-	-
-	-	-	133.19	-	-	-	-
-	64.57	163.20	438.06	-	-	-	152.06
-	-	58.10	58.10	-	-	-	-
-	-	256.54	369.08	-	-	-	83.08
-	19.73	71.12	71.12	-	-	-	-
81.06	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	0.75	-	-	-	-	-	-
30.47	-	-	-	-	-	-	-
180.18	241.67	-	-	-	-	-	-
-	-	-	-	-	-	-	-
59.79	-	85.79	289.17	-	-	-	3.17
166.23	157.95	-	97.74	-	-	-	-
25.00	74.42	96.58	186.54	-	-	-	-
94.89	-	-	111.64	-	-	-	-
135.17	-	112.34	192.27	-	-	-	-
-	105.71	235.00	249.36	-	-	-	-
44.09	-	-	-	-	-	-	-
-	-	25.50	25.50	-	-	-	-
-	86.86	110.62	110.62	-	-	-	-
41.56	132.91	-	-	-	-	-	-
55.59	134.37	239.52	265.54	-	-	-	-
159.98	72.33	-	30.80	-	-	-	-
132.58	44.62	-	-	-	-	-	-
31.30	42.54	113.93	113.93	-	-	-	-
201.76	-	119.19	119.19	-	-	-	-
-	-	-	-	-	-	-	-
167.18	224.87	245.82	452.98	-	-	-	166.98
-	-	114.93	244.68	-	-	-	-
8.45	-	-	-	-	-	-	-
7.41	48.35	-	-	-	-	-	-
122.11	213.10	-	127.85	-	-	-	-
-	121.02	219.64	219.64	-	-	-	-
33.83	-	-	9.38	-	-	-	-
-	-	-	-	-	-	-	-
107.78	82.56	161.27	161.27	-	-	-	-
189.65	27.11	-	55.25	-	-	-	-
196.39	112.12	-	-	-	-	-	-
72.15	17.61	188.59	390.71	-	-	-	104.71
-	35.74	256.57	256.57	-	-	-	-
58.30	-	162.98	450.32	-	-	-	164.32
143.84	100.38	188.22	188.22	-	-	-	-
98.79	127.20	37.51	37.51	-	-	-	-
3.11	-	65.78	65.78	-	-	-	-
93.19	137.89	-	-	-	-	-	-
140.08	16.82	-	-	-	-	-	-

170.99	249.02	-	-	-	-	-	-
182.75	119.74	7.21	7.21	-	-	-	-
167.67	216.23	-	-	-	-	-	-
-	61.49	7.16	147.39	-	-	-	-
-	75.66	-	-	-	-	-	-
-	63.15	47.39	108.46	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
186.53	84.15	-	-	-	-	-	-
41.63	-	204.14	204.14	-	-	-	-
171.47	21.94	263.48	611.02	-	-	-	325.02
9.35	54.32	46.42	143.51	-	-	-	-
114.25	-	108.50	108.50	-	-	-	-
-	-	105.98	105.98	-	-	-	-
7.10	-	152.20	152.20	-	-	-	-
64.60	-	-	-	-	-	-	-
148.03	-	172.39	298.59	-	-	-	12.59
95.97	83.25	-	-	-	-	-	-
198.39	-	234.81	374.59	-	-	-	88.59
61.15	-	159.15	241.24	-	-	-	-
186.97	125.63	-	-	-	-	-	-
-	-	68.61	68.61	-	-	-	-
77.79	-	-	-	-	-	-	-
84.40	155.66	36.95	36.95	-	-	-	-
97.64	105.57	-	118.65	-	-	-	-
42.66	-	236.34	236.34	-	-	-	-
128.76	189.27	-	-	-	-	-	-
52.40	-	-	-	-	-	-	-
75.70	44.49	145.61	145.61	-	-	-	-
-	-	33.18	33.18	-	-	-	-
-	-	-	-	-	-	-	-
125.38	-	52.80	183.94	-	-	-	-
58.41	-	23.74	178.35	-	-	-	-
21.79	-	-	42.90	-	-	-	-
170.15	97.15	-	0.93	-	-	-	-
41.45	-	140.46	251.87	-	-	-	-
-	46.76	-	-	-	-	-	-
67.44	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	184.35	298.85	-	-	-	12.85
-	-	-	-	-	-	-	-
169.22	260.96	63.07	92.35	-	-	-	-
144.61	95.52	-	-	-	-	-	-
-	49.10	227.06	521.83	-	-	-	235.83
-	-	140.30	322.42	-	-	-	36.42
-	83.80	-	-	-	-	-	-
201.31	55.20	21.76	21.76	-	-	-	-

d) Extra passenger of each peck hours at Lideta station

Table 10 Extra passenger of each peck hours at Lideta station

Total Passengers more the tramcar capacity os the simulation hours				Total passengers more than the sum of the tramcar capacity and a single tramcar				Total passengers more than the sum of the tramcar capacity and two single tramcar			
7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
160.97	340.80	337.40	342.55	-	54.80	51.40	56.55	-	-	-	-
192.50	520.13	80.55	-	-	234.13	-	-	-	-	-	-
336.47	629.73	125.44	-	50.47	343.73	-	-	-	57.73	-	-
61.76	-	-	-	-	-	-	-	-	-	-	-
205.31	219.81	32.97	-	-	-	-	-	-	-	-	-
-	-	-	172.00	-	-	-	-	-	-	-	-
-	-	70.60	356.99	-	-	-	70.99	-	-	-	-
31.79	148.09	307.35	778.38	-	-	21.35	492.38	-	-	-	206.38
-	-	204.57	-	-	-	-	-	-	-	-	-
43.90	-	430.67	601.64	-	-	144.67	315.64	-	-	-	29.64
-	106.42	175.73	92.09	-	-	-	-	-	-	-	-
199.06	186.55	-	29.10	-	-	-	-	-	-	-	-
-	0.72	-	-	-	-	-	-	-	-	-	-
-	-	-	9.94	-	-	-	-	-	-	-	-
56.49	141.76	-	102.77	-	-	-	-	-	-	-	-
159.17	171.60	-	-	-	-	-	-	-	-	-	-
292.65	596.92	-	-	6.65	310.92	-	-	-	24.92	-	-
25.81	10.95	18.20	-	-	-	-	-	-	-	-	-
179.44	178.79	170.91	543.59	-	-	-	257.59	-	-	-	-
317.65	538.89	-	167.48	31.65	252.89	-	-	-	-	-	-
128.27	324.53	244.45	452.14	-	38.53	-	166.14	-	-	-	-
225.02	257.49	-	245.86	-	-	-	-	-	-	-	-
280.71	284.28	204.29	363.48	-	-	-	77.48	-	-	-	-
36.33	265.72	405.99	486.50	-	-	119.99	200.50	-	-	-	-
184.20	178.02	-	70.65	-	-	-	-	-	-	-	-
46.26	-	116.85	20.27	-	-	-	-	-	-	-	-
12.90	190.42	175.01	55.06	-	-	-	-	-	-	-	-
108.54	310.36	-	-	-	24.36	-	-	-	-	-	-
177.45	409.00	381.87	517.56	-	123.00	95.87	231.56	-	-	-	-
220.46	356.89	-	205.40	-	70.89	-	-	-	-	-	-
291.30	425.33	55.98	-	5.30	139.33	-	-	-	-	-	-
144.94	306.27	255.62	72.38	-	20.27	-	-	-	-	-	-
335.36	395.41	258.06	227.92	49.36	109.41	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
267.25	549.91	386.57	704.96	-	263.91	100.57	418.96	-	-	-	132.96
148.06	107.55	285.78	535.15	-	-	-	249.15	-	-	-	-
157.13	137.91	-	86.54	-	-	-	-	-	-	-	-
184.93	325.95	-	-	-	39.95	-	-	-	-	-	-
210.26	468.22	21.24	239.74	-	182.22	-	-	-	-	-	-
96.98	351.76	346.59	348.58	-	65.76	60.59	62.58	-	-	-	-
167.24	222.74	-	179.88	-	-	-	-	-	-	-	-
106.55	41.73	-	-	-	-	-	-	-	-	-	-
280.15	448.21	251.93	67.04	-	162.21	-	-	-	-	-	-
344.55	425.05	155.89	363.48	58.55	139.05	-	77.48	-	-	-	-
283.68	438.26	-	-	-	152.26	-	-	-	-	-	-
239.50	393.38	280.98	656.81	-	107.38	-	370.81	-	-	-	84.81
-	122.53	362.33	336.29	-	-	76.33	50.29	-	-	-	-
150.13	155.44	275.80	645.26	-	-	-	359.26	-	-	-	73.26
224.68	419.72	316.53	374.65	-	133.72	30.53	88.65	-	-	-	-
180.24	368.86	118.98	-	-	82.86	-	-	-	-	-	-
96.80	-	251.67	399.64	-	-	-	113.64	-	-	-	-

190.47	384.65	-	-	-	98.65	-	-	-	-	-	-
271.95	389.25	-	26.21	-	103.25	-	-	-	-	-	-
270.73	631.50	-	132.99	-	345.50	-	-	-	59.50	-	-
322.40	541.63	105.60	28.96	36.40	255.63	-	-	-	-	-	-
323.57	629.38	132.31	-	37.57	343.38	-	-	-	57.38	-	-
24.56	195.19	191.67	432.85	-	-	-	146.85	-	-	-	-
80.64	254.88	-	0.25	-	-	-	-	-	-	-	-
-	119.75	153.32	394.03	-	-	-	108.03	-	-	-	-
82.17	-	34.38	-	-	-	-	-	-	-	-	-
51.67	182.70	16.91	78.93	-	-	-	-	-	-	-	-
363.20	562.62	-	-	77.20	276.62	-	-	-	-	-	-
160.86	10.76	303.48	285.27	-	-	17.48	-	-	-	-	-
276.63	406.92	424.30	872.79	-	120.92	138.30	586.79	-	-	-	300.79
144.65	311.32	153.25	357.99	-	25.32	-	71.99	-	-	-	-
194.96	309.20	275.69	349.50	-	23.20	-	63.50	-	-	-	-
93.90	38.68	273.47	337.72	-	-	-	51.72	-	-	-	-
105.96	168.71	298.76	295.37	-	-	12.76	9.37	-	-	-	-
195.11	177.16	-	30.16	-	-	-	-	-	-	-	-
273.65	307.36	370.95	608.16	-	21.36	84.95	322.16	-	-	-	36.16
185.83	322.79	-	15.42	-	36.79	-	-	-	-	-	-
252.12	276.84	300.61	609.17	-	-	14.61	323.17	-	-	-	37.17
202.03	100.63	261.33	416.57	-	-	-	130.57	-	-	-	-
358.45	550.61	-	-	72.45	264.61	-	-	-	-	-	-
-	-	235.46	84.41	-	-	-	-	-	-	-	-
196.92	252.01	115.56	-	-	-	-	-	-	-	-	-
155.44	372.77	144.55	209.13	-	86.77	-	-	-	-	-	-
212.31	425.27	-	271.84	-	139.27	-	-	-	-	-	-
210.91	82.01	357.35	401.75	-	-	71.35	115.75	-	-	-	-
254.38	507.43	79.66	-	-	221.43	-	-	-	-	-	-
201.20	39.95	-	-	-	-	-	-	-	-	-	-
150.80	253.34	242.69	160.93	-	-	-	-	-	-	-	-
50.86	53.74	189.74	25.18	-	-	-	-	-	-	-	-
4.61	-	-	-	-	-	-	-	-	-	-	-
281.82	330.41	199.49	495.93	-	44.41	-	209.93	-	-	-	-
186.03	95.69	135.50	417.91	-	-	-	131.91	-	-	-	-
104.63	213.29	-	144.86	-	-	-	-	-	-	-	-
333.17	492.88	-	91.24	47.17	206.88	-	-	-	-	-	-
165.24	138.52	311.67	516.84	-	-	25.67	230.84	-	-	-	-
98.86	220.45	-	-	-	-	-	-	-	-	-	-
236.62	272.18	-	-	-	-	-	-	-	-	-	-
-	-	115.79	39.00	-	-	-	-	-	-	-	-
-	-	328.04	620.90	-	-	42.04	334.90	-	-	-	48.90
78.76	152.61	-	-	-	-	-	-	-	-	-	-
319.29	697.73	180.46	301.38	33.29	411.73	-	15.38	-	125.73	-	-
211.23	388.24	-	8.18	-	102.24	-	-	-	-	-	-
-	168.05	324.52	740.54	-	-	38.52	454.54	-	-	-	168.54
88.73	-	308.05	658.99	-	-	22.05	372.99	-	-	-	86.99
55.43	252.49	-	-	-	-	-	-	-	-	-	-
308.83	411.54	137.29	118.94	22.83	125.54	-	-	-	-	-	-

The above extra passenger required from 100 Monte Carlo random number generated with their corresponding extra tramcar required summarized as below.

Table 11 Summary of Monte Carlo random number generation

Station	Torhailoch station				Lideta station			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
Minimum	-	-	-	-	-	-	-	-
Maximum	201.76	260.96	263.48	611.02	363.20	697.73	430.67	872.79
Percentage of extra Tramcar required	65	51	49	60	87	85	63	714

Histogram representation of the extra-passenger due to congestion shows the summary of the additional capacity of tramcar required. This histogram shows the appropriate expression of the extra tramcar with its equivalent capacity.

I. Histogram representation of additional tramcar at Torhailoch station

The histogram representation of 7 - 8 AM peak hour should be

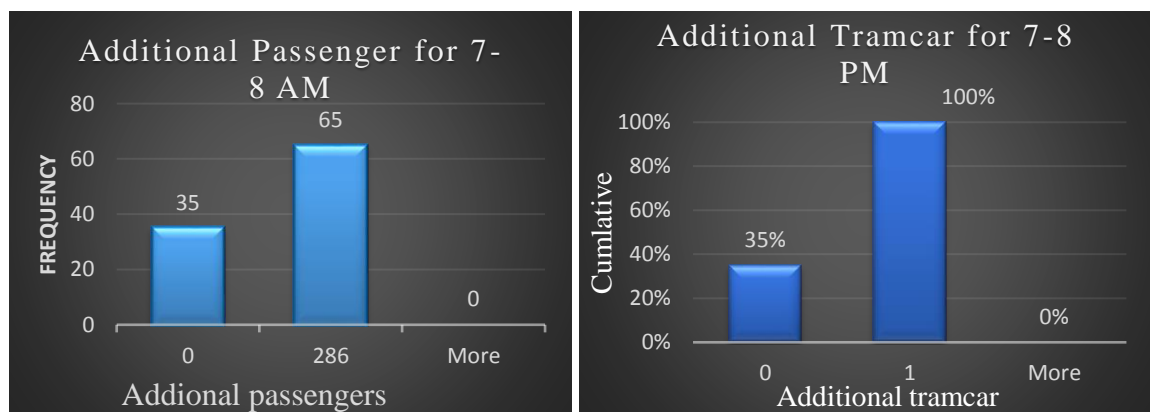


Figure 24 Histogram representation of extra passengers and tramcar from 7–8 AM at Torhailoch.

After histogram developed for the rest of the peak hours using the above additional tramcar required due to passenger congestion, the following summarization conducted for the other peak hours at Torhailoch station;

- From 7-8 AM peak hours, adding a single tramcar will reduce the congestion by up to 100%.
- From 8-9 AM peak hours, adding a single tramcar will reduce the congestion by up to 100%.
- From 4-5 PM peak hours, adding a single tramcar will reduce the congestion by up to 100%.
- From 5-6 PM peak hours, adding a single tramcar will reduce the congestion by up to 88%.

Therefore, a single extra tramcar would eliminate the passenger congestion at the morning shift, but it will reduce about 88% of passenger congestion at the afternoon of AALRT in Torhailoch station.

II. Histogram representation of additional tramcar at Lideta station

The histogram representation of at 7 - 8 AM should be

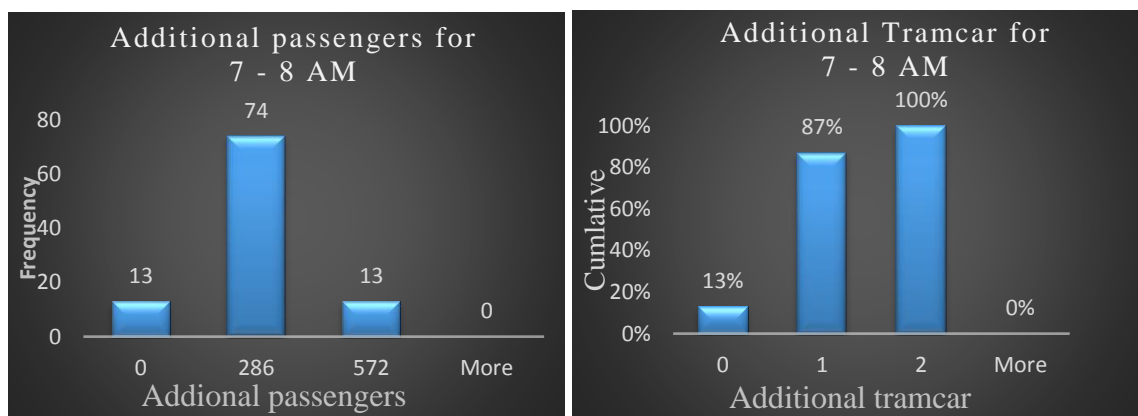


Figure 25 Histogram representation of extra passengers and tramcar from 7 – 8 AM at Lideta

Similar to Torhailoch station, the summary of the rest of the peak hours at Lideta station should be as follows:

- From 7-8 AM peak hours, a single tramcar will reduce the congestion by up to 87%.
- From 8-9 AM peak hours, double Tramcar will reduce the congestion by up to 95%.
- From 4-5 PM peak hours, a single additional tramcar will reduce the congestion by up to 81%.

- From 5-6 PM peak hours, double Tramcar will reduce the congestion by up to 89%.

Therefore, an additional double Tramcar would reduce about 95% of passenger congestion during the morning shift. In addition, double Tramcar would improve the congestion up to 89% in the afternoon shift of AALRT at Lideta station.

III. Summary of the optimization of waiting time using the Monte Carlo simulation method

For 7-9 AM peak hours a double tramcar will reduce the congestion up to 95% at Lideta station, and it will eradicate almost all passengers' congestion at Torhailoch station. Since Lideta and Torhailoch are in the same route, the tramcar that passes through Lideta will reach Torhailoch station, and the passenger congestion of Lideta station is the largest and the governing one for this section. Therefore, a double tramcar would reduce passenger congestion up 95% in the morning shift. In same way, for 4-6 PM peak hours a double tramcar will reduce the congestion up to 89 % at Lideta station, and it will eradicate all of the passengers' congestion at Torhailoch station. Like the morning shift, Lideta station is the largest and the governing one for this section. Therefore, a double tramcar would reduce passenger congestion up 89% in the afternoon shift. Adding extra tramcar increase tramcar arrival rate that reduce the waiting time as stated on Table 13. Schedule for tramcar arrival with their analogous waiting time for three cases of extra tramcar are;

Table 12 Schedule for tramcar arrival with their analogous waiting time

Item			Morning shift (per hour)	Afternoon shift (per hour)	Percentage improving in waiting time		Percentage of reduction of congestion	
					Morning	Afternoon	Morning	Afternoon
Average waiting time on Torhailoch to Lideta stretch (minutes)			17.18	14.90				
case 1	A single tramcar	waiting time of passenger(minutes)	12	12	30%	19%	58%	64%
		No of the arrival of Tramcar (numbers)	5	5				
case 2	2 single tramcars	waiting time of passenger(minutes)	10	10	42%	33%	95%	89%
		No of the arrival of Tramcar (numbers)	6	6				
case 1	A double tramcar	waiting time of passenger(minutes)	12	12	30%	19%	95%	89%
		No of the arrival of Tramcar (number)	5	5				

The above table indicates that the current waiting time of the Addis Ababa Light railway is 16.04 minutes as per the current data simulated through Monte Carlo methods. The 16.04 minutes is the average of 17.18 and 14.90 minutes of the morning and afternoon waiting time respectively in the specified stations.

4.4.2 Summary of optimization

The optimization of AALRT through the Monte Carlo simulation method has shown the above study concludes that two single extra tramcars can reduce the waiting time up to 42% and the congestion up to 95% in the morning. In the same manner, it can reduce the waiting time up to 33% and the congestion up to 89% in the afternoon. The summary of the output of the simulation of the Torhailoch – Lideta section of AALRT would be as follows.

Table 13 New optimization model of LRT at Torhailoch and Lideta station

Case	The capacity of the train added.	Number of trains per hour	Improving in waiting time	Improving in congestion
1	2 single tramcars	6	33% – 42%	89% - 95%
2	a single tramcar	5	19% – 30%	58% - 64%

The maximum waiting time that can be minimized based on the designed passengers' tramcar capacity and geometry AALRT is 7.5 minutes (Tekle 2017). The output of this optimization study, either 10 or 12 minutes is acceptable based on the current capacity of AALRT since the waiting time greater than the minimum waiting time of the basic study. **Therefore, in the case study of Torhailoch and Lideta station of Addis Ababa Light railway the best service would be when the organization adds 2 single tramcars. This will reduce waiting time up to 42% and congestion up to 95% as it stated in Table 11.**

4.5 Performance and cost comparison of the existing and the new model

4.5.1 Performance measurement and comparison of the model

It is the performance evaluation of the current operated and developed model. It also uses to compare how the newly developed model improves the performance of the AALRT at Torhailoch and Lideta station. The calculation of the Performance measurement based on the passenger count, tramcar arrival, capacity of tramcar using following formulas stated.

- Probability of getting server idle

$$= \text{total random number} - \frac{\text{Number of (capacity of server - passenger count)} > 0}{\text{No of Trips}}$$
- Percentage of time that the server became idle =

$$\frac{(\text{Total Random number generated} - \text{Total number of idel server})}{\text{Total Random number generated}}$$
- The average service time =
*(average of (peck hours passenger collected * ideal service time))*, the ideal service time is one hour minus the product of number of trips with 3.5.
- The expected service time =

$$\frac{\sum \text{total capacity of server}}{\sum \text{total capacity of server}} * (\text{simulation hours} - \text{trip no.} * 3.5)$$

- Tramcar stopping time at the station per hours is multiple of number of trips by average stop time at station, here 3.5 minutes at Torhailoch and 1.5 minutes at Lideta
- The average time between arrivals (The average waiting time of those who wait) =
$$\frac{\sum(\text{no. of passenger} - \text{capacity of tramcar}) / (\text{No of trips per hr.})}{\sum \text{total no. of extra passengers}} + (\text{simulation hours} - \text{total stop time per station})$$
- The average time customers spend in the queue =
$$\frac{\text{simulation hours}}{2 * \text{no. of Trips}} + \text{The average time between arrivals (The average waiting time of those who wait)}$$
- The average time customers spend in the system = The average time customers spend in the queue +
$$\frac{\text{distance from start and end station}}{\text{Average speed of travel}} * \text{simulation hours}$$

Table 14 Performance measurement and comparison of the model

It No.	Parameters	Normal (the current operating system)				New model for the system			
		Torhailoch		Lideta		Torhailoch		Lideta	
		Morning	Afternoon	Morning	Afternoon	Morning	Afternoon	Morning	Afternoon
1	Probability of getting server idle	0.45	0.87	0.24	0.57	1.55	1.77	1.07	1.31
2	Percentage of time that the server became idle	42%	58%	14%	33%	100%	100%	98%	95%
3	Average service time	43.62	42.29	45.78	46.59	45.00	45.00	53.94	53.75
4	Expected service time	45.51	48.84	46.11	48.50	70.49	75.65	57.64	60.63
5	Tramcar stopping time at the station per hours	14	14	6	6	15	15	6	6
6	The average time between arrivals (The average waiting time of those who wait)	15.29	12.87	16.95	14.92	-	-	8.60	6.80
7	The average time customers spend in the queue	22.79	20.37	24.45	22.42	5.00	5.00	13.60	11.80
8	The average time customers spend in the system	28.45	26.03	27.55	25.52	10.67	10.67	16.71	14.90
9	Probability of customers waiting (more than 6 minutes)	0.05	0.08	0.15	0.14	-	-	0.001	0.005

Due to the optimization of AALRT at Torhailoch and Lideta station, the probability of getting server idle, percentage of time that the server became idle, average service time and expected service time slightly increased. However, the model improves the average time between arrivals (the average waiting time of those who wait), the average time customers spend in the queue, the average time customers spend in the system and the probability of customers waiting more than 6 minutes. So, the main aim of this research is to improve this parameter of optimization is achieved.

4.5.2 Cost comparison of currently operating and new model of AALRT

It is the compression of the new and old model to see the economic impact of optimization on AALRT on the specific stretch of the case study. It would undertake through the finding of all the variables that incurred the cost and brought

benefit. Then the net economic benefit of the new and old model would be compared by taking the following data to find the cost-benefit analysis variables

- The average monthly earnings of a person in Addis Ababa is 5,851 ETB or 205.56 US\$ (Salaryexplorer 2019).
- The value of saving time (VOT) for the non-business trip is 30% of VOT of the business trip, and the Percentage compositions of business trips vs. non-business trips are 0.25: 0.75, (Mohapatra 2015).
- According to Addis Ababa LRT project east- west line (2009), The rated passengers' capacity of AALRT for one unit of the tramcar is 286 persons per tramcar with 64 seats and 6 standing persons per m². When two units are coupled together to form one train, the rated passengers of the train are 572 persons with 128 seats and 6 standing persons per m². The distance from Torhailoch to Mexico is 2.632 Km

The revenue from tariff, saving of waiting time, fuel saving, accident saving and tramcar capacity cost at peak hours in Torhailoch and Lideta metro station stated from 1 up to 5.

1) Revenue from Tariff

The committee set up by the government proposed the cost of a passenger ticket from start to the end of the journey @ ETB 20 to 30. However, the government is charging the price of ETB 6 for the journey, (Mohapatra 2015). Therefore, the researcher has taken this price of ETB 6 (0.21 US\$) for the whole journey and ETB 2 for each intermediate station based on data collected at the site. To find out the revenue from tariff two-month primary data was collected at peak hour, and the tariff of AALRT from Torhailoch to Mexico was 2 ETB and the US dollar exchange at that time is 28.464 ETB. The passenger numbers and their corresponding passenger tariff study hours presented in Table 15.

Table 15 Passenger arrival with revenue from Tariff

Pick hours	Passenger arrival				Revenue from tarrif (USD)			
	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
1	1,244.00	1,239.00	908.00	898.00	87.41	87.06	63.80	63.10
2	1,251.00	1,244.00	1,023.00	971.00	87.90	87.41	71.88	68.23
3	1,201.00	1,196.00	1,168.00	1,163.00	84.39	84.04	82.07	81.72
4	1,201.00	1,196.00	967.00	703.00	84.39	84.04	67.95	49.40
5	1,074.00	842.00	906.00	660.00	75.46	59.16	63.66	46.38
6	1,008.00	887.00	1,070.00	932.00	70.83	62.33	75.18	65.49
7	1,198.00	1,062.00	925.00	758.00	84.18	74.62	65.00	53.26
8	997.00	1,190.00	924.00	821.00	70.05	83.62	64.93	57.69
9	1,150.00	1,027.00	726.00	718.00	80.80	72.16	51.01	50.45
10	1,265.00	1,094.00	846.00	850.00	88.89	76.87	59.44	59.73
11	1,194.00	1,177.00	947.00	810.00	83.90	82.70	66.54	56.91
12	1,279.00	1,052.00	789.00	875.00	89.87	73.92	55.44	61.48
13	980.00	860.00	937.00	1,038.00	68.86	60.43	65.84	72.94
14	1,257.00	1,266.00	866.00	988.00	88.32	88.96	60.85	69.42
15	1,002.00	1,137.00	807.00	788.00	70.41	79.89	56.70	55.37
16	1,324.00	1,241.00	852.00	879.00	93.03	87.20	59.87	61.76
17	1,149.00	1,203.00	820.00	946.00	80.73	84.53	57.62	66.47
18	1,115.00	1,159.00	904.00	925.00	78.35	81.44	63.52	65.00
19	1,348.00	1,059.00	711.00	768.00	94.72	74.41	49.96	53.96
20	1,123.00	994.00	1,163.00	1,002.00	78.91	69.84	81.72	70.41
21	1,243.00	1,095.00	841.00	912.00	87.34	76.94	59.09	64.08
22	1,311.00	1,187.00	1,409.00	1,284.00	92.12	83.40	99.00	90.22
23	1,242.00	1,045.00	759.00	922.00	87.27	73.43	53.33	64.78
24	1,123.00	1,131.00	711.00	985.00	78.91	79.47	49.96	69.21
25	1,244.00	1,251.00	830.00	1,000.00	87.41	87.90	58.32	70.27
26	1,312.00	1,105.00	826.00	905.00	92.19	77.64	58.04	63.59
27	1,228.00	1,185.00	924.00	920.00	86.29	83.26	64.93	64.64
28	1,093.00	1,183.00	1,017.00	1,121.00	76.80	83.12	71.46	78.77
29	1,348.14	1,216.11	1,067.43	1,121.21	94.73	85.45	75.00	78.78
30	1,325.14	1,223.11	1,056.43	985.21	93.11	85.94	74.23	69.23
31	1,266.14	1,201.11	998.43	994.21	88.97	84.40	70.15	69.86
32	1,354.14	1,247.11	1,076.43	1,014.21	95.15	87.63	75.64	71.26
33	1,331.14	1,232.11	1,084.43	1,103.21	93.53	86.57	76.20	77.52
34	1,334.14	1,213.11	1,049.43	1,064.21	93.74	85.24	73.74	74.78
35	1,278.14	1,207.11	1,045.43	1,057.21	89.81	84.82	73.46	74.29
36	1,331.14	1,236.11	1,075.43	1,046.21	93.53	86.86	75.57	73.51
37	1,327.14	1,172.11	996.43	1,022.21	93.25	82.36	70.01	71.83
38	1,249.14	1,184.11	1,012.43	983.21	87.77	83.20	71.14	69.09
39	1,301.14	1,203.11	1,063.43	1,074.21	91.43	84.54	74.72	75.48
40	1,335.14	1,228.11	1,055.43	1,071.21	93.81	86.29	74.16	75.27
41	1,328.14	1,236.11	1,056.43	1,025.21	93.32	86.86	74.23	72.04
42	1,346.14	1,211.11	1,066.43	1,032.21	94.59	85.10	74.93	72.53
43	1,358.14	1,259.11	1,102.43	1,089.21	95.43	88.47	77.46	76.53
44	1,262.14	1,196.11	986.43	1,010.21	88.68	84.04	69.31	70.98
45	1,259.14	1,194.11	983.43	978.21	88.47	83.90	69.10	68.73
Average	1,233.12	1,154.82	963.38	960.30	86.65	81.14	67.69	67.48
The average of passengers arrival in morning and afternoon shif					83.89		67.58	

2) Saving of waiting time due to AALRT operation

The savings of waiting time of passengers traveling in LRT calculated by multiplying the number of passengers traveled daily and the time saved by Addis Ababa LRT operation. The Value of Time (VOT) of a passenger in Addis Ababa is calculated as below:

- I. The supply of public transportation facilities and the number of passengers served in Addis Ababa in 2016 G.C. (Mesfin 2018).

Table 16 Public transportation facilities and the number of passengers served in Addis Ababa in 2016.

No.	Vehicle Types, Numbers and Activities				Average No. of Trips per day	Number of Passengers per day in 2016	Number of Passengers per day in 2017
	Types	Total	Active				
			No.	%			
1	Anbessa bus	723	440	61	10	396,000	411,048.00
2	Sheger bus	131	89	68	8	39,160	40,648.08
5	Alliance bus	25	17	68	7	10,710	11,116.98
3	Higer bus	393	280	71	12	134,400	139,507.20
4	Kitkit bus	291	191	66	10	76,400	79,303.20
7	Code -3 Minibus	6646	4,392	66	16	843,264	875,308.03
6	Code -1 taxi	4830	3,481	72	16	668,352	693,749.38
9	Light rail	41	18	44	17	97,002	100,688.08
Total		13,080	8,908			2,265,288	2,351,369

- ❖ In the table 16 the number of passengers per day in 2017 is projected from number of passengers per day of 2016 based on 3.8% of population growth in Addis Ababa city. Mesfin (2018) stated the average waiting time of passengers to get public transport services in 2017. Then this average waiting time of passengers in Addis Ababa would be projected from 2017 to 2019 by the population growth as shown below.

Table 17 the average waiting time of public passengers in Addis Ababa (Mesfin 2018).

No.	Types of public transportation service provider	Average waiting time (min)	Number of passengers per day in 2017	Total waiting time
1	Light rail transit	17	100,688	1,711,697.29
2	Anbessa bus	86	411,048	35,350,128.00
3	Sheger bus	24	40,648	1,242,361.44
4	Higer bus/Kitkit buss	20	218,810	4,376,208.00
5	Minibus	14	875,308	12,719,976.32
Total passengers			1,690,881.27	55,400,371.05
Average waiting time				32.76
population increasing of Addis Ababa				3.80%
Increasing waiting time due to increasing population in AA in 2019				35.30

- ❖ The total waiting time obtained by multiplying the average waiting time (min) and the number of passengers per hour in 2017.
- ❖ The average waiting time is the total waiting time of all transportation modes divided by total passengers. Besides that, the current waiting time of the Addis Ababa Light railway is 17 minutes from the above literature and 16.04 minutes as per the current data simulated through Monte Carlo methods.

Value of Time (VOT): The Value of Time (VOT) was estimated for the population greater than 5 years of age, based on the average earnings per person in Addis Ababa. The unit of VOT for work is taken as the average earning per hour. The VOT of commuting trips (i.e. from home to work and back/home to school and back /other social and recreational purposes) has taken as 30% of the VOT of work/ business trips (Mohapatra 2015). The unit of value of saving time, VOT of a person in Addis Ababa has been estimated based on the following:

- The average monthly earnings per person in Addis Ababa is 5,851 birr or 205.56 US\$.
- Hourly income, considering 8 working hours a day and 22 working days a month 33.24 birr or 1.17 US\$. This wage rate or VOT for a business trip, but the VOT for Non-business trip is 30% of VOT of a business trip with 9.97 birrs or 0.35 US\$.
- The percentage composition of business trips Vs. non-business trips is 0.25: 0.75 with 15.79 birrs or 0.55 US\$.

- The average waiting time of AALRT is 17.18 minutes and the average waiting time of passengers in Addis Ababa city is 35.30 minutes.

Saving of money due to LRT operation shown in Table 18 was calculated by multiplying number of passengers arrived, the deference between the average waiting time of passengers in Addis Ababa and the amount of money cost due to loss of time by business Vs. non-business passengers. The table 18 shows the calculation of saving of money due to LRT operation for each peck hours of both shifts.

Table 18 saving of money due to LRT operation

Peck hors	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
1	12,506.56	12,456.29	9,128.58	9,028.05
2	12,576.94	12,506.56	10,284.74	9,761.95
3	12,074.26	12,023.99	11,742.49	11,692.23
4	12,074.26	12,023.99	9,721.74	7,067.61
5	10,797.46	8,465.05	9,108.48	6,635.31
6	10,133.93	8,917.46	10,757.25	9,369.87
7	12,044.10	10,676.82	9,299.49	7,620.56
8	10,023.34	11,963.67	9,289.44	8,253.93
9	11,561.53	10,324.95	7,298.84	7,218.42
10	12,717.68	10,998.53	8,505.27	8,545.48
11	12,003.89	11,832.98	9,520.67	8,143.34
12	12,858.43	10,576.29	7,932.22	8,796.82
13	9,852.44	8,646.01	9,420.13	10,435.54
14	12,637.26	12,727.74	8,706.34	9,932.86
15	10,073.61	11,430.84	8,113.18	7,922.16
16	13,310.84	12,476.40	8,565.59	8,837.03
17	11,551.48	12,094.37	8,243.87	9,510.62
18	11,209.66	11,652.01	9,088.37	9,299.49
19	13,552.13	10,646.66	7,148.04	7,721.09
20	11,290.09	9,993.18	11,692.23	10,073.61
21	12,496.51	11,008.59	8,455.00	9,168.80
22	13,180.15	11,933.51	14,165.39	12,908.70
23	12,486.45	10,505.91	7,630.61	9,269.33
24	11,290.09	11,370.51	7,148.04	9,902.70
25	12,506.56	12,576.94	8,344.41	10,053.51
26	13,190.20	11,109.12	8,304.20	9,098.42
27	12,345.70	11,913.40	9,289.44	9,249.22
28	10,988.48	11,893.30	10,224.41	11,269.98
29	13,553.56	12,226.14	10,731.40	11,272.13
30	13,322.33	12,296.51	10,620.81	9,904.86
31	12,729.17	12,075.34	10,037.71	9,995.34
32	13,613.88	12,537.80	10,821.88	10,196.41
33	13,382.65	12,387.00	10,902.31	11,091.17
34	13,412.81	12,195.98	10,550.44	10,699.08
35	12,849.82	12,135.66	10,510.22	10,628.71
36	13,382.65	12,427.21	10,811.83	10,518.12
37	13,342.44	11,783.79	10,017.60	10,276.84
38	12,558.26	11,904.43	10,178.46	9,884.75
39	13,081.05	12,095.44	10,691.18	10,799.62
40	13,422.87	12,346.78	10,610.76	10,769.46
41	13,352.49	12,427.21	10,620.81	10,307.00
42	13,533.45	12,175.87	10,721.35	10,377.37
43	13,654.10	12,658.44	11,083.27	10,950.42
44	12,688.96	12,025.07	9,917.06	10,156.19
45	12,658.80	12,004.96	9,886.90	9,834.48
Average	12,397.18	11,609.97	9,685.39	9,654.41

3) Fuel-saving due to the operation of AALRT

The operation of AALRT will result in reductions in the number of vehicles plying in Addis Ababa road. Since some portion of passengers will travel in LRT. Further, this reduction in vehicles based on the Addis Ababa cities passenger's preference. In this case, Taxis and other modes of vehicles are personal preference, thus may not be affected by LRT. Taking these as parameters, the calculation of fuel savings has done with the consideration of calculation of the vehicle composition and average fuel consumption of public transport in Addis Ababa by excluding the AALRT.

Table 19 Vehicle composition and average fuel consumption of public transport in Addis Ababa

Type of Transportation	Number of Passengers per day in 2019 G.C.	Percentage composition	Fuel consumption per 100km	Fuel rate in Addis Ababa (US\$)	Fuel cost/km, US\$
Minibus	978,933	57.14%	10.8	0.57	6.11
Higer/Kitkit bus	235,756	13.76%	14.4	0.57	8.15
Sheger buss	55,774	3.26%	18	0.57	10.18
Anbessa bus	442,881	25.85%	21.6	0.57	12.22
Total	1,713,344				37

Calculation of fuel-saving by considering the above vehicle composition of public transport with their corresponding fuel consumption in Addis Ababa when it replaces AALRT from Torhailoch to Lideta of 2.63Km.

Table 20 Fuel-saving due to LRT operation

No.	Pick hours			
	7-8 AM	8-9 AM	4-5 PM	5-6 PM
1	8.86	8.76	6.48	6.37
2	8.86	8.86	7.22	7.01
3	8.51	8.41	8.30	8.30
4	8.51	8.41	7.01	5.29
5	7.67	6.02	6.48	4.73
6	7.11	6.37	7.57	6.80
7	8.51	7.57	6.58	5.60
8	7.11	8.41	6.48	5.92
9	7.99	7.22	5.39	5.39
10	8.97	7.78	6.02	6.02
11	8.41	8.41	6.90	5.81
12	8.97	7.57	5.71	6.27
13	7.01	6.02	6.80	7.32
14	8.86	8.97	6.13	7.11
15	7.11	7.99	5.81	5.71
16	9.28	8.86	6.02	6.27
17	7.99	8.51	5.92	6.90
18	7.88	8.09	6.48	6.58
19	9.39	7.57	5.29	5.60
20	7.88	7.11	8.30	7.11
21	8.86	7.78	6.02	6.48
22	9.18	8.41	10.05	9.07
23	8.86	7.32	5.60	6.48
24	7.88	7.88	5.29	7.01
25	8.86	8.86	5.92	7.11
26	9.18	7.78	5.92	6.48
27	8.76	8.41	6.48	6.48
28	7.78	8.41	7.22	7.88
29	4.97	4.50	4.00	4.17
30	4.91	4.63	4.00	3.71
31	4.74	4.50	3.76	3.76
32	4.97	4.69	4.06	3.82
33	4.91	4.63	4.06	4.11
34	4.91	4.50	3.95	4.00
35	4.74	4.50	3.87	4.00
36	4.91	4.63	4.06	3.87
37	4.91	4.39	3.76	3.82
38	4.69	4.45	3.82	3.71
39	4.80	4.50	4.00	4.06
40	4.91	4.63	4.00	4.06
41	4.91	4.63	4.00	3.82
42	4.97	4.50	4.00	3.87
43	4.97	4.69	4.11	4.06
44	4.74	4.45	3.71	3.82
45	4.69	4.45	3.71	3.71
Average	7.04	6.64	5.56	5.54

4) Accident saving

The introduction of AALRT will result in a reduction in the number of vehicles from Addis Ababa road. This reduction will result in a reduction of fatal (killed) as well as serious injury accidents (KSI). Mohapatra states that the reduction in damage due to killing and serious injuries (KSI) traffic accidents as a result of the introduction of LRT is 30% of the total damage of KSI of the whole Addis Ababa (Mohapatra 2015). Studies worldwide show that LRT measures generally result in reducing KSI, saves damage to vehicles, helps in reduction in compensation paid to the affected by insurance agency (Murty, Dhavala, & Ghosh, 2006).

Addis Ababa city transport office collected the daily traffic accident and corresponding accident cost in 2011 ETC. The researcher takes this traffic accident data for the particular time of data collected. This data is 70% of the traffic accident since the introduction of LRT reduces the traffic accident in the city by 30% as stated in Mohapatra (Mohapatra 2015). That is why the other significant benefit of LRT is the reduction in KSI. Then it saved the human loss and insurance cost.

Table 21 Accident saving due to the operation of AALRT

No.	No. of Daeth	Cost of daeth	No. of Injury	Injury cost	Accident Cost (ETB) Per day	Accident Cost (USD) per hour
1	1.00	40,000.00	-	-	17,142.86	37.64
2	-	-	-	-	-	-
3	2.00	80,000.00	-	-	34,285.71	75.28
4	2.00	80,000.00	-	-	34,285.71	75.28
5	2.00	80,000.00	-	-	34,285.71	75.28
6	-	-	-	-	-	-
7	2.00	80,000.00	1.00	68,837.99	63,787.71	140.06
8	1.00	40,000.00	2.00	69,027.07	46,725.89	102.60
9	1.00	40,000.00	3.00	103,632.47	61,556.77	135.17
10	1.00	40,000.00	1.00	34,477.33	31,918.86	70.09
11	-	-	1.00	34,473.31	14,774.27	32.44
12	1.00	40,000.00	1.00	34,557.79	31,953.34	70.16
13	-	-	-	-	-	-
14	1.00	40,000.00	-	-	17,142.86	37.64
15	-	-	1.00	34,453.19	14,765.65	32.42
16	1.00	40,000.00	-	-	17,142.86	37.64
17	1.00	40,000.00	1.00	34,517.56	31,936.10	70.12
18	1.00	40,000.00	1.00	34,525.61	31,939.55	70.13
19	-	-	1.00	34,465.26	14,770.83	32.43
20	1.00	40,000.00	2.00	68,974.77	46,703.47	102.55
21	1.00	40,000.00	2.00	68,958.68	46,696.58	102.54
22	1.00	40,000.00	1.00	34,469.28	31,915.41	70.08
23	-	-	2.00	68,970.75	29,558.89	64.91
24	-	-	-	-	-	-
25	1.00	40,000.00	3.00	103,828.41	61,640.75	135.35
26	-	-	1.00	34,481.35	14,777.72	32.45
27	1.00	40,000.00	-	-	17,142.86	37.64
28	-	-	-	-	-	-
29	3.00	120,000.00	-	-	51,428.57	112.93
30	-	-	-	-	-	-
31	-	-	-	-	-	-
32	2.00	80,000.00	-	-	34,285.71	75.28
33	1.00	40,000.00	-	-	17,142.86	37.64
34	1.00	40,000.00	-	-	17,142.86	37.64
35	-	-	2.00	69,328.80	29,712.34	65.24
36	-	-	2.00	69,292.60	29,696.83	65.21
37	1.00	40,000.00	-	-	17,142.86	37.64
38	1.00	40,000.00	-	-	17,142.86	37.64
39	1.00	40,000.00	-	-	17,142.86	37.64
40	-	-	-	-	-	-
41	2.00	80,000.00	-	-	34,285.71	75.28
42	1.00	40,000.00	6.00	207,773.19	106,188.51	233.17
43	3.00	120,000.00	1.00	34,634.23	66,271.81	145.52
44	-	-	1.00	34,610.09	14,832.90	32.57
45	-	-	2.00	69,502.43	29,786.75	65.41
Average					1,229,053.78	2,698.74

1) Tramcar arrival cost

I. Human resource cost

Table 22 Human resource cost

Staff	Single tramcar	Double tramcar	Average salary (ETB)	Average salary (USD)	Cost (ETB)		Cost (USD)	
					Single tramcar	Double tramcar	Single tramcar	Double tramcar
Operator	2	2	5,851	205.56	11,702	11,702	411.12	411.12
Ticket seller	4	4			23,404	23,404	822.24	822.24
Cleaner	1	2			5,851	11,702	205.56	411.12
Maintenance worker	3	3			17,553	17,553	616.68	616.68
Police man	2	2			11,702	11,702	411.12	411.12
Total cost =					70,212	76,063	2,466.73	2,672.29

✚ The number of staff was taken from operating area at data collection time except cleaner. that was taken during the serving time of researcher at AALRT.

II. The total cost of LRT operation

It is the total cost incurred for the AALRT operation, starting from its feasibility up to the operation. The cost of investment, maintenance, interest on the debt, and equity capital as listed below with the cost incurred for the operational service (Mohapatra 2015).

Table 23 Total cost of LRT operation

Item	cost per years	cost per hours
Investment cost	12,617,187.50	2,160.48
Maintenance	19,720,000.00	3,376.71
Interest on Debt	12,110,000.00	2,073.63
Equity Capital	14,250,000.00	2,440.07
Salary of Single tramcar	29,600.75	166.49
Salary of Double tramcar	32,067.48	173.25
Electricity Single tramcar	15,584.62	213.49
Electricity Double tramcar	31,169.24	426.98
Operation cost of single tramcar =		379.98
Operation cost of double tramcar =		600.23

4.5.3 Summary of cost comparison

It is the comparison of the cost of currently operated with the new model per hour in the morning and afternoon. So, the cost analysis of existing LRT and new mode in the morning and afternoon would be summarized as follows:

Table 24 the cost analysis of currently operated LRT and new model in the morning and afternoon

No.	Variables	Morning (US\$)			Afternoon (US\$)		
		Current operated	New model		Current operated	New model	
			Single tramcar	Double tramcar		Single tramcar	Double tramcar
1	Benefit						
1.1	Revenue Tariff of Operation of LRT	83.89	83.89	83.89	67.58	67.58	67.58
1.2	Saving in Passengers Time (VOT)	12,003.58	15,434.76	16,759.55	9,669.90	12,434.01	13,501.24
1.3	Saving in fuel due to LRT operations	6.84	6.84	6.84	5.55	5.55	5.55
1.4	Saving due to reducing accidents	59.97	59.97	59.97	59.97	59.97	59.97
Total benefit		12,154.29	15,585.47	16,910.26	9,803.01	12,567.12	13,634.34
2	Cost						
2.1	Investment Cost	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01
2.2	Maintenance Cost	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71
2.3	Interest on Debt	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07
2.4	Equity Capital	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63
2.5	Operation	1,866.62	1,899.91	2,279.89	2,071.78	1,899.91	2,279.89
2.6	Passengers Electric Locomotive unit cost	380.90	476.12	571.35	380.90	380.90	380.90
Total cost		12,232.93	12,361.45	12,836.65	12,438.09	12,266.22	12,646.20
Profitability		-78.65	3,224.03	4,073.60	-2,635.08	300.90	988.14

Therefore, from the above table of AALRT optimization of Torhailoch and Lideta station, the optimization will improve not only the services, but also the profit of the organization. It improves the profit from loss of 78.65 to the profit of 4,073.60 US\$ per hour in the morning similarly in the afternoon from the loss of 2,635.08 US\$ to the profit of 988.14 US\$ per hour.

4.6 Optimization solution and Marginal benefit

In this section, the researcher will examine the potential optimization solutions based on combined Queuing Theory and Monte Carlo simulation results. Besides, it discusses limits for future work, including examining the marginal benefits of adding extra tramcar to improve the congestion of AALRT. This research is based on the particular case study of Torhailoch and Lideta station.

I. Optimization Solutions

Having acquired information regarding the optimization of LRT at Torhailoch and Lideta via simulation, the researcher analyzes different scenarios. The premise for this work is that an existing LRT service involving two shifts: one from 6:00 AM to 2:00 PM, and the other from 2:00 PM until 10:00 PM as per the interview of OCC staff of AALRT. The results of our simulations suggest that this optimization plan is optimal with a steady-state condition at rush hours of 7-9 AM of the morning and 4-6 PM of the afternoon. As an example, see the results of Figure 23 by implementing the Monte Carlo simulation under the assumption that each service provider works a two shift. The zigzag curve represents the ideal tramcars recommended by the Monte Carlo simulation, while the two straight lines represent the tramcars number the researcher obtains from the simulations. The green straight line indicates when two separate tramcars added to improve the service, but the blue straight line indicates when a single tramcar adds in average service of the current system.

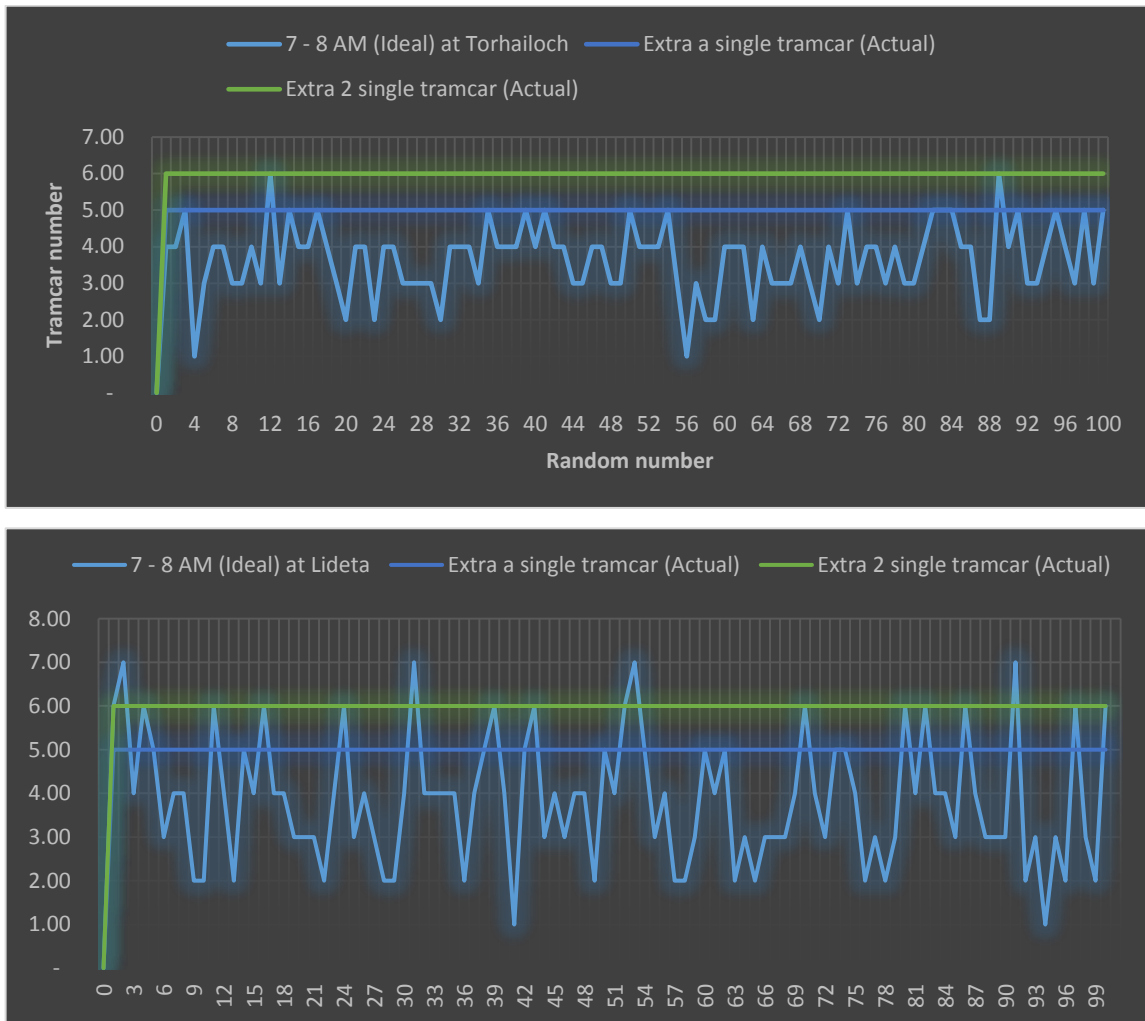


Figure 26 the ideal and the actual number of tramcars at 7 – 8 AM of the morning shift

The above graph of the ideal and the actual number of tramcars on Torhailoch and Lideta station at 7 – 8 AM of the morning shift and others stated in appendix. The actual straight line is a clear indication of the steady-state performance of the model developed.

II. Marginal benefit of additional tramcars

The capacity of tramcar of AALRT is 286 passengers. So, using the optimization methods described in the above, the researcher found the minimum number of tramcars needed to alleviate the congestion at a steady state. Figure 25 shows the average percentage of passengers served within an hour as a function of the number of tramcars used in the simulations for the morning and afternoon shifts. Interestingly, the figure indicates that adding a few additional tramcars could increase the average percentage of passengers served within an hour by a

significant amount. The marginal benefit of optimal tramcar and additional tramcar saw as the slope of the graph. From the standpoint of percentage of service provided, it may make sense to increase the number of tramcars working until the marginal benefit of adding another tramcar begins to decline, which does occur until the percentage of passengers served within an hour is 100%.

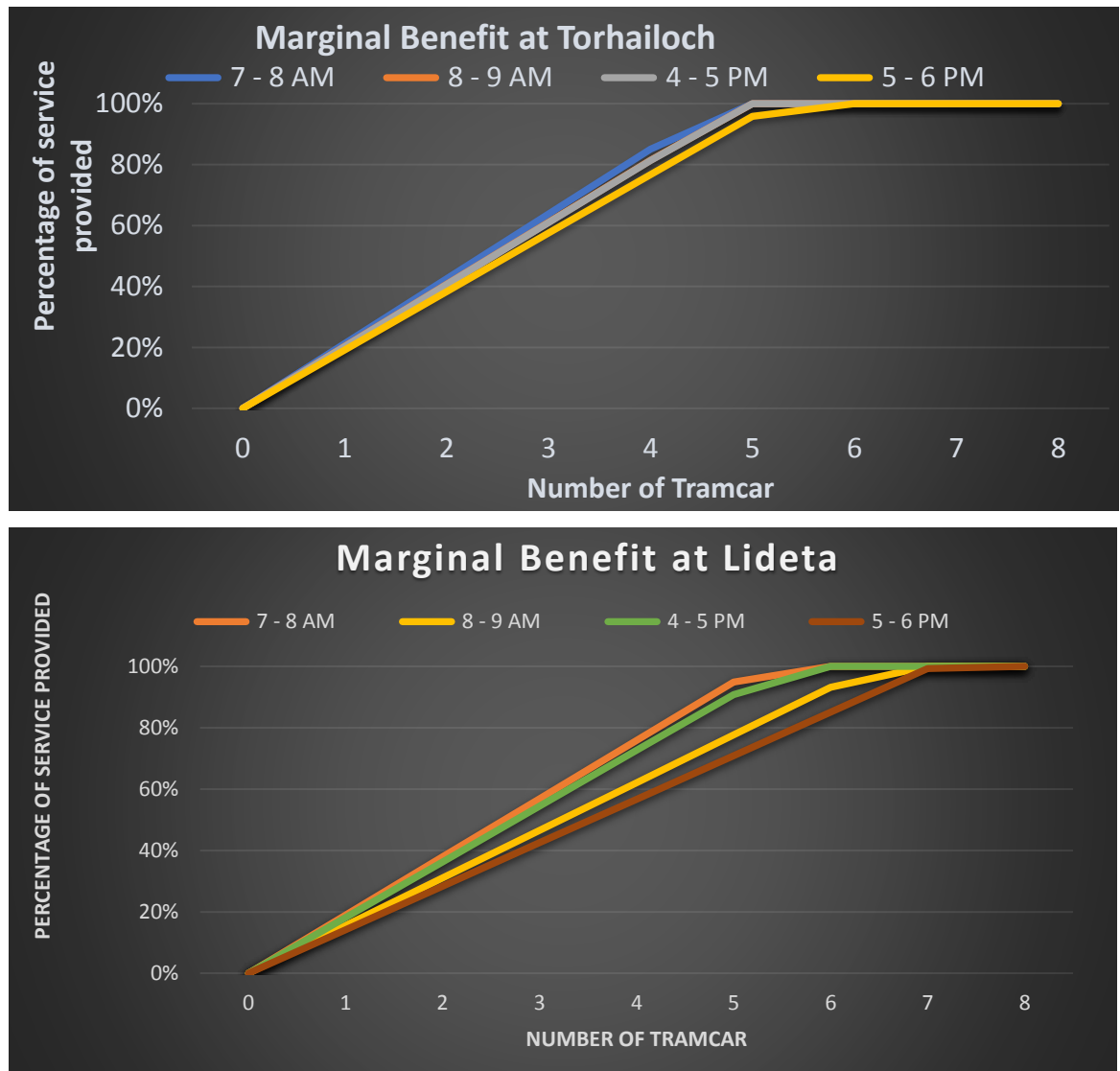


Figure 27 The marginal service provides by adding extra tramcar at Torhailoch and Lideta station

AALRT has 41 tramcars. The unit cost of tramcar was 3,222,913 USD, with 10% transportation cost from China to Addis Ababa as per the contract document. The minimum tramcar arrival per hour required to cover the essential cost without considering benefit is 3 in the morning and 5 in the afternoon. However, adding

tramcar can increase the marginal benefit up to the optimum tramcar arrival stated in section 4.4.2. After the optimum service level, adding tramcar increase both the cost and benefit, but the cost is high as compared to the benefit. This cost decreases the profit as compared to the optimum service level. All in all, the marginal benefit of increasing tramcar in consideration of percentage of service provided as of figure 23 and cost-benefit analysis of figure 25 proved that the optimum service at the current situation of AALRT is six tramcar arrival per hour.

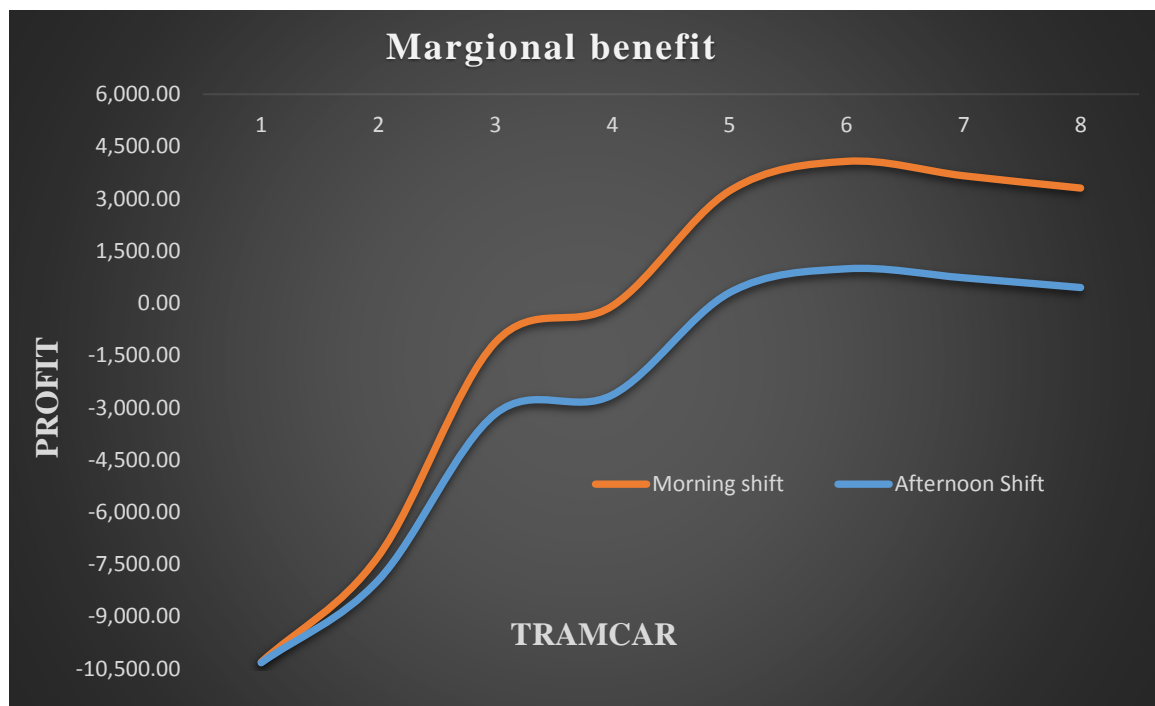


Figure 28 The marginal benefit of adding extra tramcar at Torhailoch and Lideta station

CHAPTER FIVE - CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the finding and analysis of AALRT on Torhailoch and Lideta station, the following conclusions have summarized.

1. Addis Ababa Light Railway Transit is congested and with low satisfaction of customers.
2. The probability distribution of the arrivals of passengers is binomial, negative binomial, or uniform distribution.
3. A new optimization model is developed based on the optimization of the cost of service on hand loss of benefit due to the dissatisfaction of passengers on other hands - the optimum waiting time is 10 minutes.
4. This optimum waiting time decreases the waiting time of passengers by 7.18 and 4.90 minutes in the morning and afternoon, respectively.
5. The total benefit of AALRT service can be improved through optimization on each station just like Torhailoch and Lideta. It also indicated that the serviceability could also be improved.
6. The new model indicates the company can improve both the income and service only through increasing the number of tramcars. For example, the company can obtain 4,073.60 and 988.14 US\$ per hour in the morning and afternoon shift, respectively, only by adding two tramcars in the morning and the afternoon.
7. The tramcar arrival or the service of AALRT be consistent; the optimum is six single tramcars per hour.

All in all, the new model indicates that Addis Ababa Light Railway Transit is not functioning as planned, and its service can be modified if properly optimized. The modification through optimization would increase the satisfaction of customers by reducing the waiting time and passenger congestion and increasing the benefit through optimizing the cost-benefit of the company.

5.2 Recommendation

- ✚ The company should improve its service by developing a new model through optimizing the cost and benefit. This improvement would reduce the cost of operating, capital cost, and maintenance cost. It also brings additional benefits to the company in both profit and increasing the passengers as a whole.
- ✚ The ticketing system of Addis Ababa Light Railway Transit should be electronically rather than the current manual system.
- ✚ The government should expand LRT in the other corridors of Addis Ababa to give more coverage, and it is better to make underground in all stations.
- ✚ The tramcar should hold as per the design capacity to eradicate losing doors on the landing station due to massive congestion within the tramcars.
- ✚ The company should develop a strategy to collect raw data for researchers.
- ✚ Overall, optimizations have to be undertaking on the whole stretch of Addis Ababa Light Railway Transit to improve serviceability.
- ✚ The company should improve the serviceability through optimization by taking each year population growth and economic fluctuation.

5.3 Recommendation for further studies

- ✚ The whole stretch of AALRT should be studied.
- ✚ Further researchers have to be developed using discrete event simulation to optimize the AALRT.
- ✚ The further study shall conduct to improve the passenger service through the multimodal transport
- ✚ The further model shall develop by increasing the critical station to increase accuracy.

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APPENDIX 1

Table 25 Monte Carlo random number passenger arrival and tramcar capacity at Torhailoch station

Monte carlo simulation of Random Number for Pasenger arrival				MC Random number pules extra passenger transferd from previous pick hours				Arrival of Tramcar Capacity			
7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
1,246.23	1,097.63	1,368.21	759.97	1,246.23	1,199.85	1,368.21	984.18	1,144	1,144	1,144	1,144
1,250.37	1,249.20	1,047.92	679.98	1,250.37	1,355.57	1,047.92	679.98	1,144	1,144	1,144	1,144
1,315.25	1,169.29	1,106.50	823.92	1,315.25	1,340.54	1,106.50	823.92	1,144	1,144	1,144	1,144
1,126.37	925.74	777.95	987.59	1,126.37	925.74	777.95	987.59	1,144	1,144	1,144	1,144
1,260.83	998.00	1,104.01	949.62	1,260.83	1,114.83	1,104.01	949.62	1,144	1,144	1,144	1,144
995.54	933.80	770.14	1,157.05	995.54	933.80	770.14	1,157.05	1,144	1,144	1,144	1,144
1,008.10	954.12	1,063.15	1,277.19	1,008.10	954.12	1,063.15	1,277.19	1,144	1,144	1,144	1,144
1,062.99	1,208.57	1,307.20	1,255.67	1,062.99	1,208.57	1,307.20	1,418.87	1,144	1,144	1,144	1,144
983.03	948.34	1,202.10	678.08	983.03	948.34	1,202.10	736.18	1,144	1,144	1,144	1,144
1,094.57	948.74	1,400.54	999.99	1,094.57	948.74	1,400.54	1,256.53	1,144	1,144	1,144	1,144
982.26	1,163.73	1,215.12	874.62	982.26	1,163.73	1,215.12	945.74	1,144	1,144	1,144	1,144
1,225.06	952.85	721.37	1,016.02	1,225.06	1,033.92	721.37	1,016.02	1,144	1,144	1,144	1,144
1,059.15	1,051.69	953.74	907.82	1,059.15	1,051.69	953.74	907.82	1,144	1,144	1,144	1,144
989.70	980.64	1,027.01	1,017.32	989.70	980.64	1,027.01	1,017.32	1,144	1,144	1,144	1,144
1,112.04	1,144.75	790.12	1,125.16	1,112.04	1,144.75	790.12	1,125.16	1,144	1,144	1,144	1,144
1,174.47	1,028.85	1,035.85	854.83	1,174.47	1,059.32	1,035.85	854.83	1,144	1,144	1,144	1,144
1,324.18	1,205.50	715.77	968.52	1,324.18	1,385.67	715.77	968.52	1,144	1,144	1,144	1,144
1,003.42	1,053.67	982.01	828.32	1,003.42	1,053.67	982.01	828.32	1,144	1,144	1,144	1,144
1,203.79	970.31	1,229.79	1,261.60	1,203.79	1,030.10	1,229.79	1,347.39	1,144	1,144	1,144	1,144
1,310.23	1,135.72	1,022.12	1,241.74	1,310.23	1,301.95	1,022.12	1,241.74	1,144	1,144	1,144	1,144
1,169.00	1,193.42	1,240.58	1,137.37	1,169.00	1,218.42	1,240.58	1,233.96	1,144	1,144	1,144	1,144
1,238.89	1,022.27	957.80	1,255.64	1,238.89	1,117.15	957.80	1,255.64	1,144	1,144	1,144	1,144
1,279.17	934.08	1,256.34	1,111.59	1,279.17	1,069.26	1,256.34	1,223.93	1,144	1,144	1,144	1,144
1,082.43	1,249.71	1,379.00	923.36	1,082.43	1,249.71	1,379.00	1,158.36	1,144	1,144	1,144	1,144
1,188.09	960.42	982.40	1,096.95	1,188.09	1,004.51	982.40	1,096.95	1,144	1,144	1,144	1,144
1,008.61	972.82	1,169.50	849.97	1,008.61	972.82	1,169.50	875.48	1,144	1,144	1,144	1,144
1,014.11	1,230.86	1,254.62	711.73	1,014.11	1,230.86	1,254.62	822.35	1,144	1,144	1,144	1,144
1,185.56	1,235.36	851.93	740.47	1,185.56	1,276.91	851.93	740.47	1,144	1,144	1,144	1,144
1,199.59	1,222.78	1,383.52	930.50	1,199.59	1,278.37	1,383.52	1,170.02	1,144	1,144	1,144	1,144
1,303.98	1,056.35	948.51	1,174.80	1,303.98	1,216.33	948.51	1,174.80	1,144	1,144	1,144	1,144
1,276.58	1,056.03	1,043.65	676.15	1,276.58	1,188.62	1,043.65	676.15	1,144	1,144	1,144	1,144
1,175.30	1,155.24	1,257.93	763.79	1,175.30	1,186.54	1,257.93	877.72	1,144	1,144	1,144	1,144
1,345.76	892.47	1,263.19	893.85	1,345.76	1,094.23	1,263.19	1,013.04	1,144	1,144	1,144	1,144
1,025.49	955.48	941.57	766.50	1,025.49	955.48	941.57	766.50	1,144	1,144	1,144	1,144
1,311.18	1,201.69	1,389.82	1,105.34	1,311.18	1,368.87	1,389.82	1,351.16	1,144	1,144	1,144	1,144
1,120.64	1,027.45	1,258.93	1,158.81	1,120.64	1,027.45	1,258.93	1,273.74	1,144	1,144	1,144	1,144
1,152.45	1,000.68	880.04	1,082.97	1,152.45	1,009.13	880.04	1,082.97	1,144	1,144	1,144	1,144
1,151.41	1,184.94	828.46	1,030.53	1,151.41	1,192.35	828.46	1,030.53	1,144	1,144	1,144	1,144
1,266.11	1,234.99	1,034.59	1,271.85	1,266.11	1,357.10	1,034.59	1,271.85	1,144	1,144	1,144	1,144
1,135.00	1,265.02	1,363.64	785.40	1,135.00	1,265.02	1,363.64	1,005.04	1,144	1,144	1,144	1,144
1,177.83	1,067.54	787.19	1,153.38	1,177.83	1,101.38	787.19	1,153.38	1,144	1,144	1,144	1,144
1,109.42	1,033.98	806.12	850.56	1,109.42	1,033.98	806.12	850.56	1,144	1,144	1,144	1,144
1,251.78	1,118.78	1,305.27	710.31	1,251.78	1,226.56	1,305.27	871.59	1,144	1,144	1,144	1,144
1,333.65	981.45	1,121.49	1,199.25	1,333.65	1,171.11	1,121.49	1,199.25	1,144	1,144	1,144	1,144
1,340.39	1,059.73	896.21	774.63	1,340.39	1,256.12	896.21	774.63	1,144	1,144	1,144	1,144
1,216.15	1,089.46	1,332.59	1,157.53	1,216.15	1,161.61	1,332.59	1,346.12	1,144	1,144	1,144	1,144
985.23	1,179.74	1,400.57	759.46	985.23	1,179.74	1,400.57	1,016.03	1,144	1,144	1,144	1,144

1,202.30	978.13	1,306.98	1,268.35	1,202.30	1,036.43	1,306.98	1,431.34	1,144	1,144	1,144	1,144
1,287.84	1,100.54	1,332.22	913.84	1,287.84	1,244.38	1,332.22	1,102.06	1,144	1,144	1,144	1,144
1,242.79	1,172.41	1,181.51	693.70	1,242.79	1,271.20	1,181.51	731.21	1,144	1,144	1,144	1,144
1,147.11	912.74	1,209.78	1,050.01	1,147.11	915.85	1,209.78	1,115.79	1,144	1,144	1,144	1,144
1,237.19	1,188.70	958.34	811.03	1,237.19	1,281.89	958.34	811.03	1,144	1,144	1,144	1,144
1,284.08	1,020.74	765.86	1,045.93	1,284.08	1,160.82	765.86	1,045.93	1,144	1,144	1,144	1,144
1,314.99	1,222.03	765.09	1,096.65	1,314.99	1,393.02	765.09	1,096.65	1,144	1,144	1,144	1,144
1,326.75	1,081.00	1,151.21	892.16	1,326.75	1,263.74	1,151.21	899.37	1,144	1,144	1,144	1,144
1,311.67	1,192.56	1,086.29	705.69	1,311.67	1,360.23	1,086.29	705.69	1,144	1,144	1,144	1,144
1,040.59	1,205.49	1,151.16	1,277.07	1,040.59	1,205.49	1,151.16	1,284.23	1,144	1,144	1,144	1,144
1,130.66	1,219.66	869.45	996.65	1,130.66	1,219.66	869.45	996.65	1,144	1,144	1,144	1,144
989.07	1,207.15	1,191.39	1,157.67	989.07	1,207.15	1,191.39	1,205.06	1,144	1,144	1,144	1,144
1,068.97	850.25	1,037.59	895.33	1,068.97	850.25	1,037.59	895.33	1,144	1,144	1,144	1,144
1,088.59	1,129.47	1,017.22	1,059.70	1,088.59	1,129.47	1,017.22	1,059.70	1,144	1,144	1,144	1,144
1,330.53	1,041.62	985.73	978.93	1,330.53	1,228.15	985.73	978.93	1,144	1,144	1,144	1,144
1,185.63	844.51	1,348.14	777.61	1,185.63	886.13	1,348.14	981.74	1,144	1,144	1,144	1,144
1,315.47	994.47	1,407.48	1,228.06	1,315.47	1,165.94	1,407.48	1,491.54	1,144	1,144	1,144	1,144
1,153.35	1,188.97	1,190.42	1,194.67	1,153.35	1,198.32	1,190.42	1,241.09	1,144	1,144	1,144	1,144
1,258.25	1,011.83	1,252.50	1,026.00	1,258.25	1,126.08	1,252.50	1,134.50	1,144	1,144	1,144	1,144
1,065.60	977.35	1,249.98	1,024.46	1,065.60	977.35	1,249.98	1,130.44	1,144	1,144	1,144	1,144
1,151.10	1,100.08	1,296.20	843.88	1,151.10	1,107.18	1,296.20	996.09	1,144	1,144	1,144	1,144
1,208.60	983.81	937.75	1,086.05	1,208.60	1,048.42	937.75	1,086.05	1,144	1,144	1,144	1,144
1,292.03	963.50	1,316.39	1,097.81	1,292.03	1,111.54	1,316.39	1,270.20	1,144	1,144	1,144	1,144
1,239.97	1,131.28	718.55	1,054.30	1,239.97	1,227.25	718.55	1,054.30	1,144	1,144	1,144	1,144
1,342.39	927.18	1,378.81	1,048.97	1,342.39	1,125.56	1,378.81	1,283.78	1,144	1,144	1,144	1,144
1,205.15	868.92	1,303.15	1,066.94	1,205.15	930.07	1,303.15	1,226.09	1,144	1,144	1,144	1,144
1,330.97	1,082.66	885.94	791.50	1,330.97	1,269.63	885.94	791.50	1,144	1,144	1,144	1,144
999.21	1,027.05	1,212.61	758.19	999.21	1,027.05	1,212.61	826.80	1,144	1,144	1,144	1,144
1,221.79	1,039.32	1,140.90	771.23	1,221.79	1,117.12	1,140.90	771.23	1,144	1,144	1,144	1,144
1,228.40	1,215.26	1,180.95	1,013.50	1,228.40	1,299.66	1,180.95	1,050.44	1,144	1,144	1,144	1,144
1,241.64	1,151.93	788.85	1,262.65	1,241.64	1,249.57	788.85	1,262.65	1,144	1,144	1,144	1,144
1,186.66	863.87	1,380.34	773.96	1,186.66	906.53	1,380.34	1,010.29	1,144	1,144	1,144	1,144
1,272.76	1,204.51	1,091.72	744.25	1,272.76	1,333.27	1,091.72	744.25	1,144	1,144	1,144	1,144
1,196.40	871.13	1,013.88	907.83	1,196.40	923.53	1,013.88	907.83	1,144	1,144	1,144	1,144
1,219.70	1,112.79	1,289.61	808.55	1,219.70	1,188.49	1,289.61	954.16	1,144	1,144	1,144	1,144
1,102.01	1,004.89	1,177.18	857.82	1,102.01	1,004.89	1,177.18	891.00	1,144	1,144	1,144	1,144
1,060.80	914.99	1,016.37	762.86	1,060.80	914.99	1,016.37	762.86	1,144	1,144	1,144	1,144
1,269.38	983.68	1,196.80	1,222.34	1,269.38	1,109.06	1,196.80	1,275.14	1,144	1,144	1,144	1,144
1,202.41	909.89	1,167.74	1,274.88	1,202.41	968.29	1,167.74	1,298.62	1,144	1,144	1,144	1,144
1,165.79	1,110.17	757.77	1,186.90	1,165.79	1,131.97	757.77	1,186.90	1,144	1,144	1,144	1,144
1,314.15	1,071.00	958.51	1,144.93	1,314.15	1,241.15	958.51	1,144.93	1,144	1,144	1,144	1,144
1,185.45	969.12	1,284.46	1,114.96	1,185.45	1,010.57	1,284.46	1,255.41	1,144	1,144	1,144	1,144
1,069.02	1,190.76	824.61	797.21	1,069.02	1,190.76	824.61	797.21	1,144	1,144	1,144	1,144
1,211.44	1,023.93	1,019.14	1,016.93	1,211.44	1,091.37	1,019.14	1,016.93	1,144	1,144	1,144	1,144
1,049.70	944.39	1,127.87	951.80	1,049.70	944.39	1,127.87	951.80	1,144	1,144	1,144	1,144
1,022.22	1,010.08	1,328.35	1,074.15	1,022.22	1,010.08	1,328.35	1,258.50	1,144	1,144	1,144	1,144
1,115.19	1,074.37	1,045.76	1,042.17	1,115.19	1,074.37	1,045.76	1,042.17	1,144	1,144	1,144	1,144
1,313.22	1,235.75	1,207.07	1,110.22	1,313.22	1,404.96	1,207.07	1,173.29	1,144	1,144	1,144	1,144
1,288.61	1,094.91	956.17	1,014.77	1,288.61	1,239.52	956.17	1,014.77	1,144	1,144	1,144	1,144
1,029.84	1,193.10	1,371.06	1,211.72	1,029.84	1,193.10	1,371.06	1,438.77	1,144	1,144	1,144	1,144
1,141.51	847.11	1,284.30	1,185.82	1,141.51	847.11	1,284.30	1,326.12	1,144	1,144	1,144	1,144
1,066.95	1,227.80	913.12	935.37	1,066.95	1,227.80	913.12	935.37	1,144	1,144	1,144	1,144
1,345.31	997.89	1,165.76	1,029.43	1,345.31	1,199.20	1,165.76	1,051.19	1,144	1,144	1,144	1,144

Table 26 Monte Carlo random number passenger arrival and tramcar capacity at Lideta station

Arrival of passenger at Lideta station				MC Random number pules extra passenger transferd from previous pick hours				Arrival of Tramcar Capacity			
7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM	7 - 8 AM	8 - 9 AM	4 - 5 PM	5 - 6 PM
1,304.97	1,323.84	1,481.40	1,149.15	1,304.97	1,484.80	1,481.40	1,486.55	1,144	1,144	1,144	1,144
1,336.50	1,471.64	1,224.55	751.12	1,336.50	1,664.13	1,224.55	831.67	1,144	1,144	1,144	1,144
1,480.47	1,437.27	1,269.44	1,003.52	1,480.47	1,773.73	1,269.44	1,128.97	1,144	1,144	1,144	1,144
1,205.76	974.43	916.76	1,132.83	1,205.76	1,036.20	916.76	1,132.83	1,144	1,144	1,144	1,144
1,349.31	1,158.51	1,176.97	1,090.03	1,349.31	1,363.81	1,176.97	1,123.00	1,144	1,144	1,144	1,144
1,123.84	1,040.65	922.11	1,316.00	1,123.84	1,040.65	922.11	1,316.00	1,144	1,144	1,144	1,144
1,141.47	1,033.15	1,214.60	1,430.39	1,141.47	1,033.15	1,214.60	1,500.99	1,144	1,144	1,144	1,144
1,175.79	1,260.30	1,451.35	1,615.03	1,175.79	1,292.09	1,451.35	1,922.38	1,144	1,144	1,144	1,144
1,142.61	1,001.02	1,348.57	869.04	1,142.61	1,001.02	1,348.57	1,073.61	1,144	1,144	1,144	1,144
1,187.90	1,035.44	1,574.67	1,314.97	1,187.90	1,079.34	1,574.67	1,745.64	1,144	1,144	1,144	1,144
1,111.35	1,250.42	1,319.73	1,060.36	1,111.35	1,250.42	1,319.73	1,236.09	1,144	1,144	1,144	1,144
1,343.06	1,131.50	796.62	1,173.10	1,343.06	1,330.55	796.62	1,173.10	1,144	1,144	1,144	1,144
1,136.44	1,144.72	1,051.91	1,075.21	1,136.44	1,144.72	1,051.91	1,075.21	1,144	1,144	1,144	1,144
1,085.11	1,119.92	1,139.95	1,153.94	1,085.11	1,119.92	1,139.95	1,153.94	1,144	1,144	1,144	1,144
1,200.49	1,229.27	946.54	1,246.77	1,200.49	1,285.76	946.54	1,246.77	1,144	1,144	1,144	1,144
1,303.17	1,156.43	1,143.18	1,053.11	1,303.17	1,315.60	1,143.18	1,053.11	1,144	1,144	1,144	1,144
1,436.65	1,448.27	899.73	1,128.40	1,436.65	1,740.92	899.73	1,128.40	1,144	1,144	1,144	1,144
1,169.81	1,129.14	1,162.20	939.20	1,169.81	1,154.95	1,162.20	957.39	1,144	1,144	1,144	1,144
1,323.44	1,143.35	1,314.91	1,516.68	1,323.44	1,322.79	1,314.91	1,687.59	1,144	1,144	1,144	1,144
1,461.65	1,365.24	1,137.06	1,311.48	1,461.65	1,682.89	1,137.06	1,311.48	1,144	1,144	1,144	1,144
1,272.27	1,340.26	1,388.45	1,351.70	1,272.27	1,468.53	1,388.45	1,596.14	1,144	1,144	1,144	1,144
1,369.02	1,176.47	1,081.49	1,389.86	1,369.02	1,401.49	1,081.49	1,389.86	1,144	1,144	1,144	1,144
1,424.71	1,147.57	1,348.29	1,303.19	1,424.71	1,428.28	1,348.29	1,507.48	1,144	1,144	1,144	1,144
1,180.33	1,373.39	1,549.99	1,224.51	1,180.33	1,409.72	1,549.99	1,630.50	1,144	1,144	1,144	1,144
1,328.20	1,137.82	1,135.70	1,214.65	1,328.20	1,322.02	1,135.70	1,214.65	1,144	1,144	1,144	1,144
1,190.26	1,086.43	1,260.85	1,047.42	1,190.26	1,132.69	1,260.85	1,164.27	1,144	1,144	1,144	1,144
1,156.90	1,321.52	1,319.01	1,024.05	1,156.90	1,334.42	1,319.01	1,199.06	1,144	1,144	1,144	1,144
1,252.54	1,345.82	1,029.36	913.99	1,252.54	1,454.36	1,029.36	913.99	1,144	1,144	1,144	1,144
1,321.45	1,375.55	1,525.87	1,279.69	1,321.45	1,553.00	1,525.87	1,661.56	1,144	1,144	1,144	1,144
1,364.46	1,280.43	1,041.78	1,349.40	1,364.46	1,500.89	1,041.78	1,349.40	1,144	1,144	1,144	1,144
1,435.30	1,278.03	1,199.98	869.79	1,435.30	1,569.33	1,199.98	925.77	1,144	1,144	1,144	1,144
1,288.94	1,305.33	1,399.62	960.76	1,288.94	1,450.27	1,399.62	1,216.38	1,144	1,144	1,144	1,144
1,479.36	1,204.05	1,402.06	1,113.86	1,479.36	1,539.41	1,402.06	1,371.92	1,144	1,144	1,144	1,144
1,116.92	1,089.76	1,028.55	941.86	1,116.92	1,089.76	1,028.55	941.86	1,144	1,144	1,144	1,144
1,411.25	1,426.67	1,530.57	1,462.39	1,411.25	1,693.91	1,530.57	1,848.96	1,144	1,144	1,144	1,144
1,292.06	1,103.49	1,429.78	1,393.37	1,292.06	1,251.55	1,429.78	1,679.15	1,144	1,144	1,144	1,144
1,301.13	1,124.77	1,037.71	1,230.54	1,301.13	1,281.91	1,037.71	1,230.54	1,144	1,144	1,144	1,144
1,328.93	1,285.02	908.86	1,135.44	1,328.93	1,469.95	908.86	1,135.44	1,144	1,144	1,144	1,144
1,354.26	1,401.96	1,165.24	1,362.49	1,354.26	1,612.22	1,165.24	1,383.74	1,144	1,144	1,144	1,144
1,240.98	1,398.78	1,490.59	1,146.00	1,240.98	1,495.76	1,490.59	1,492.58	1,144	1,144	1,144	1,144
1,311.24	1,199.50	929.62	1,323.88	1,311.24	1,366.74	929.62	1,323.88	1,144	1,144	1,144	1,144
1,250.55	1,079.18	900.46	1,019.82	1,250.55	1,185.73	900.46	1,019.82	1,144	1,144	1,144	1,144
1,424.15	1,312.06	1,395.93	959.11	1,424.15	1,592.21	1,395.93	1,211.04	1,144	1,144	1,144	1,144
1,488.55	1,224.50	1,299.89	1,351.59	1,488.55	1,569.05	1,299.89	1,507.48	1,144	1,144	1,144	1,144
1,427.68	1,298.58	981.03	831.29	1,427.68	1,582.26	981.03	831.29	1,144	1,144	1,144	1,144
1,383.50	1,297.88	1,424.98	1,519.83	1,383.50	1,537.38	1,424.98	1,800.81	1,144	1,144	1,144	1,144
1,091.66	1,266.53	1,506.33	1,117.95	1,091.66	1,266.53	1,506.33	1,480.29	1,144	1,144	1,144	1,144

1,294.13	1,149.30	1,419.80	1,513.46	1,294.13	1,299.44	1,419.80	1,789.26	1,144	1,144	1,144	1,144
1,368.68	1,339.04	1,460.53	1,202.12	1,368.68	1,563.72	1,460.53	1,518.65	1,144	1,144	1,144	1,144
1,324.24	1,332.63	1,262.98	904.08	1,324.24	1,512.86	1,262.98	1,023.05	1,144	1,144	1,144	1,144
1,240.80	974.82	1,395.67	1,291.97	1,240.80	1,071.62	1,395.67	1,543.64	1,144	1,144	1,144	1,144
1,334.47	1,338.18	1,035.99	867.41	1,334.47	1,528.65	1,035.99	867.41	1,144	1,144	1,144	1,144
1,415.95	1,261.29	958.65	1,170.21	1,415.95	1,533.25	958.65	1,170.21	1,144	1,144	1,144	1,144
1,414.73	1,504.77	886.33	1,276.99	1,414.73	1,775.50	886.33	1,276.99	1,144	1,144	1,144	1,144
1,466.40	1,363.24	1,249.60	1,067.36	1,466.40	1,685.63	1,249.60	1,172.96	1,144	1,144	1,144	1,144
1,467.57	1,449.81	1,276.31	791.68	1,467.57	1,773.38	1,276.31	923.99	1,144	1,144	1,144	1,144
1,168.56	1,314.63	1,335.67	1,385.18	1,168.56	1,339.19	1,335.67	1,576.85	1,144	1,144	1,144	1,144
1,224.64	1,318.24	1,019.37	1,144.25	1,224.64	1,398.88	1,019.37	1,144.25	1,144	1,144	1,144	1,144
1,087.42	1,263.75	1,297.32	1,384.71	1,087.42	1,263.75	1,297.32	1,538.03	1,144	1,144	1,144	1,144
1,226.17	924.43	1,178.38	1,038.53	1,226.17	1,006.60	1,178.38	1,072.91	1,144	1,144	1,144	1,144
1,195.67	1,275.04	1,160.91	1,206.02	1,195.67	1,326.70	1,160.91	1,222.93	1,144	1,144	1,144	1,144
1,507.20	1,343.42	1,082.06	1,103.69	1,507.20	1,706.62	1,082.06	1,103.69	1,144	1,144	1,144	1,144
1,304.86	993.89	1,447.48	1,125.79	1,304.86	1,154.76	1,447.48	1,429.27	1,144	1,144	1,144	1,144
1,420.63	1,274.29	1,568.30	1,592.49	1,420.63	1,550.92	1,568.30	2,016.79	1,144	1,144	1,144	1,144
1,288.65	1,310.67	1,297.25	1,348.75	1,288.65	1,455.32	1,297.25	1,501.99	1,144	1,144	1,144	1,144
1,338.96	1,258.24	1,419.69	1,217.81	1,338.96	1,453.20	1,419.69	1,493.50	1,144	1,144	1,144	1,144
1,237.90	1,088.79	1,417.47	1,208.25	1,237.90	1,182.68	1,417.47	1,481.72	1,144	1,144	1,144	1,144
1,249.96	1,206.74	1,442.76	1,140.61	1,249.96	1,312.71	1,442.76	1,439.37	1,144	1,144	1,144	1,144
1,339.11	1,126.05	1,068.58	1,174.16	1,339.11	1,321.16	1,068.58	1,174.16	1,144	1,144	1,144	1,144
1,417.65	1,177.71	1,514.95	1,381.21	1,417.65	1,451.36	1,514.95	1,752.16	1,144	1,144	1,144	1,144
1,329.83	1,280.96	770.69	1,159.42	1,329.83	1,466.79	770.69	1,159.42	1,144	1,144	1,144	1,144
1,396.12	1,168.72	1,444.61	1,452.56	1,396.12	1,420.84	1,444.61	1,753.17	1,144	1,144	1,144	1,144
1,346.03	1,042.60	1,405.33	1,299.23	1,346.03	1,244.63	1,405.33	1,560.57	1,144	1,144	1,144	1,144
1,502.45	1,336.15	972.58	869.35	1,502.45	1,694.61	972.58	869.35	1,144	1,144	1,144	1,144
1,077.98	1,091.19	1,379.46	992.95	1,077.98	1,091.19	1,379.46	1,228.41	1,144	1,144	1,144	1,144
1,340.92	1,199.10	1,259.56	941.04	1,340.92	1,396.01	1,259.56	1,056.60	1,144	1,144	1,144	1,144
1,299.44	1,361.32	1,288.55	1,208.58	1,299.44	1,516.77	1,288.55	1,353.13	1,144	1,144	1,144	1,144
1,356.31	1,356.96	855.66	1,415.84	1,356.31	1,569.27	855.66	1,415.84	1,144	1,144	1,144	1,144
1,354.91	1,015.10	1,501.35	1,188.40	1,354.91	1,226.01	1,501.35	1,545.75	1,144	1,144	1,144	1,144
1,398.38	1,397.06	1,223.66	895.21	1,398.38	1,651.43	1,223.66	974.87	1,144	1,144	1,144	1,144
1,345.20	982.74	1,078.25	1,091.59	1,345.20	1,183.95	1,078.25	1,091.59	1,144	1,144	1,144	1,144
1,294.80	1,246.54	1,386.69	1,062.24	1,294.80	1,397.34	1,386.69	1,304.93	1,144	1,144	1,144	1,144
1,194.86	1,146.89	1,333.74	979.43	1,194.86	1,197.74	1,333.74	1,169.18	1,144	1,144	1,144	1,144
1,148.61	1,006.16	1,089.24	880.20	1,148.61	1,010.77	1,089.24	880.20	1,144	1,144	1,144	1,144
1,425.82	1,192.59	1,343.49	1,440.45	1,425.82	1,474.41	1,343.49	1,639.93	1,144	1,144	1,144	1,144
1,330.03	1,053.66	1,279.50	1,426.40	1,330.03	1,239.69	1,279.50	1,561.91	1,144	1,144	1,144	1,144
1,248.63	1,252.67	943.76	1,288.86	1,248.63	1,357.29	943.76	1,288.86	1,144	1,144	1,144	1,144
1,477.17	1,303.72	1,039.67	1,235.24	1,477.17	1,636.88	1,039.67	1,235.24	1,144	1,144	1,144	1,144
1,309.24	1,117.28	1,455.67	1,349.17	1,309.24	1,282.52	1,455.67	1,660.84	1,144	1,144	1,144	1,144
1,242.86	1,265.59	908.17	980.69	1,242.86	1,364.45	908.17	980.69	1,144	1,144	1,144	1,144
1,380.62	1,179.56	1,099.67	1,078.31	1,380.62	1,416.18	1,099.67	1,078.31	1,144	1,144	1,144	1,144
1,122.88	1,054.87	1,259.79	1,067.21	1,122.88	1,054.87	1,259.79	1,183.00	1,144	1,144	1,144	1,144
1,117.44	1,069.16	1,472.04	1,436.86	1,117.44	1,069.16	1,472.04	1,764.90	1,144	1,144	1,144	1,144
1,222.76	1,217.85	1,123.57	1,114.15	1,222.76	1,296.61	1,123.57	1,114.15	1,144	1,144	1,144	1,144
1,463.29	1,522.45	1,324.46	1,264.91	1,463.29	1,841.73	1,324.46	1,445.38	1,144	1,144	1,144	1,144
1,355.23	1,321.01	1,132.33	1,152.18	1,355.23	1,532.24	1,132.33	1,152.18	1,144	1,144	1,144	1,144
1,134.70	1,312.05	1,468.52	1,560.01	1,134.70	1,312.05	1,468.52	1,884.54	1,144	1,144	1,144	1,144
1,232.73	931.11	1,452.05	1,494.94	1,232.73	1,019.84	1,452.05	1,802.99	1,144	1,144	1,144	1,144
1,199.43	1,341.07	1,043.75	1,066.88	1,199.43	1,396.49	1,043.75	1,066.88	1,144	1,144	1,144	1,144
1,452.83	1,246.71	1,281.29	1,125.65	1,452.83	1,555.54	1,281.29	1,262.94	1,144	1,144	1,144	1,144

Table 27 Extra passenger and their corresponding ideal extra tramcar at Torhailoch station

7 - 8 AM			8 - 9 AM			4 - 5 PM			5 - 6 PM		
Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	12.20	12.20	1	-	-	-	-	-	-
438.87	438.87	2	438.87	438.87	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	14.98	14.98	1
-	-	-	-	-	-	-	-	-	-	-	-
126.91	126.91	1	126.91	126.91	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	26.89	26.89	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
303.87	303.87	2	303.87	303.87	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
64.49	64.49	1	64.49	64.49	1	-	-	-	-	-	-
214.01	214.01	1	399.20	399.20	2	-	-	-	-	-	-
127.21	127.21	1	207.48	207.48	1	-	-	-	-	-	-
84.60	84.60	1	84.60	84.60	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	290.05	290.05	2
-	-	-	117.93	117.93	1	-	-	-	-	-	-
130.58	130.58	1	130.58	130.58	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	88.12	88.12	1	88.12	88.12	1
-	-	-	-	-	-	-	-	-	-	-	-
149.62	149.62	1	149.62	149.62	1	-	-	-	-	-	-
-	-	-	11.41	11.41	1	109.45	109.45	1	109.45	109.45	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	14.86	14.86	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
39.05	39.05	1	39.05	39.05	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
308.27	308.27	2	308.27	308.27	2	66.66	66.66	1	66.66	66.66	1
-	-	-	-	-	-	59.96	59.96	1	242.93	242.93	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	177.76	177.76	1	-	-	-	18.30	18.30	1
406.23	406.23	2	453.82	453.82	2	-	-	-	-	-	-
-	-	-	-	-	-	130.03	130.03	1	130.03	130.03	1
206.44	206.44	1	206.44	206.44	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	182.86	182.86	1	-	-	-	-	-	-
16.04	16.04	1	16.04	16.04	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	194.20	194.20	1	-	-	-	69.34	69.34	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	254.40	254.40	1
-	-	-	-	-	-	-	-	-	55.70	55.70	1
33.12	33.12	1	33.12	33.12	1	-	-	-	-	-	-

30.88	30.88	1	30.88	30.88	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
215.21	215.21	1	215.21	215.21	1	-	-	-	-	-	-
183.31	183.31	1	183.31	183.31	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	24.82	24.82	1	15.93	15.93	1	15.93	15.93	1
-	-	-	-	-	-	-	-	-	-	-	-
73.93	73.93	1	73.93	73.93	1	-	-	-	-	-	-
51.78	51.78	1	51.78	51.78	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
91.80	91.80	1	91.80	91.80	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	141.03	141.03	1
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
306.37	306.37	2	306.37	306.37	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
252.78	252.78	1	252.78	252.78	1	-	-	-	-	-	-
-	-	-	163.82	163.82	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
15.87	15.87	1	15.87	15.87	1	-	-	-	-	-	-
-	-	-	171.95	171.95	1	-	-	-	57.79	57.79	1
310.72	310.72	2	310.72	310.72	2	-	-	-	-	-	-
317.70	317.70	2	317.70	317.70	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
267.19	267.19	1	267.19	267.19	1	-	-	-	-	-	-
23.50	23.50	1	23.50	23.50	1	7.94	7.94	1	7.94	7.94	1
119.30	119.30	1	119.30	119.30	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	216.66	216.66	1
-	-	-	-	-	-	-	-	-	-	-	-
204.51	204.51	1	204.51	204.51	1	-	-	-	-	-	-
296.12	296.12	2	391.60	391.60	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
52.37	52.37	1	52.37	52.37	1	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
4.58	4.58	1	4.58	4.58	1	-	-	-	156.60	156.60	1
-	-	-	235.15	235.15	1	-	-	-	42.51	42.51	1
-	-	-	-	-	-	96.42	96.42	1	96.42	96.42	1
198.88	198.88	1	198.88	198.88	1	-	-	-	-	-	-
-	-	-	7.04	7.04	1	-	-	-	-	-	-
315.91	315.91	2	315.91	315.91	2	-	-	-	-	-	-

Table 28 Extra passenger and their corresponding ideal extra tramcar at Lideta station

7 - 8 AM			8 - 9 AM			4 - 5 PM			5 - 6 PM		
Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar	Passenger	Required capacity of Tramcar	No of Tramcar
406.79	406.79	2	316.55	316.55	2	380.52	380.52	2	-	-	-
668.05	668.05	3	428.30	428.30	2	-	-	-	-	-	-
-	-	-	-	-	-	19.09	19.09	1	-	-	-
612.17	612.17	3	-	-	-	-	-	-	-	-	-
608.56	608.56	3	369.57	369.57	2	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	85.36	85.36	1
95.28	95.28	1	-	-	-	-	-	-	-	-	-
-	-	-	94.52	94.52	1	202.65	202.65	1	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	73.91	73.91	1	412.96	412.96	2
319.70	319.70	2	-	-	-	-	-	-	-	-	-
581.69	581.69	3	-	-	-	-	-	-	-	-	-
-	-	-	50.65	50.65	1	-	-	-	432.83	432.83	2
396.76	396.76	2	-	-	-	184.58	184.58	1	282.51	282.51	1
-	-	-	547.61	547.61	2	-	-	-	-	-	-
685.38	685.38	3	-	-	-	224.03	224.03	1	-	-	-
-	-	-	238.68	238.68	1	-	-	-	-	-	-
300.06	300.06	2	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	30.44	30.44	1
148.46	148.46	1	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	0.05	0.05	1	-	-	-
-	-	-	-	-	-	191.96	191.96	1	-	-	-
421.24	421.24	2	-	-	-	-	-	-	-	-	-
555.17	555.17	2	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
188.68	188.68	1	45.48	45.48	1	-	-	-	-	-	-
137.23	137.23	1	-	-	-	266.34	266.34	1	136.78	136.78	1
-	-	-	335.05	335.05	2	-	-	-	-	-	-
-	-	-	81.70	81.70	1	-	-	-	322.60	322.60	2
140.35	140.35	1	-	-	-	-	-	-	521.18	521.18	2
802.40	802.40	3	-	-	-	-	-	-	-	-	-
282.28	282.28	1	-	-	-	408.89	408.89	2	-	-	-
509.88	509.88	2	-	-	-	156.23	156.23	1	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
254.53	254.53	1	665.50	665.50	3	249.26	249.26	1	-	-	-
-	-	-	187.09	187.09	1	-	-	-	-	-	-
1.47	1.47	1	-	-	-	-	-	-	622.55	622.55	3
631.33	631.33	3	-	-	-	-	-	-	380.72	380.72	2
520.03	520.03	2	-	-	-	-	-	-	-	-	-
118.50	118.50	1	167.67	167.67	1	1.13	1.13	1	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
210.71	210.71	1	-	-	-	-	-	-	-	-	-
544.64	544.64	2	-	-	-	-	-	-	44.05	44.05	1
-	-	-	397.10	397.10	2	-	-	-	378.51	378.51	2
458.97	458.97	2	-	-	-	-	-	-	255.28	255.28	1
253.45	253.45	1	167.88	167.88	1	-	-	-	171.61	171.61	1
430.31	430.31	2	-	-	-	105.42	105.42	1	-	-	-
2.58	2.58	1	264.94	264.94	1	-	-	-	420.29	420.29	2
-	-	-	272.72	272.72	1	-	-	-	-	-	-
682.07	682.07	3	-	-	-	127.35	127.35	1	133.04	133.04	1

282.52	282.52	1	-	-	-	-	-	-	-	-	-	-
384.97	384.97	2	-	-	-	87.54	87.54	1	-	-	-	-
822.74	822.74	3	-	-	-	-	-	-	-	-	-	-
414.22	414.22	2	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	180.20	180.20	1	-	-	-	-
21.18	21.18	1	-	-	-	134.81	134.81	1	-	-	-	-
44.73	44.73	1	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	51.13	51.13	1	170.31	170.31	1	-
-	-	-	244.43	244.43	1	-	-	-	-	-	-	-
482.96	482.96	2	-	-	-	164.49	164.49	1	-	-	-	-
-	-	-	12.68	12.68	1	-	-	-	-	-	-	-
254.40	254.40	1	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	159.46	159.46	1	-	-	-	-
-	-	-	-	-	-	-	-	-	84.80	84.80	1	-
-	-	-	40.34	40.34	1	248.84	248.84	1	-	-	-	-
-	-	-	-	-	-	-	-	-	232.31	232.31	1	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
242.11	242.11	1	-	-	-	-	-	-	-	-	-	-
623.29	623.29	3	361.73	361.73	2	-	-	-	-	-	-	-
446.95	446.95	2	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	461.39	461.39	2	-
552.51	552.51	2	-	-	-	-	-	-	-	-	-	-
420.38	420.38	2	-	-	-	-	-	-	-	-	-	-
-	-	-	169.06	169.06	1	21.04	21.04	1	260.31	260.31	1	-
-	-	-	119.44	119.44	1	300.85	300.85	2	221.33	221.33	1	-
-	-	-	-	-	-	113.27	113.27	1	598.08	598.08	3	-
-	-	-	76.40	76.40	1	-	-	-	553.85	553.85	2	-
111.06	111.06	1	40.93	40.93	1	-	-	-	-	-	-	-
367.43	367.43	2	-	-	-	49.34	49.34	1	-	-	-	-
164.85	164.85	1	-	-	-	-	-	-	22.67	22.67	1	-
659.76	659.76	3	522.60	522.60	2	-	-	-	-	-	-	-
513.59	513.59	2	297.28	297.28	2	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	383.28	383.28	2	-	-	-	-	-	-	-
335.14	335.14	2	-	-	-	-	-	-	622.78	622.78	3	-
150.12	150.12	1	311.87	311.87	2	-	-	-	-	-	-	-
166.49	166.49	1	-	-	-	-	-	-	-	-	-	-
226.90	226.90	1	-	-	-	-	-	-	-	-	-	-
-	-	-	293.83	293.83	2	-	-	-	-	-	-	-
696.68	696.68	3	355.48	355.48	2	-	-	-	260.47	260.47	1	-
-	-	-	-	-	-	-	-	-	-	-	-	-
52.04	52.04	1	-	-	-	210.93	210.93	1	461.59	461.59	2	-
-	-	-	334.31	334.31	2	-	-	-	215.89	215.89	1	-
-	-	-	202.17	202.17	1	-	-	-	604.81	604.81	3	-
-	-	-	322.76	322.76	2	-	-	-	-	-	-	-
389.40	389.40	2	-	-	-	-	-	-	591.66	591.66	3	-
-	-	-	184.52	184.52	1	122.28	122.28	1	309.98	309.98	2	-
-	-	-	717.02	717.02	3	76.74	76.74	1	492.44	492.44	2	-
686.73	686.73	3	409.41	409.41	2	161.14	161.14	1	-	-	-	-

Histogram representation of additional passenger and tramcar at Torhailoch and Lideta station



Figure 29 Histogram representation of additional passenger and tramcar at Torhailoch station

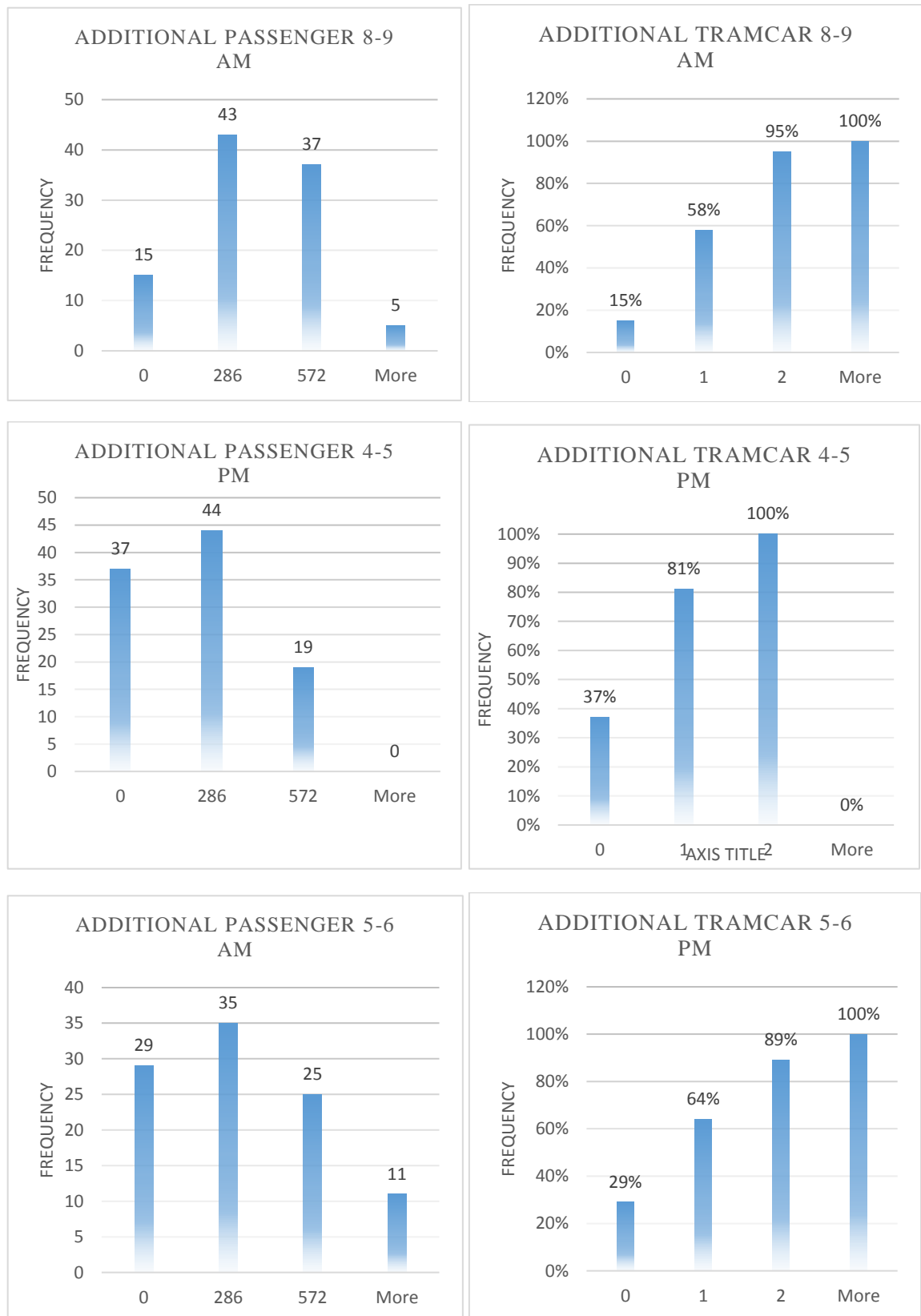


Figure 30 Histogram representation of additional passenger and tramcar at Lideta station

Comparisons of the ideal and actual number of tramcars at Torhailoch station for 8–9 AM and 4–6 PM

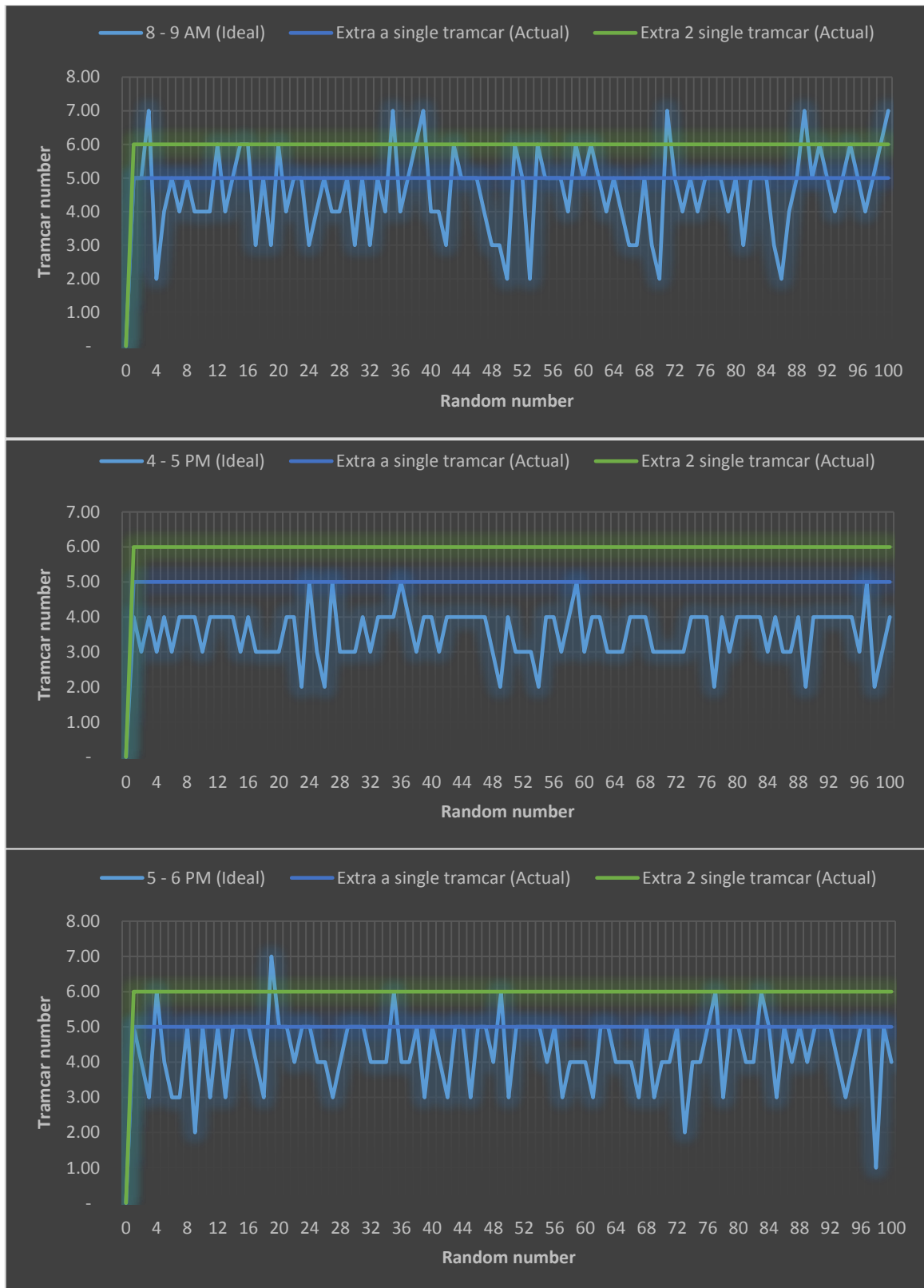


Figure 31 The ideal and actual number of tramcars at Torhailoch station for 8–9 AM and 4–6 PM

Comparisons of the ideal and actual number of tramcars at Lideta station for 8-9 AM and 4-6 PM

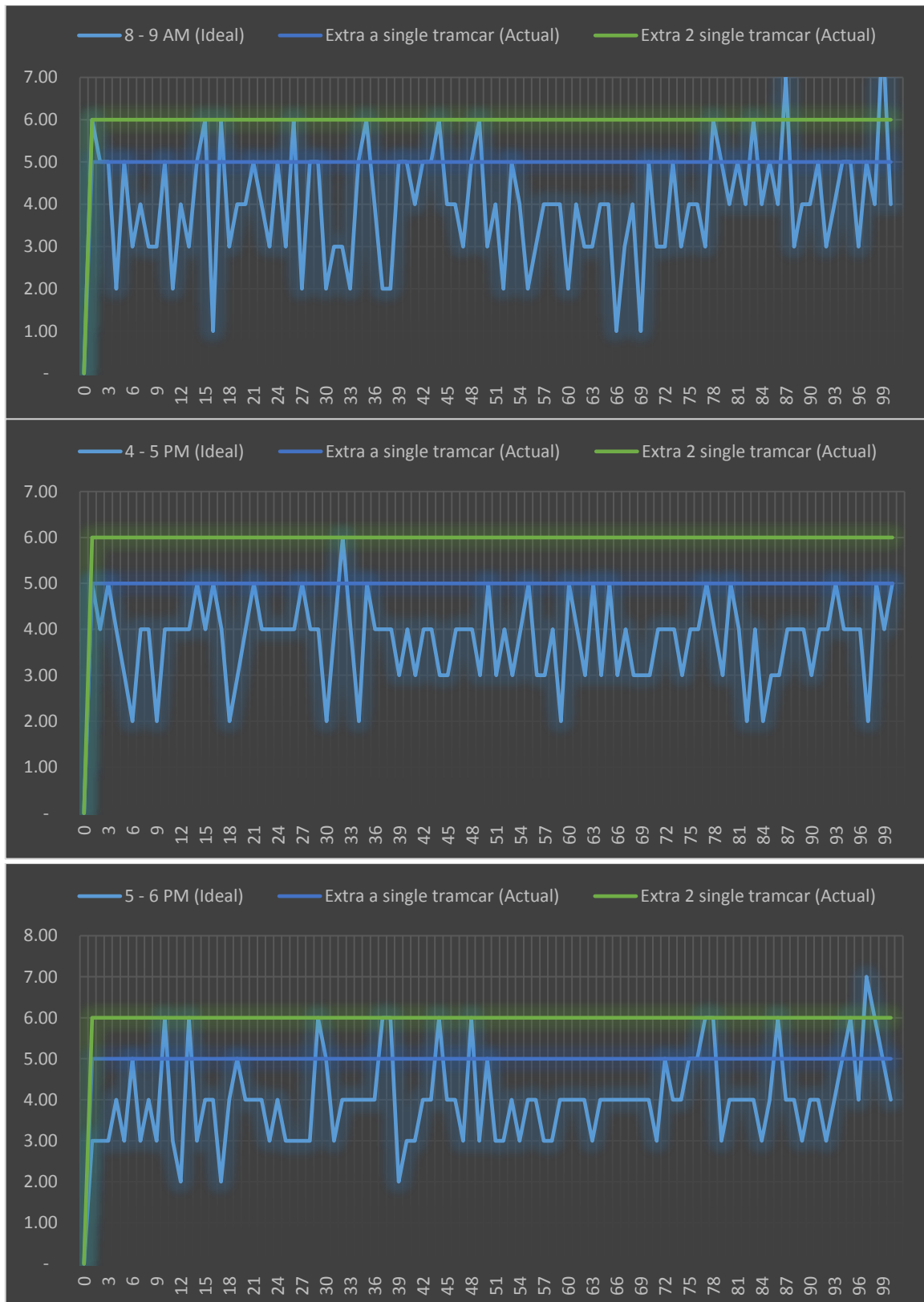


Figure 32 the ideal and actual number of tramcars at Lideta station for 8-9 AM and 4-6 PM

Table 29 The marginal benefit of adding tramcar in the morning shift


No.	Variables	Morning (US\$)								
		Existing model (Four server/hr)	New model							
			No service	single server/hr.	Two server/hr.	Three server/hr.	Five server/hr.	Six server/hr.	Seven server/hr.	Eight server/hr.
1	Benefit									
1.1	Revenue Tariff of Operation of LRT	83.89	83.89	83.89	83.89	83.89	83.89	83.89	83.89	83.89
1.2	Saving in Passengers Time (VOT)	12,003.58	-	-	3,511.73	10,135.64	15,434.76	16,759.55	16,820.53	16,942.28
1.3	Saving in fuel due to LRT operations	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84
1.4	Saving due to reducing accidents	59.97	59.97	59.97	59.97	59.97	59.97	59.97	59.97	59.97
Total benefit		12,154.29	150.71	150.71	3,662.44	10,286.35	15,585.47	16,910.26	16,971.24	17,092.99
2	Cost									
2.1	Interest Cost	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01
2.2	Maintenance	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71
2.3	Interest on Debt	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07
2.4	Equity Capital	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63
2.5	Operation	1,866.62	-	379.98	759.96	1,139.94	1,899.91	2,279.89	2,659.87	3,039.85
2.6	Passengers Electric Locomotive unit cost	380.90	-	95.22	190.45	285.67	476.12	571.35	666.57	761.80
Total cost		12,232.93	9,985.42	10,460.62	10,935.83	11,411.04	12,361.45	12,836.65	13,311.86	13,787.06
Profitability		-78.65	-9,834.71	-10,309.92	-7,273.40	-1,124.69	3,224.03	4,073.60	3,659.38	3,305.93

Table 30 The marginal benefit of adding tramcar in the afternoon shift

No.	Variables	Afternoon (US\$)								
		Current operated (Four server/hr.)	New model							
			No service	single server/hr.	Two server/hr.	Three server/hr.	Five server/hr.	Six server/hr.	Seven server/hr.	Eight server/hr.
1		Benefit								
1.1	Revenue Tariff of Operation of LRT	67.58	83.89	67.58	83.89	0.00	67.58	67.58	67.58	67.58
1.2	Saving in Passengers Time (VOT)	9,669.90	-	-	2,828.99	8,165.11	12,434.01	13,501.24	13,621.68	13,722.62
1.3	Saving in fuel due to LRT operations	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55
1.4	Saving due to reducing accidents	59.97	59.97	59.97	59.97	59.97	59.97	59.97	59.97	59.97
	Total benefit	9,803.01	149.42	133.11	2,978.41	8,230.64	12,567.12	13,634.34	13,754.79	13,855.73
2		Cost								
2.1	Interest Cost	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01	2,095.01
2.2	Maintenance	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71	3,376.71
2.3	Interest on Debt	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07	2,440.07
2.4	Equity Capital	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63	2,073.63
2.5	Operation	2,071.78	0.00	379.98	759.96	1,139.94	1,899.91	2,279.89	2,659.87	3,039.85
2.6	Passengers Electric Locomotive unit cost	380.90	0.00	95.22	190.45	285.67	380.90	380.90	380.90	380.90
	Total cost	12,438.09	9,985.42	10,460.62	10,935.83	11,411.04	12,266.22	12,646.20	13,026.18	13,406.17
	Profitability	-2,635.08	-9,836.00	-10,327.52	-7,957.42	-3,180.40	300.90	988.14	728.60	449.56

APPENDIX 2

Letters to ERC and AALRT to collect data



AAiT
Addis Ababa Institute of Technology

School of Civil & Environmental Engineering
 ቤተ-ሰሎሞን ስኬት ስኬት ስኬት

To: Ethiopian Railway Corporation (ERC) Date: 24/12/2018

Subject:- Request for Co-operation

Dear Sir/Madam,

The following students at Addis Ababa University, Addis Ababa Institute of Technology, School of Civil and Environmental Engineering are conducting their thesis/term paper entitled "Improving Addis Ababa Railway Transit Service using queueing theory" case study of Torhailoch - Lideta station.


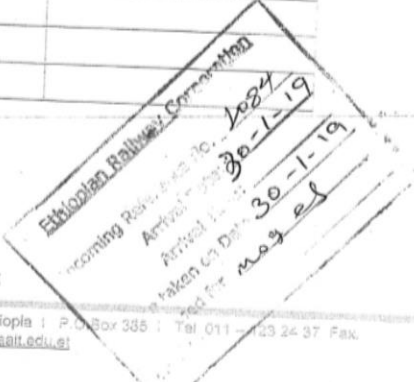
We kindly request your organization/company to provide them with the necessary support that could help them conduct their project.

The school strongly appreciates any sort of assistance you provide to our students related to their project. In addition, we would like to inform you that the data is required for educational purpose only and if you have any question, please do not hesitate to contact us.

No.	Full Name	ID. Number
1	Tamene Taye W/orku	GSE/0233/08
2		
3		
4		
5		

Thank you for your cooperation.

Agizew Nigussie
 Agizew Nigussie
 Dean, School of Civil & Environmental Engineering

Addis Ababa Institute of Technology | Addis Ababa | Ethiopia | P.O. Box 335 | Tel. 011 - 423 24 37 Fax. 011 - 12 39 480 | E-mail: info@ceae.aait.edu.et | www.aait.edu.et



School of Civil & Environmental Engineering

የኢትዮጵያ ሲቪልና አካባቢ ግብይት ስራ ስራ ትምህርት ቤቅ

Date: 24/12/2018

To: AAiT Addis Ababa LRTS

Subject:- Request for Co-operation

Dear Sir/Madam,

The following students at Addis Ababa University, Addis Ababa Institute of Technology, School of Civil and Environmental Engineering are conducting their thesis/term paper entitled "Improving Addis Ababa Railway Transit Service Using Queuing theory" case study of Torhailoch-Lideta Station"

We kindly request your organization/company to provide them with the necessary support that could help them conduct their project.

The school strongly appreciates any sort of assistance you provide to our students related to their project. In addition, we would like to inform you that the data is required for educational purpose only and if you have any question, please do not hesitate to contact us.

No.	Full Name	ID. Number
1	Tamene Taye Worku	GSE/0233/08
2		
3		
4		
5		

Thank you in advance for your cooperation.


 Agizew Nigussie
 Dean, School of Civil and Environmental Engineering



Addis Ababa Institute of Technology | Addis Ababa | Ethiopia | P.O.Box 385 | Tel. 011 - 123 24 37 | Fax. 011 - 12 39 480 | E-mail: eng.aait.edu.et | www.aait.edu.et

Transport Society for your cooperation!

*To: OCC
 Cooperate this by giving us Non-confidential Data only.
 Dec 31, 2018*