Analysis and Optimization of Passenger Waiting Time: In Case Anbessa City Bus.

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ABSTRACT

In public transportation providing the fast transport service is the main concern to satisfy the passenger demand. The bus service accessibility in response to the passenger demand is deferent from route to route. This deference resulted in short passengers waiting time for high frequency and long passengers waiting time for the route of low bus service frequency. The long passengers waiting time is one of the measure of poor public transit service quality. In this thesis mathematical modeling was developed based on the dynamic passengers demand and bus service operational constraint to optimize passengers waiting time at bus terminals of Addis Ababa city in case of Anbessa bus transport using the data collected during literature review, interview, field study and secondary data collected from ACBSE. Mixed Integer Non-Linear Programing MINLP and Mixed Integer Linear Programing MILP model were developed for static and dynamic passenger demand. The dynamic passenger demand was solved as Mixed Integer Linear Programing MILP model by discretizing the bus planning horizon into small time (in minutes) to linearize and make the model tractable to solve it using software. LINGO software was used to solve the model. The result was evaluated with bus headway, bus frequency and bus capacity. The evaluation shows that the overall average bus departure time reduction is 39.62% and 37.74% for DAF or rigid Bishoftu bus and articulated bus respectively. The improved average frequency for DAF or rigid and articulate bus is 62.44% and 60.67% of actual bus frequency. The total average passengers waiting time for the DAF and Bishoftu bus was 8.03% more than the passengers waiting time for articulated bus. The overall average passengers waiting time reduction is 39.62% and 37.74% for DAF or rigid Bishoftu bus and articulated bus respectively, through the proposed mathematical optimization models.

Key words: Bus, Passengers Waiting Time, Passengers' Arrival Rate, Bus Frequency, Bus Headway

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ACRONYMS.

ACBSE - Anbessa City Bus Service Enterprise

AM - Ante Medium

ANN - Artificial Neural network

AWT - Average Waiting Time

DTR - Demand and Travel time Responsive

LCL - Lower Control Limit

LOS - Level of Service

LR - Linear Regression

MILP - Mixed Integer Linear Programming

MINLP - Mixed Integer Non-Linear Programming

PTC - Public Transport Corporation

SSE - Sum of Squared Error

SVM - Support Vector Machine

UCL - Upper Control Limit

MANOVA-Multivariate Analysis of Variance

PRT- Personal Rapid Transit

DT - Dwell time

DTR - Demand and Travel time Responsive

TBST - Total bus stop time

CHABTER ONE

BACKGROUND AND JUSTIFICATION OF THE STUDY

1.1. Introduction

Peoples move from one place to another area for different activities. They may move for education, business, office work, daily work, relative visit, tours, medical treatment and etc. Some of these passengers prefers their own foot while others select animals, vehicles, air plane and water transport based on their destination. In urban area the passengers prefer the public transport based on affordability (for poor) and as an alternative means of transport (for others).

Public transport is known as transport services available to the public in opposite to private transport and a shared passenger transport service which is available for use. It can be supplied by public or private operators, with or without predetermined schedules, routes, stops, fares and subsidies. Private operators can be officially recognized by the public authority or informal, and the state of informality can in turn range from being 'illegal' and unregulated to being 'legal' and regulated. According to Stucki and Martin [1] the public transport modes are buses, trolley buses, trams and trains, rapid transit and ferries. The services of bus Public transportation is normally regular operation along a route according to an issued public transportation timetable.

Bus transportation is one of the oldest and most shared types of transportation. The objective of bus transport is to simplify the movement of people in the interior of a city or to distant places. If there is no traffic, it has the benefit of being reasonably priced and appropriate. In towns and cities, as well as in most countryside areas buses are the most shared way to move people over short and medium remotes. Public transport bus service is the most mutual urban or suburban services and is used to transport enormous numbers of people in city areas, or to and from the suburbs to inhabitants' centers.

In developing country the transport service accessibility is low due to the rapid urban population growth. According to Stucki and Martin [1] Large and small, urban areas of Africa are currently experiencing the fastest population growth in the history of the planet. In meeting the needs of current and future urban dwellers main accessibility and mobility the policy and decision makers face enormous challenges faced by African urban areas, namely stemming from point of reference analysis among representative urban areas selected across the continent. In 2011 the urban areas of Africa were home to about 414 million inhabitants. This number is expected to rise to almost 750 million by 2030, and to over 1.2 billion by 2050. The annual urban population growth rate of this continent is by far the highest in the World, with 3.09% for the 2011-2030 period, to be equated with 1.87% in Asia, 1.13% in Latin America, 0.98% in North America and 0.33% in Europe. As a result the urban share of the total African population will also increase rapidly and presently 65 % of Africa's urban population lives in urban areas of less than 1,000,000 dwellers and 55 % in cities of less than 500,000 dwellers. By 2025, the majority of urban inhabitants will still live in urban areas of less than 1,000,000 dwellers. According to Tilahun Meshesha Fenta [2], Ethiopia as parts of Africa, the increase of population of Addis Ababa is a mixture of three basic processes: rural-urban migration; natural increase, and re-classification of land from rural to urban categories. The Addis Ababa annual population growth rate is 3.8%. This population growth rate leads to the change to another social group of the residents and consequently the demand for public transport for the movement. As, Ethiopia is a developing country, compared to the developed countries, the transport service standard accessibility observed in the city of Addis Ababa is low. In the cities of developed countries average mobility rate per person or trip/day is 2.5. According to Ministry Of Transport [3] the Addis Ababa mobility rate or average trip/day/person is 1.08. Old neighborhoods far from the main roads and expansion areas of the city are not well served by public transport.

The Addis Ababa city is growing in economy, geographical region and population sizes which requires urgent attention and needs supplementary mass transport service provision supported by capacity. To solve this problem the ACBSE increases the number of bus required from time to time to increase the service quality and bus reliability. In addition to increasing the number buses, ACBSE provides the single deck bus which can transport large number of passengers at a time. The speed of this bus is lower than the rest buses. In addition, it cannot give service equally to every routes because of its design was not appropriate to the hilly road.

The mobility rate and low service standards of transport accessibility leads the passenger for delays and the passenger wait the service for a long time at morning and afternoon during rush hours. The arrival rate of the passengers and the service rate of the transport was not proportional. That means the passenger arrival rate is very high in relation to the required service rate. This deference creates variation between the service supply and the demands of the passengers. In otherward, at bus terminals the bus assignment is irregular during un-rush hours in relation to rush hours. When the bus arrives at the terminals the bus hides its number of direction and waits order from the terminal dispatcher. The dispatcher dispatches the bus by trial and error. This changeability and the relations between the arrival and service methods make the dynamics of service systems very intricate. As a result, it’s too difficult to predict levels of waiting time or to determine how much capacity is needed to achieve some wished level of performance without the help of optimization model.

In transportation planning it is important to optimize the transport service with the passenger transportation service demand to reduce the passenger waiting time for the transport. To minimize the passenger waiting time it requires to distribute the available transport capacity proportionally according to the number of passengers demand for transport service. Before distributing/assigning the available capacity proportionally some analysis method is required. In this thesis, to optimize the passenger waiting time, passenger waiting time model was developed by mathematical modeling based on passenger arrival rate and the available bus resources.

Based on the deferent factors passengers prefer public transport or private public transport. These factors are the parameters which hinder the service rate and leads the passengers to waiting for a transportation service. By considering the possible causes of passenger waiting time being in queue/without queuing for transportation service optimization method was used to determine the capacity required along each route. Then the capacity will be evaluated, the transportation service rate will be analyzed, passenger arrival rate be measured and, to reduce the passenger waiting time the constrained based L.P model will be used. Therefore the passenger waiting time for the transport service will be optimized in Addis Ababa city.

1.2. Statement of the Problem

According to United Nations Economic and Social Council [4] reports Africa is lagging far behind in transport infrastructure efficient and reliable services. According to the World Bank [5]report the city's approach to address urban transport problems, predominantly, by expanding the transport infrastructure. But this has not made the desired improvements in accessibility for pedestrians and many public transport users. Daily time spent traveling in the city has increased, and the city is facing high levels of road traffic accidents, frequent congestion, and high levels of air pollution. These challenges are clear even though motorization in Addis is quite low by world standards; investments in expansion of the road network has not been accompanied by improvements in traffic management or the development of public transport services. Mobility for the poor is effected primarily through walking and bus services provided by Anbessa City Bus Service Enterprise (ACBSE), the city's public bus operator.

The purpose of governmental public transport is basically to provide the scheduled service for the passengers transport with the low transport cost by taking, the level of population life standard, into consideration. But the purpose of private public transport is business oriented. Life standard is not their business. Their daily effort is only to make money regardless of the cost of transport and the schedule of passenger transport services. Taxis provide a publicly available service and are therefore part of public transport. However, the lack of regular schedules, routes and set station –all features characteristics of public transport-gives it a semi private character. Fixed public transport services cannot support all travel demand.

During rush hours, morning and evening, the bus was assigned based on the regular schedule. In contrary, during unrushed hours the bus was assigned based on the passenger demand available. That means to assign the bus to the route the ACBSE follows the principles of demand oriented bus service assignment. The bus was assigned to the route by trial and error by observing the passengers wait for the bus service which is difficult to identify this passengers go to this route or that route because of an identified bus waiting area. This create unbalance between the available capacity and the demand available for bus transportation. This resulted in short waiting time for some for those the bus assigned and long waiting time to those that the bus was not assigned.

1.3. Objective

Under this section two types of research objectives were discussed. The first research objective is the general objective which holds the overall concept about this thesis. The second research objective is the specific objective which guide as a procedure to answer the research questions.

1.3.1. General objective

The general objective of the study is to analyses and optimize the passenger waiting time for Anbessa City bus public transport service in Addis Ababa city.

1.3.2. Specific objective

- To measure and analyses the existing route wise bus service rate of Anbessa City Bus transport Service of Addis Ababa city.
- To measure and analyses passenger arrival rate for Anbessa City Bus Service transport in Addis Ababa city.
- To identify available bus fleet size of Anbessa City Bus Service Enterprise (ACBSE) to respond to the demand of passenger transportation service in Addis Ababa city.
- To develop the method of optimizing Anbessa City Bus Service to minimize passenger waiting time for transportation service of Addis Ababa city.

1.4. The research question

1. What is the bus service rate of Anbessa City Bus Service transport in Addis Ababa city?
2. What are the passenger arrival rate for Anbessa City Bus Service transport in Addis Ababa city?
3. What is the available bus transportation fleet size of ACBSE of Addis Ababa city?
4. How the bus transport service rate will be improved to reduce passenger waiting time in Addis Ababa city?

1.5. Significance of the Study

This study helps the Planners and policy makers of the city to forecast the transport required as well as the demand of the passenger transport service based on the number of population growth rate and rural to urban population mobility rate. It helps not only Planners and policy makers but also it enables the Passenger and Drivers to use their time efficiently. Passenger get access easily to go to their destination without delaying. As a result, the cost of waiting time would be minimized. The Drivers transport the passengers more frequently than the before. The more trips they prove service they receive more benefited from the speed of service provided. In general the Addis Ababa road authority and any passenger who uses the Addis Ababa road passenger transport would benefited from this research.

1.6. Scope of the Study

In this research, some important issues related to the bus transit system of Addis Ababa city have been assumed. It is well known that making more productive use of resources is an important concern of any transport system. Though all the constituents of the transit planning process are important, some of them have more impact on the operational economy and customer satisfaction. Bearing this in mind and the current status of research, the scope of the research is limited to the analysis of the present or on hand bus transport capacity using mathematical model based on timely based passengers arrival rates, bus service frequency, route operational characteristics and, develop the method of minimizing the passengers waiting time for bus transport service. To minimize the passengers waiting time or delay time, constrained based MILP model was developed.

1.7. Limitation of the Study

The limitation of this study is;

In the first place, in the analysis of optimization it does not consider the mix of both articulated and single DAF or Bishoftu rigid buses. Because to find the best optimum solution it requires huge arrangement of the data's of capacity constraints in relation to the time of study and the number bus available. The optimization analysis focus on separated bus capacity, only single rigid and articulated buses.

Secondly, the time of the study was limited to the certain time; it does not consider all the service times of the planning horizon of days.

Thirdly, the analysis considers single direction. That means the passengers arrival rate and the bus service rate used in optimization was the data collected from the bus terminal which do not include the passenger's arrival rate along the route. Similarly it does not consider the passenger's arrival rate the destination and the passengers along the route from destination to the bus terminals.

Fourthly, the optimization process analyzed was only the MILP, but not MINLP.

Fifthly, in the analysis of hourly passenger's arrival rate some bus inter arrival rate was more than the separated hours of study. To analysis the hourly passengers arrival rate the passengers of the bus inter departure was distributed uniformly to the hourly study.

Sixthly, considers the road congestion as stable; not so much crowded and almost free.

1.8. Organization of the Study

This thesis consists of seven chapters. The first chapters contains background and justification of the study which describe in detail about the introduction of the overall thesis, the statements of the problem, objective of the study, significance of the study, scope of the study and limitation of the study. The second chapter reviews the past literature about bus passengers waiting time, transportation service quality, factors influences bus passengers waiting time, the effect of bus passengers waiting time and waiting time optimization methods that the scholars used to solve the passengers waiting time. The third chapter is about the method of study and discuses about the methods how to achieve the objective of the study. This chapter consists of the research design, research methodologies and research tools. The fourth chapter overview the ACBSE service performance. This chapters discusses about the growth history and the current status of ACBSE. The fifth chapter is about the analysis and interpretation of the data. The data analyzed were the interview data, operational data and the case study. The sixth chapter is about the design of optimum bus passengers waiting time. This designing method encompasses model assumption, model formulation, running the model code, solving the passengers waiting time model, model inputs and outputs, model computation procedure, outputs of the model, the sensitivity analysis, and model evaluation and validation. The final and chapter seven is about the conclusion, recommendation and future work.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

In public transit, the timetable establish the link between the transportation agency and the passenger in search of a consistent service. Poor and/or incorrect timetables confuse the passengers and reduces the good image of public transit as a whole. The sources of unreliable service was the deference of the assumption of the planners' and the passengers demand adjustment. When passenger demand is not satisfy, transportation buses slow down, travelling late schedule and entering the unavoidable process of further slowing down. To exploit the system's capability to the greatest level and maximize the system's productivity and efficiency the framework for the transit operational planning process activity was set. This operational planning framework is the systematic decision sequence of the four basic planning activities, Ceder [6]. The four operational planning activates are:-

1. **Network Route Design: -** in this planning activity bus lines, stations and line routes would be defined/designed.
2. **Timetable Preparation and Development: -** this planning activity was used for establishing alternative frequencies and timetables is to meet general public transportation demand.
3. **Vehicle Scheduling: -** this planning activity aimed at creating a sequence of revenue and non-revenue activities for an individual vehicle of trips; each is referred to as a vehicle schedule according to given timetables. This chaining process is often called 'vehicle blocking'.
4. **Crew scheduling: -** this planning activity is often called driver-run cutting (splitting and recombining vehicle blocks into legal driver shifts or runs). This step involve scheduling of drivers and managers. Its goal is to assign drivers according to the vehicle scheduling.

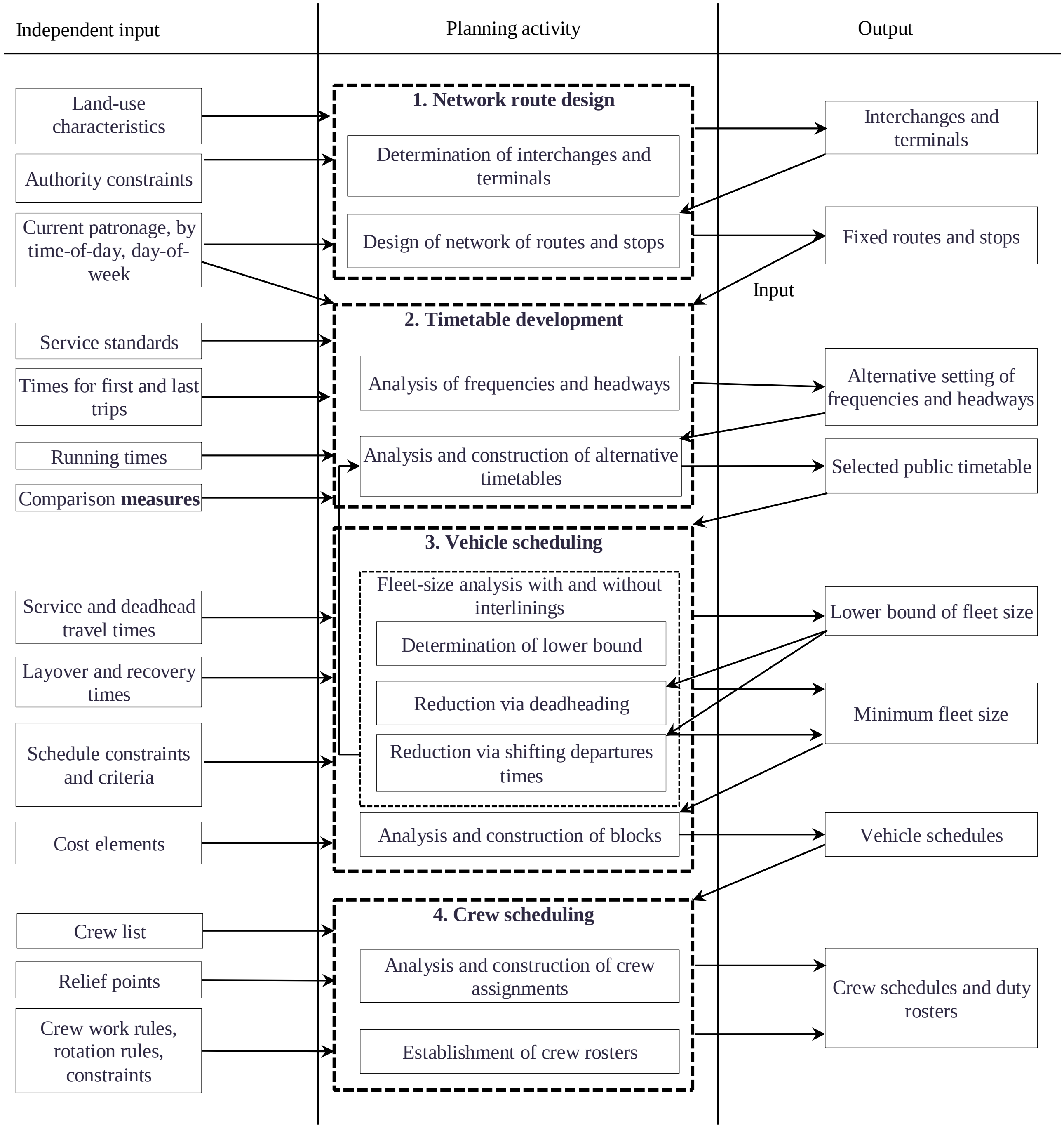


Figure 2.1 Framework of transit-operation planning process

2.2. Public Transportation Service Quality

2.2.1. Concepts of Service Quality

Service quality has got a substantial responsiveness and focus from academicians, practitioners & Researchers during the past three decades. Many scholars Christian Gronroos [7], Parasuraman et al. [8], Zeithaml et al. [9], Cronin and Taylor [10], Mohd. Imran Siddiquei [11] have studied the concept, design and measurement of service quality.

2.2.2. Definitions of Service Quality:

1. "A perceived judgment, resulting from an evaluation process where customers compare their expectation with the service they have received" Christian Gronroos [7], Mohd. Imran Siddiquei [11].

2. Service quality is defined as "the difference between expectations and performance of the service" Parasuraman *et al.* [12], Mohd. Imran Siddiquei [11].

2.2.3. Model of Service Quality Gaps:

There are seven most important gaps in the service quality concept, which are revealed in Figure 1. The model is an extension of Parasuraman et al. [12]. According to the next clarification ASI Quality Systems [13], Adrienne Curry [14] Sh.T.K. Luk and R. Layton [15], Mohd. Imran Siddiquei [11] the three important gaps, which are more associated with the external customers, are Gap1, Gap5 and Gap6; since they have a direct relationship with customers.

Gap1: Customers' expectations versus management perceptions: As an outcome of the deficiency of Marketing research orientation, insufficient upward communication and too many layers of Management.

Gap2: Management perceptions versus service specifications: as an outcome of insufficient Assurance to service quality, a perception of unfeasibility, inadequate task standardization and an absence of goal setting.

Gap3: Service specifications versus service delivery: as an outcome of role vagueness and conflict, Poor employee-job fit and poor technology-job fit, unsuitable supervisory control systems, absence of perceived control and absence of teamwork.

Gap4: Service delivery versus external communication: as an outcome of insufficient Horizontal communications and tendency to over-promise.

Gap5: The difference between customer expectations and their perceptions of the service delivered: as a result of the influences engaged from the customer side and the shortages (gaps) on the part of the service provider. In this case, customer expectations are inclined by the extent of individual needs, word of mouth recommendation and previous service experiences.

Gap6: The difference between customer expectations and employees' perceptions: as an outcome of the variances in the understanding of customer expectations by front-line service providers.

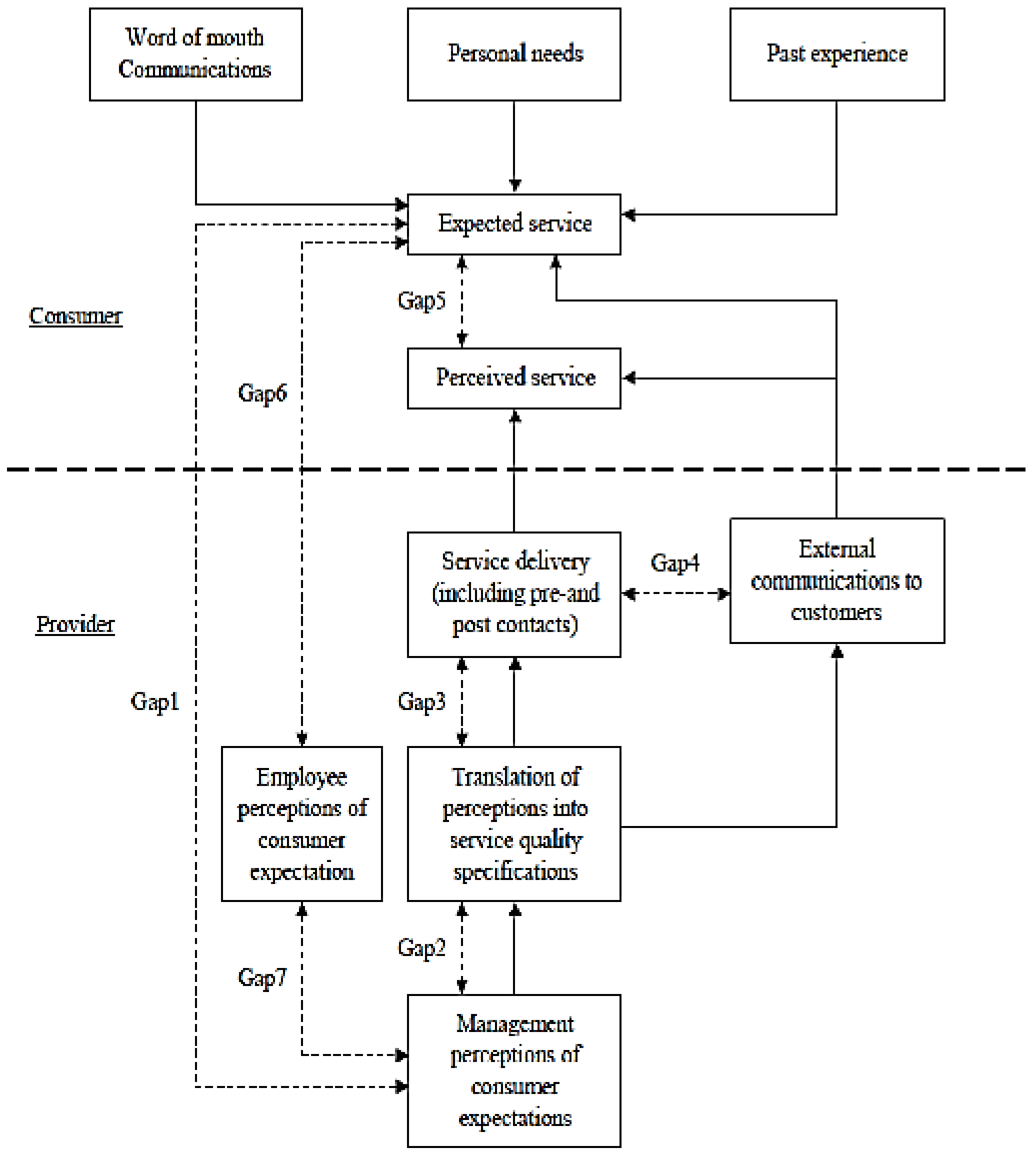


Figure 2.2 Model of service quality gaps

Source: Parasuraman et al. [8], A. Curry [14] Sh.T.K. Luk and R. Layton [15], Mohd. Imran Siddiquei [11].

2.2.4. Public Transport Service Quality and Passengers Satisfaction

There were many service quality characteristics that caused gaps in public transportation service quality. Reliability, treatment by drivers, bus stop facilities, lack of modern buses and lack of information were areas causing dissatisfaction while safety, treatment by drivers, getting a seat on the bus and service frequency caused satisfaction. Eileen Conlon [16]. The noticeable and non-noticeable passenger satisfaction influencing factors on the quality of public transport services were investigated. First, the Relationships among hidden dimensions (quality, satisfaction and loyalty) were defined through suitable statistical measuring techniques (Factor Analysis with Categorical Principal Component Analysis) on the basis of a sample survey. Then, the characteristics of the passengers and their quality perception were used in order to search by multivariate methods of classification (Segmentation Analysis and Cluster Analysis). Francesco Domenico d'Ovidioa et al. [17].

In the city bus transportation of Addis Ababa there is a strong relationship between perceived service quality and passengers satisfaction. The improved SERVPERF scopes have main effects for decisive overall service quality and confirming satisfaction of bus passengers and it was suggested. There is a moderately low perceived service quality and passengers were mostly satisfied with the transport service provided by HIGER city bus enterprise. Suffocation, lack of enough seats, service irregularity, increasing transportation cost, and lack of concern in keeping passengers' interest were the factors contributing to passengers' overall dissatisfaction. Ababa. Belayneh Aniley and Rakshit Negi [18]

Rida Khurshid et al. [19] The way of service quality effects customer satisfaction was investigated in transport sector. To indicate the relation between customer satisfaction and service quality was used to analyze. The relation between service quality and passengers satisfaction in the public transportation area is positive relationship. The two independent groups of data relation was analyzed by Regression coefficient.

The analysis of passengers characteristics collected through Customer Satisfaction Surveys designates that the analysis convey very powerful information for framing satisfactory transportation plans and attaining an on-going improvement of the quality of the transportation service dedicated on the passengers. According to Rocío de Oña et al. [20]Thomas Kolawole Ojo et al. [21].

To increase the bus service quality, according to Farzana Rahman et al. [22], Passengers' perceptions of service performance and the role of these perceptions in travel decisions are needed. The related service quality attributes that influence overall customer satisfaction the most was measured and investigated. The mode of transport, reliability, travel time, availability of seat, cost, female/disable/elderly people seat availability, cleanliness, overcrowding condition and safety are the important attributes that effect the bus service quality most. Binary logit model was developed to discover the essential attributes and their effect on overall bus service quality.

The primary factor that affects the overall passenger's satisfaction is the type of bus. The passenger's satisfaction with the articulated bus is very low since it always undertakes large-scale passenger movement. The lowest satisfaction score of first-level displays is timeliness which is mostly influenced by three factors: the passenger's age, travel purpose and time. The first effective measure to improve the overall satisfaction is increasing the timeliness of the bus service. To improving public transport service quality is an effective way to increase bus desirability. To improve public transport service quality a satisfaction indicators evaluation matrix were constructed from the opinion of passengers. These indicators are: 6-first-level, 21-second-level and 77 third-level. According to Jiancheng Weng et al. [23]. The six Satisfaction Evaluation System of the first and second level shown on the table 1.

Table 2.1 Satisfaction evaluation index system.

First-Level	**Second-Level**	**First-Level**	**Second-Level**
1. Timeliness	• Arrival time at the bus stop • Waiting time at the bus stop • Travel time • Transfer time	4. Comfort	• Stop environment • Condition of vehicle hardware • Dynamic environment on the bus • Quality of services
2. Security	• Security of waiting • Security of boarding • Traffic security • Emergency management	5. Reliability	• Travel time punctuality • Transit dispatching Reliability • Driver and conductor in service • Bus service information
3. Convenience	• Facilities convenience • Travel convenience • Information services	6. Economy	• Fare and system rationality • Fare of personalized services rationality

2.3. Passengers Waiting Time for Public Bus Transport Service

2.3.1. Definition and Types of Passengers Waiting Time

According to Frested and Torset [24] the waiting time is defined as the amount of time spent at a bus stop waiting, and categorized waiting time at public transport journeys into hidden and open waiting time. But, in nowadays transport models the waiting time is not separated, and is defined as half of the time between departures. Open waiting time is the length of passengers' stay on the bus stop, from when they arrive at the platform until the bus departures. The hidden waiting time is time between the point of time passengers want to travel, and the point of time the journey starts, because passengers are not able to travel whenever passengers need. When a passenger knows the bus departure time, and start the journey in accordance to this, the hidden waiting time in the start of the journey will be non-existent in many situations. Besides, in most conditions when a passengers encounters hidden waiting, they are able to convert this into longer open waiting time and even access time. This resulted in that the number of passengers who experience a considerable hidden waiting time is low. Considering that the preferred open waiting time, and the actual open waiting time is approximately the same for passengers at all headways, it is in fact the hidden waiting time that is the reason for calculating different travel demands at different headways. The preferred waiting time is the time when the passengers do not wants to wait for a longer time than their desired buffer time.

Rabi G. Mishalani et.al. [25] The passenger's actual waiting time is less than the passengers' perceived waiting time. The relationship between perceived and actual waiting times experienced by passengers awaiting the arrival of a bus at a bus stop were quantified. In quantifying the value of providing real-time information to passengers on the time until the next bus is expected to arrive at a bus stop understanding a relationship would be useful. Nevertheless, the hypothesis that the actual waiting time relative to the rate of change of perceived time does not vary is accepted over a range of 3 to 15 minutes. Assuming that a passenger's perceived waiting time is equal to the actual time when presented with accurate real-time bus arrival information, the value of the eliminated additional time is assessed in the form of reduced vehicle hours per day resulting from a longer headway that produces the same mean passenger waiting time. The eliminated additional time is also considered in the form of uncertainty in the headway resulting in the same extra waiting time.

Traveler approach is seriously affected by waiting time in bus stops towards public transportation, therefore, during planning and operating a bus system it is a concern. Using hazard-based duration models actual and perceived waiting times at bus stops was investigated an empirically. The factors that increase perceived waiting time with older persons, work, and education trips while age, trip purpose, and trip time period seem to have an impact on the perception waiting time. Perceived waiting time lead to an overestimation of actual waiting. According to Matthew G. Karlaftis et.al. [26].

The waiting time at stops served by up to two lines and stops served by three lines or more stops were normally overestimates to the actual passenger's waiting time. The existing clear difference passenger arrivals rate between stops was suggested. The passenger waiting times at public transportation amenities using information collected from bus network by means of physical counts, measurements and observations, and complemented by on-site passenger interviews, the waiting behavior is analyzed for a number of bus stops served by different numbers of lines. The passenger inter arrival time, passenger actual waiting time, and passenger perceived waiting time is analyzed by employing a wide range of statistical methods and tools. Trozzi et.al. [27].

2.3.2. The Impact of Passengers Waiting Time

The passenger sensitivities of bus service can be defined in terms of passengers' satisfaction with waiting time, and it is affected by many factors. According to Zhenning Li et al. [28] the passengers satisfaction related with waiting time is affected by perceived waiting time. The increment of perceived waiting time reduces the passenger's satisfaction. To increase or keep the passengers satisfaction it is essential to reduce passengers' perceived waiting time of public transportation. The relation of influencing factors over the passengers' perceived waiting is observed using the method of a multiple linear regression model. Passengers annoying level was increased with longer waiting time. The behavior of passengers waiting time has an effect on the passengers' frustration level at the bus stop. The relation between passengers' bus waiting behavior and their frustration levels to waiting at bus stops describes that longer waiting time increased passengers' frustration levels, sitting on benches alleviated their frustration levels and the effects were greater for the elderly than for non-elderly passengers, engaging in some activities including spending time in a nearby convenience store while waiting contributed alleviation of frustration levels, Cantwell et al. [29]. The level of passengers satisfaction using public transportation service were decreased for passengers who travel on crowded and passengers that have long waiting time. The level of passengers stress associated with these factors were analyzed by linear regression method. The Passengers who spend longer times waiting for a public transport service were more strained. That means the extended the wait-time increases the feelings of anxiety become more strong. With the analysis of multi logit model the relation of crowding and reliability was analyzed. The results reveal that a reduction in crowding was more beneficial than an improvement in reliability for both the bus and rail.

2.4. Factors Influence Passengers Waiting Time

The differences between passengers' waiting time in different areas compared using the perception factor. The perception factor is the new concept introduced based on perceived and actual waiting time. Then the relationship among passengers' personal behavior environment and perception factor were analyzed, in addition Multivariate analysis of variance (MANOVA) and correlation tests have done. The result showed that the age, number of partners, visiting times, weather, waiting facilities, waiting information had substantial impact on the perception factor. The relation between the proportion of occurrences of boredom sense in waiting and perception factor was established by the method of multiple linear regression model. The perception factor and level of service (LOS) has a negative correlation. Similarly, the perception factor and the service level were in negative correlation in the survey data, which means that reducing the passengers' perception factor could improve their service level of the waiting area, Ying En GEb et al. [30].

Hazard-based duration models was used to investigate the effects of various factors on perceived waiting time. The nature of the problem at hand dictated the use of duration models. Two types if perception was identified. The first was the seam to have an impact on perceived waiting time (age, trip purpose, and trip time), and the second was factors that have an impact and increases perceived waiting time (older individuals, work trips, and education trips) and lead it to overestimates real waiting time. On the other hand, during morning period the perceived waiting time is decreased. [31].

The influencing factors like trip purpose, riding frequency, waiting mood, waiting time interval, and reserved waiting time has a positive correlation with passengers perceived waiting time while having a timing device, presence of a companion, and waiting behavior has negative correlation with passengers' perceived waiting time, Ohta et al [32].

2.5. Passengers Waiting Time Minimization Problem

Henk van Zuylen et al. [33] compromised the passengers waiting time cost with the operation costs intuitively. The concept behind the compromising is a larger fleet size provide a quick response to the specified passengers demand and reduces the passengers waiting time. On the other hand increasing the number fleet increases investment cost plus capital cost per vehicle and extra operation and maintenance cost. Optimal fleet size minimized the sum of these two costs.

Fraser McLeod [34] contributes the general theory of estimating headway variance using incomplete data. The average waiting times are estimated from bus headways; time gaps between buses. The problem of estimating bus passenger waiting times at bus stops using incomplete bus arrivals data was the missing data. Measuring bus arrival times manually is time-consuming and costly instead using automatic vehicle location systems are more attractive.

When the public transport service is reliable the passengers start to arrive at the public transport service station around the scheduled head way times; even with short departure times. The average waiting time of passengers relative to departure time was modeled as the logarithmic function. In the same manner the microscopic passengers' arrival distribution, shows the variation and distribution pattern between successive services modeled as superposition of a uniform distribution, An A. Nash et al. [35].

According to Vahid and Navadad [36] the increase of the bus line fleet resulted in the more crowding in some routes of the network at the joint of multimodal transportation line (light transit rail line and bus line) on personal network. The crowding of the fleet fluctuates the time spent and travel time across the distance in the network. This events consequently increases the costs of the passengers or the users along the network. But, in the reality by reducing the trip time of the passengers, public transportation system is selected as the low-cost and the safest part of urban transportation system by the users because passengers desire more trip than any other factors. To minimize the costs for the passengers' the assignment of the fleet was made by introducing a dynamic model to determine the optimum assignment of the public transportation fleet in which the optimum policy and combination of the fleet. Equation 1 shows the relation between the number of fleet and the headway of vehicles in the route.

$$\text{Headway} = \frac{60}{\text{fleet}} \qquad 2.1$$

Average passenger waiting time is a function of the departure time distribution between consecutive buses and the arrival time distribution of a bus. The method of predicting average passenger waiting time was proposed considering both random and non-random passenger arrivals. In opposed to the past models the proposed model focus on the effect of service reliability over wait time, Mark A. Turnquist [37].

Proper bus departure values and the optimum number of departure time intervals was established by the proposed methods. The proposed model is an intelligent procedure which is used to determine the head way interval based on the passengers downfall rate. The intelligent procedure follows, first a Similar Days Detection approach enable to find similar days of the data set based on passenger behaviors. This approach used K-Means and replaced Euclidian distance measurement with Fast DTW that enables it to compare time series. Then, a Headway Interval Detection Procedure is developed to use specific patterns in each cluster, Motlagh et al [38].

According to D. Deva Hema and R. Angeline [39] Operating cost of buses and total waiting time cost of passengers boarding the bus was minimized without reducing the level of service by the determined frequency. The determined frequency for the fixed period used to make flexible scheduling. The quicker travel, convenience and comfort of the public transport system can be made attractive to the passengers. The satisfaction of the passengers transport would be improved by providing optimum frequency.

The waiting and in-vehicle times that the passenger spend while traveling (relative to the standard single frequency service along the entire route) was decreased by reducing the cost of the operator by the method of short turn model strategy. Short turn model strategy set the optimal values of frequencies (inside and outside the loop), capacity of vehicles and the station of the short turn limit positions, Alejandro Tirachini et al [40].

Md. Kamrul Islam and Upali Vandebona [41] the headway variation increases the spread of passenger waiting times. The size of the vehicle type has an effect on passengers waiting time. The simulation result shows that the smaller vehicle size waiting time increases while waiting time of the larger vehicle sizes decreases. On the other hand unreliable vehicle headway resulted in uneven passengers load on buses.

According to Makrand Wagale et al. [42] Service frequency at each bus stop was optimized at which the total cumulative cost and total cumulative profit become equal. This is done by optimizing the bus scheduling of both the bus stop and route subdivisions of the city in a combined way. To realize a timetable for each bus stop on the basis of optimal bus frequency Demand and Travel time Responsive (DTR) model was applied. Then bus departure time table was developed.

In a dense metropolitan region total bus stop time (TBST) is used to improve scheduling and transit bus systems planning. TBST is defined as the summation of dwell time (DT) and the time it takes a bus at a bus stop and the re-entering the traffic stream. It was suggested that if the TBST is reduced at bus stops the total bus transit reliability along routes could be improved. Using ordinary least squares method the TBST models for bus stops located at mid-blocks and near joints were developed based on multivariate regression analysis. The reliability of the bus transit was not only affected by the bus stop but also bus stop conditions along the route, traffic conditions, route of travel and time of day. Generally, the overall transit bus reliability is affected by dwell time (DT), the fare payment method, the bus stop location, and the number of passengers alighting or boarding. According to Stephen Arhin et al. [43].

The proposition of the random passengers arrivals used by today's transportation model overestimates the actual transportation travel costs passengers experienced in long departure time. Passengers reduce the waiting time considered in transportation model at bus stations when the bus headway is long their own bus station arrival strategy. The arrival patterns in high frequency is greatly different from the arrival patterns of low frequency, Trude et al. [44].

Passengers expected waiting time was decreased for the passengers have been informed the bus schedule and the possible early or late departures by developing the "reliability-based arrival pattern model". Assuming that the buses are uncontrolled after the release of the buses from the depot. That means whenever there are no more waiting passengers' the buses leave the stops. The occurrence of bunching due to the values of demand lower than the planned one. Bunching generated by unexpected demand was not considered with previous models, which assumed uniform demand. The more severe bunching effects over time was led by non-uniform arrival patterns without considering the holding points or headway equalizing strategies. The other factor to more sever bunching effect over time was non-uniform arrival patterns which needs effective control measures, Ronghui Liuc et al. [45].

The expected average waiting time and the reliability of the bus service was evaluated by the punctuality index which is the measurement of a service quality of the public bus transport in the mixed traffic. Punctuality index is used to determine the expected average waiting time of stage buses in the mixed traffic and the level bus service, M. Napiah [46].

2.6. Overview of Passengers Waiting Time Optimization

Niu and Tian [47] had developed a bi-objective optimization model based on some reasonable assumptions to minimize the number of required vehicles and the total waiting times of passengers. To formulate the transit scheduling problem the departure times of transit vehicles under strict capacity constraints of dynamic traffic assignment in urban road network divides an operation day into several equal time periods a novel heuristic algorithm was developed. The result of the solution shows that all passengers can board the vehicles using the designed schedule, while some cannot when using the regular one and the average passengers waiting time associated with the proposed method was reduced by 66.27%.

Zhong-Ren Peng et al. [48] Designed the timetable for each operation model at different periods by adopting an adaptive heuristic algorithm to solve the problem of passenger demand fluctuation. Here a flexible timetable optimization method was proposed based on hybrid vehicle size model to tackle the bus demand fluctuations in transit operation. Then different models was built for hybrid vehicle, large vehicle and small vehicle. With the operation Transit Route at peak and off-peak hours, a heuristic algorithm was proposed to solve the problem. The outcomes show that the hybrid vehicle size model excels the other two modes both in the total time and total cost. The study validates the rationality of the approach of hybrid vehicle size model and highlights the significance of the adaptive vehicle size in dealing with the bus demand fluctuation.

Reducing passengers waiting time improve bus operation and keep good services to the passengers. Journeys planning for passengers is problematic when they have no information on the service route and definite arrival times at stops. Adaptive neuro fuzzy inference system

ANFIS was used to evaluate the travel time of the current bus arrival time when the bus departure scheduling is unreliable at a stop with multiple routes to forecast arrival times, Ruslawati Abdul Wahab et.al. [49].

According to Z¨undorf et al. [50] for travel time in public transport both demand and supply are significant. The supply side of public transport can be integrated into an agent-based model of travel demand. While it is clear that the supply side in the form of the timetable matches openly to the travel time, the demand side influences the travel time only partially, but in critical moments. During rush hours, when the demand reaches the capacity of the vehicles, the relations between demand and supply becomes significant. Congested vehicles, deterring passengers to catch their chosen route, lead to longer travel times. Consequently, it is essential to incorporate the supply side of public transport into a travel demand model.

To optimize the bus scheduling process the Stop departures and arrivals for buses operating on a line-based time-table and bus traffic costs was applied and bus headway time-table was developed. Optimizing bus service frequency optimizes total cumulative cost and total cumulative income by the method of DTR model. The borderline representing the stops with unnecessary investment and stops with revenues was defined by the optimal total transportation cost route. The optimal cost for whole route per hour and optimal service frequency of per hour in contrast to the maximum traffic cost per hour and minimum traffic cost per hour with average frequency of buses per hour, Arkatkar et al. [51].

Providing of perfect bus arrival information is vibrant to passengers for reducing their anxieties and waiting times at bus stop. To predict bus arrival times at the same bus stop but with different routes Mei Lam Tam et al. [52] proposed the model. The bus running times of multiple routes were used for predicting the bus arrival time of each of these bus routes in the proposed model. To predict the time of bus arrival support vector machine (SVM), artificial neural network (ANN), k nearest neighbors' algorithm (k-NN) and linear regression (LR) models were adopted. To collect bus running and arrival time data for validation of the proposed models observation survey was conducted. The outcomes indicates that the anticipated models are more accurate than the models based on the bus running times of single route. Additionally, it is found that the SVM model performs the best among the four suggested models for expecting the bus arrival times at bus stop with multiple routes.

2.7. Dynamic Mathematical Modeling Optimization

The average passenger waiting time was affected by both bus arrival pattern and bus headway. In both entirely random and the actual situations mathematical models was developed to predict the bus passengers waiting time. The relation of bus headway and passengers arrival pattern was described by linear regression model. When bus headway is less than 10 minutes the passenger arrival rate was random and when the bus headway is above the transition of 10 minutes the arrival pattern is non-random, Fan and B. Machemehl [53].

The passengers waiting time was reduced at the public train transportation terminals by using the developed mathematical optimization model of train timetabling in relation to dynamic travel demand and capacity constraints. Both linear and non-linear model formulation problem was developed. The developed model was non-linear programming in nature which was unsolvable with optimization commercial software. The model was made solvable by converting it to linear programming heuristically and the model was solved using GAMS software, Acording to Erfan Hassannayebi [54].

According to Chen, Qun [55] the total waiting time of passengers on stages of a single bus line was minimized under the known number of total bus runs and it is efficient. The global optimization algorithm was proposed to solve the problem of bus runs arrangement of a bus line and the bus timetable setting problem using dynamic programming method.

Summary of the Reviewed Literatures and Gap

1. This section summarizes the points raised in the literature and gives conclusion by stating the weaknesses observed on models contributed to optimize passenger waiting time for public transportation service which can serve as a future study area.
2. By improving the transport facility the demand of the public passenger transportation service was not satisfied. In general term to solve this problem deferent method were used. These methods are route network design, transit scheduling, service timetabling and crew scheduling. But these methods are not enough to solve the transportation problem. Different scholars used deferent methods to increase the efficiency of the transportation to satisfy the passenger demand. Still the used methods were not fully solve the transport problem to not satisfy the passenger due to deferent shortcomings.
3. There are more literatures presented the method how to satisfy the passenger transport service. This was done by identifying the service quality gaps between passengers and passengers, passengers and the supplied service, the supplied service and the supplying service. The reducing the factors that reduces the passengers dissatisfaction. Passengers waiting time is one of the poor service quality. As a result passengers waiting service for a long time is more dissatisfied.
4. In this literature review, the impact of passengers waiting time over the passengers itself, passengers waiting time influencing factors, the method of minimizing passengers waiting time, optimization of passengers waiting time and Dynamic mathematical modeling for minimization of passengers waiting time was mostly reviewed.
5. In this review, in optimization of passengers waiting time of dynamic passengers demand, the research done was mostly on railway public transit, even though the research done relative to demand-oriented passengers waiting time was few. In bus public transportation the research done on minimization of passengers waiting time at the bus terminal based on the timely passenger demand constrained based was very few. Therefore in this research, this research gap will filled.

Table 2.2 Summary of the literatures

Research Area	Objectives	Methodology	Finding and Conclusion	Ref. no.
Introduction	To know the overall transportation planning objective	Reviewing Literatures and books	Many studies done on network design, vehicle scheduling, time table development and crew scheduling	[6]
Transportation service quality • Concept service quality • Definition service quality • Models of service quality	To understand the overall service quality	Reviewing the literature	• The general concept, design and measurement of service quality. • The horizontal and vertical gaps between passenger demand and service delivery	[7]-[11]
Service quality and passengers satisfaction	To understand the relation of service quality and passengers satisfaction	Reviewing the literature	The relation service quality and passengers satisfaction is positive	[16]-[23]
Passengers waiting time • Definition • The type • The concepts	To study the nature of passengers waiting time	Reviewing the literature	• Meaning of waiting time • Types of waiting time • Passengers waiting time preference	[24]-[27]
Impacts of passengers waiting time	To understand and relate to the study	Reviewing the literature	Waiting behavior and passengers frustrations	[28]-[29]
Passengers Waiting time influencing factors	To understand the factors influences and seam to influence passengers waiting time	Reviewing the literature Actual experience	• Actual and perception of Passengers waiting time • The relation of perception factors and service level is negative correlation	[30]-[32]
Passengers waiting time minimization problems	To understand how deferent scholars tried to minimize waiting time problems	Reviewing the literature Actual experience	• Deferent waiting minimization methods were applied • Few about hourly based demand	[33]-[46]
Waiting time optimization	To understand the method of Waiting time optimization	Reviewing the literature Personal practicing	Few waiting time optimization method was applied in bus transport passengers waiting time optimization	[47]-[52]
Dynamic Mathematical Modeling Optimization	To understand the dynamic mathematical modeling optimization method	Reviewing and arguing the literature	Finding the literature gap among the dynamic mathematical modeling of passengers waiting time optimization method	[53]-[54]

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Research Design and Methods

In this chapter the research conceptual framework, research design framework and methodologies followed would be presented as a road map of this study. Different qualitative and quantitative data sources are utilized in the methodology.

3.1.1. Research Design

The research problem was identified through observation, as one of the passenger of public transport service, the public transport arrival rate and service rate at the bus terminals, and then relevant literature review of public transport systems was made. Moving on the study passenger and transport service arrival rate, passengers inter arrival rate and bus inter arrival rate was analyzed to understand the existing supply capacity of ACBSE. At the beginning of the analysis, situational analysis was made to identify the operation stability, and to determine whether the current status of the case companies is capable of responding to the existing transport demand with their targets or not. Then, the supply capacity of ACBSE was analyzed using the past transportation performance. Based on the results of the capacity analyzed, the existing service capacity level was identified. The necessary data were collected and the interests of the ACBSE and the demands of the customers optimization model was developed to optimize the waiting time of passenger at the bus terminal. Finally, the outputs of the model was validated with different parameters and changed into optimum bus timetable.

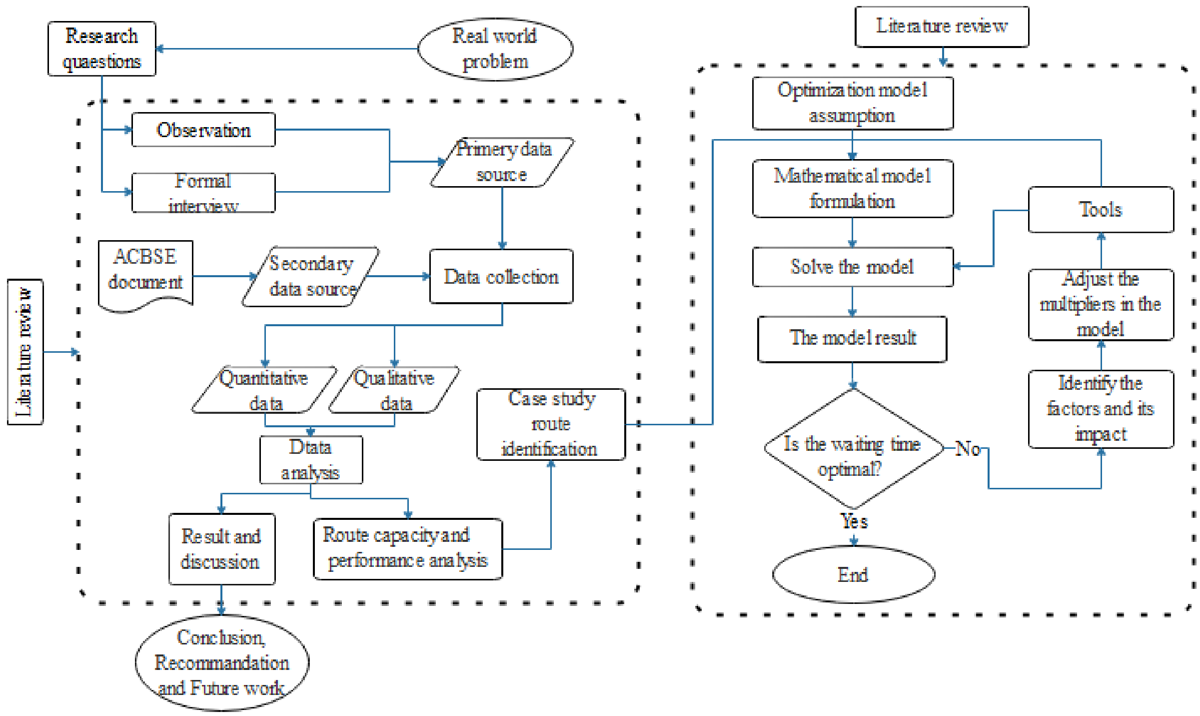


Figure 3.1 Research design framework

3.1.2. Research Methods

3.1.2.1. Literature Review

Relevant materials on public transport facility, capacity analysis and optimization techniques were gathered from journals, books, magazines, web-sites and electronic media. A review of these materials was made to investigate the supply capacity of the enterprise to respond to the passengers' transport service demand, the other customers' demands, the passengers' transportation service satisfaction, public transit utilization, operational facility, and economical and efficient transportation service. Not only this but also the available mathematical models and algorithms was reviewed and then adopted the best method to our real situation to evaluate and solve the problem of our field of study to fill the literature gap.

3.1.2.2. Data Collection Methods

3.1.2.2.1. Primary Data Source

a. Formal Interview with ACBSE

The data of existing bus service situation, how the enterprise communicate with their customer or passengers, how they assign the bus number to the customer demand of each routes, the bus service rate, the available capacity to respond to customers demand in relation to the population growth rate Addis Ababa city, the main challenges which lags the performance of the enterprise, the controlling mechanism of the transport system was collected by interviewing the Anbessa city bus enterprise through formal interviews.

After the interview was made the statistical data of route information and the number of bus assigned to each route was collected from the ACBSE. This bus assignment system was considered to satisfy the demand of the passengers of each routes. Based on the passengers travelled on this route, the number of buses assigned, the proportionality of the bus supplied and the demand of the bus.

According to the analysis made the result shows that the number of bus assigned and the demand of the number of passengers on each route was not proportional. There were where minimum number of buses serve more passengers and there were where more number of bus assigned served few number of passenger in relation to their numbers.

To identify the route which was more demand and require more buses; as well as the routes which was low demand and requires low buses control chart was used. The control chart indicates that the range where the route performance is optimum, more than optimum and less than optimum.

Based on the interview and collected information determine the area of sample study identified. According to this decision this study focus on the routes highly performed in service rate to see how it could reach the high performance and lowly performed to see why it could be low in performance.

b. Sampling Study

The population was categorized based on route wise passengers' volume using control charts ($\overline{x_i}$ and s). Where $\overline{x_i}$ is the average of the number of daily passenger transported along the routes and s-is the volume daily passenger standard deviation of each routes. The index is the bus routes i =1, 2, 3…124.

$\bar{x}_i$-is the route-wise passengers volume taken from the ACBSE,

$\bar{\bar{x}}_i$-is the average volume of passengers of all routes calculated from $\bar{x}_i$ of the population

s_i-is the standard deviation of $\bar{x}_i$ of the population of each route.

UCL and LCL- is calculated using $\bar{x}_i$ and s (the standard deviation of the volume of the passengers along each routes.

After the categorization of UCL and LCL three region of the limits identified.

Above upper control limits (UCL) region-this region is the region where the performance of the routes is above the UCL. This region is the routes where the demands of the passenger is higher than the supply.

The region between UCL and LCL- this is the region where the service performance along the route is assumed optimum. That means the the passenger transport demand and the supply of bus service transport is almost compatable.

Below the lower control limits (LCL) region-this region is the area of the routes where the demand of the passengers is lower and the service prformance supplied is higher.

c. Route Selection

Using control chart routes wise assignable passenger volume were selected. First the route was categorized based on the route wise passenger volume. These categories are UCL, LCL and the region between the UCL and LCL. Therefore the assignable region was selected for further study because of it was out of control limit.

The assignable region above upper control limit indicates that the routes performance is very high. That means the number of passenger volume along this route might be high due to the demands of the passenger is very high and the buses along this route transport the passengers more than the allowable bus loading capacity. This transportation service can only be happen when the shortage of fleet sizes faces the route. On the other hand there is high passenger demand and the number of bus capable to transport the passenger demand assigned.

The assignable region below lower control limit shows that the performance of the bus transport along the route is very low. That means the performance of bus transport is below the expected bus service. This may be due to the low demand or low number of bus assigned would be resulted in the slow transport service.

Based on criteria the percentage of the routes which indicates assignable, above UCL and LCL, and un-assignable region was shown on appendix-I and figure 6.

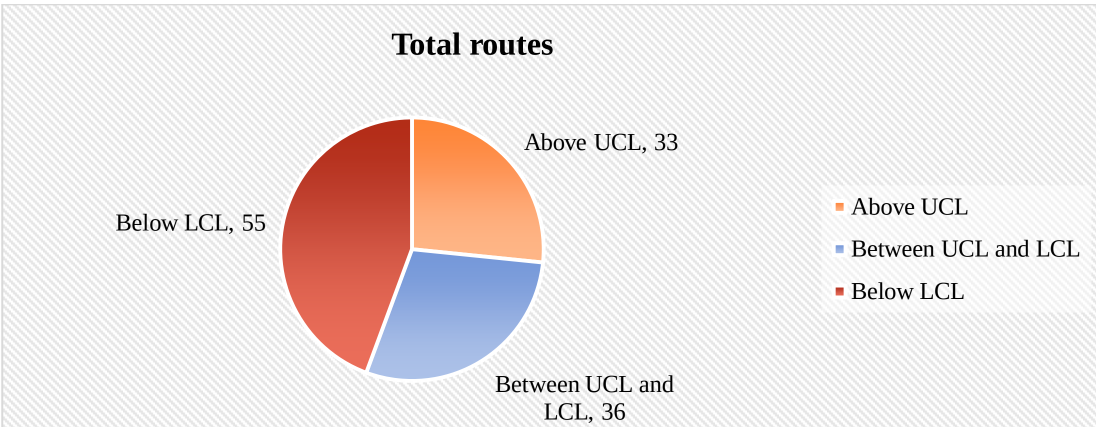


Figure 3.2 Assignable of route at each terminal and feeder routes

After obtaining this three regions, the two regions (above UCL and below LCL) was considered as the routes where there is a problem on the assignment of bus in relation to the passenger demand. The routes above UCL tells us that there is higher demand and shortages of bus supply in relation to passenger demand. Therefore, the passengers are exposed to wait the bus transport service, but the buses are busy in giving service. The routes below LCL also tells us that there is low passenger demand and higher bus supply transport service. Here the bus transport is over used and there is no passengers waiting time instead the bus waits the passengers to give service.

By having the above decision procedure the study area was identified. This area is the bus terminal where both passenger demand and the bus supply service was high, Merkato terminal, was selected.

It is difficult to study all the routes of the selected terminals. Determining the sample size is another task to reduce the number of routes for further study. The sample size of assignable (above UCL and below LCL) areas of above UCL and below LCL were evaluated separately.

To determine the sample size 95% confidential interval was used. To this effect, 14 (5 above UCL and 9 below LCL) sample routes were selected.

d. Actual Data Recording

The data was collected through physical observation presenting at the bus terminal. The collected data are passenger arrival rate, passenger inter arrival rate, bus arrival rate, bus inter arrival rate, and bus service rate of the selected sample. It was collected for peak and off-peak of working days of a week during the April, 2018. Data was obtained in the form trip-sheets and for analysis purpose data for five days was utilized. The average running time between stops and the average running speed, and the bus stop average service time by period, were used. As well, the total number of passengers boarding and egressing at each bus stop was obtained. Considering the length of the route and service hours 1h was chosen as the unit for analysis. Analysis was carried for morning peak - off peak and afternoon peak-off peak were considered.

Then the study area was selected. The study area was the routes that were more demands and low demands. The selection of the study bus terminal also selected based on this criteria.

3.1.2.2.2. Secondary Data Source

In order to have more deep understanding, and to evaluate the demand of passenger transportation and the supply capacity, in regard to the number of the available bus and the bus in operational, of ACBSE, different secondary data was collected. The sources of secondary data are the ACBSE research, reports, statistical documents of routes information and booklet. The data required are the current routes, the number of passengers served in each route, the number of trips in each route of the year 2017. The required variable to be measured are in the data collection are;

- ✓ The number of passengers transported on each route per day per bus;
- ✓ The number of bus assigned along each route;
- ✓ The number of trips per day per bus;
- ✓ The waiting time at the origin or destination after trip completion;
- ✓ The headway between the buses;
- ✓ The speed of the buses along each routes;
- ✓ The volume capacity of the bus;
- ✓ The time it takes to complete a single travel;

- ✓ The number of stops along each route.

3.2. Tools Used

3.2.1. Excel

The Microsoft excel was used to perform the calculation of quantitative data and qualitative data described in the form of quantitative data, to analysis and visualization of the data and information collected.

3.2.2. Edraw Max 9.1

Edraw Max 9.1 has a template which consist of basic diagrams, business diagram, card, chart, engineering and floor plain. It allows to create a wide range of diagrams using template, shapes and drawing tools. It also enables professionals to reliably create many kinds of diagrams to represent any ideas. It is an all-in-one graphics software that makes it simple to create professional looking flowcharts, charts and diagrams. Therefore it was selected to create conceptual framework flowcharts.

3.2.3. LINGO software

LINGO is a comprehensive tool designed to make building and solving mathematical optimization models easier and more efficient. It provides a completely integrated package that includes a powerful language for expressing optimization models, a full-featured environment for building and editing problems, and a set of fast built-in solvers capable of efficiently solving most classes of optimization models. Therefore it was preferred to solve the mathematical optimization model developed to minimize the passenger waiting time of bus transportation service.

Table 3.1 Summary of the purpose and importance of primary and secondary data source

Data collection methods and tools		Purpose	Importance
Primary data **collection**	Interviewing	To have know-how of the enterprises current situation	• Know the objective • The gap of the objective and the real performance • The source of the gap • How to communicate with the customer and vice versa
	Actual data Recording	To have an understanding of the situation on the real ground	• Analyses bus and /or passenger arrival rate. • Analyses the bus service rate and the passenger inter arrival rate • Evaluating the gap of passengers demand and bus service rate
Secondary data **collection**	Booklet	To get more information about the enterprise beyond the interview, observation and questionnaire	• Companies vision and mission • Companies values • The enterprise back ground • Where they are now
	Company research	To know how they know their weakness and improve their weaknesses	• Customer/passenger satisfaction • Administrative satisfaction
	Recorded statistical data	To know the performance they achieved	• The capacity they have • The capacity plan • Bus assignment • Number of bus stops • Distance travelled per period • Trip per bus per period • Bus head way and etc.
Tools	Excel	Describe the analysis	• Calculate the data • Analysis the data • Visualization of the data
	Edraw Max 9.1	To crate charts	• Automatic connection of the shapes • Easily shape alignment creation • Ease of chart creation
	LINGO software	To solve LP model	• Provides a completely integrated package of; powerful language for expressing optimization models, • a full-featured environment for building and editing problems, and • A set of fast built-in solvers capable of efficiently solving most classes of optimization models.

CHAPTER FOUR

OVERVIEW OF ACBSE PERFORMANCE

4.1. Introduction

This chapter highlighted the growth of ACBSE. It discusses about the place of ACBSE, the history of ACBSE growth and current status of ACBSE. Further, about the facilities and resources of ACBSE, ACBSE bus terminals, fleet size, spatial service, modal share and passengers waiting time for Anbessa bus was discussed in detail under the current status of ACBSE. Therefore this chapter is helpful to understand the status of the bus service that the ACBSE provides to satisfy the passengers demand.

4.2. Location of Addis Ababa

Addis Ababa is the capital and largest city of Ethiopia. As a chartered city, Addis Ababa also serves as a capital city of Oromia. It is where the African Union is headquartered and where its predecessor the Organization of African Unity (OAU) was based. It also hosts the headquarters of the United Nations Economic Commission for Africa (ECA), as well as various other continental and international organizations. Addis Ababa is therefore often referred to as "the political capital of Africa" for its historical, diplomatic and political significance for the continent. The city lies a few miles west of the East African Rift which splits Ethiopia into two, through the Nubian Plate and the Somali Plate**,** Admasu Woresa [56].

Addis Ababa lies at an elevation of 2,200 meters (7,200 ft.) and is a grassland biome, located at 9°1′48″N 38°44′24″E. The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. From its lowest point, around Bole International Airport, at 2,326 meters (7,631 ft.) above sea level in the southern periphery, Addis Ababa rises to over 3,000 meters (9,800 ft.) in the Entoto Mountains to the north. Yorgos Voukas and Derek Palmer [57].

4.3. The History Of ACBSE Growth in Addis Ababa City

The public transport established as a business entity in 1943 by the then work and communication minister using the trucks and garage materials left after fascist Italian occupation and was serving under this title until 1951.

In 1952 the organization re-organized as a share company named as “by Ethiopian vehicles transport service established company” and started giving service to Addis Ababa and parts of the country wide. The shareholders the then time is the state and the nobility as major shareholders.

The transport service was started with 10 buses and 4 transport routes. The tariff charged then was 0.15 birr for a single trip. By increasing the number of buses timely, the number of buses raised up to 163, it established the head office and garage around Lideta in 1974.

In 1974 the company was changed to the public property under the then Public Transport Corporation (PTC), Nationalized and owned by government until 1994.

In 1994 ACBSE was established as independent public enterprise by Council of Ministers Regulation No.187/1994. Since then to now this enterprise known by name ACBSE. Before the 2011 this enterprise was supervised by private agency. Since 2011 the supervisory authority has changed from the Privatization Agency to Addis Ababa City Administration. (Source: Booklet of ACBSE).

4.4. Current Status of ACBSE

This section discuses the current status of ACBSE level of service to respond the current customer demand as an public transport enterprise. This indicates the capacity of the ACBSE in facilities and resource, the terminals and number of terminals ,the facility size it has, the type of services it provides, the spatial service area and the modal shares of its service in addis ababa city, (Source: ACBSE). These all are discused under the following sub section.

4.4.1. Facilities and Resources

ACBSE operates out of three sites, its headquarters complex at Yeka to the east of the city, a second depot at Shegole to the northwest, and a newly opened depot at Mekanisa to the south.

The Yeka depot is 97,147sq.m.in area. The operating depot has the facilities for 438 buses are currently deployed. The site also includes the central workshops for the enterprise (developed with Dutch technical assistance), and the main spare parts warehouse. The headquarters office provides both for central administrative and depot control functions.

This depot is sited immediately adjacent to the recently completed city ring road, providing for effective vehicle positioning on routes. The depot yard is surfaced, and well laid out for efficient operation. The workshops are well equipped, and housekeeping standards are high. The fuel station has adequate capacity for the fleet based on the site. No significant near term investment is required.

The second depot at Shegole is 53,996 sq.m.in area. This facility has its own fuel station, and light maintenance and running repair facilities as well as a spare parts store operated on a satellite basis from Yeka. Currently 350 buses are deployed to this depot.

This depot is self-sufficient apart from heavy maintenance that is still carried out at Yeka, leading to some loss of control. Operating standards would be improved by surfacing the yard, but it is understood that the necessary finance has not been made available. Otherwise no major near term investment is required.

The third depot at Mekanisa has only recently been made operational. It has a site area of **74,631sq.m**, which would be more than sufficient for a further 300 buses; however only 223 are deployed there at present. Facilities are still being developed, but it is intended that this site is made increasingly self-sufficient. The major outstanding investment need is for the yard to be surfaced.

4.4.2. ACBSE Bus Terminals

The ACBSE established the bus terminals to control the route network. Primary control of the route network is carried out at the four main terminals, Addis Ketema, Leghar, Menelik Square and Megenagna. Terminal controllers adjust services as required to balance the implications of late arrivals and lost trips, and re-allocate vehicles accordingly in order to meet the most pressing levels of demand.

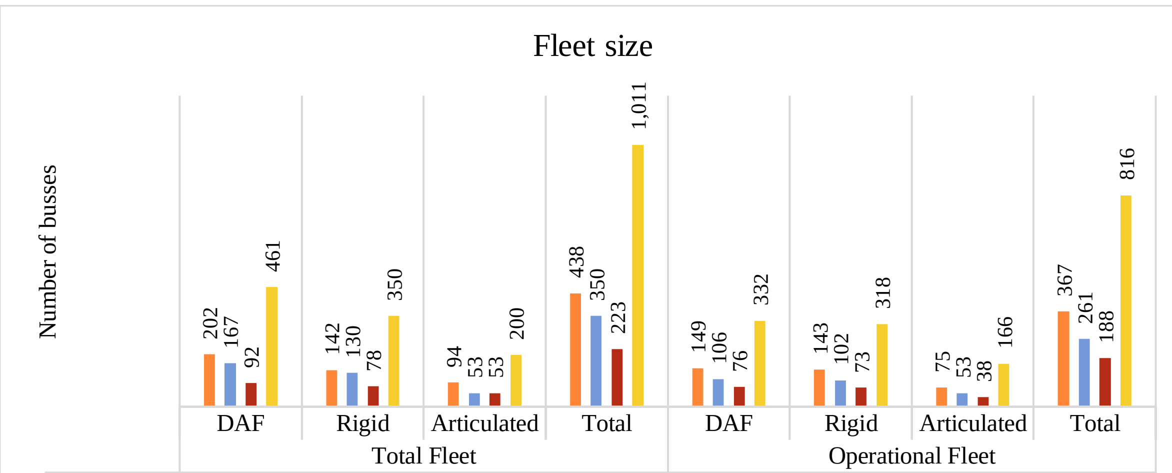
Technicians are also based at the terminals, and carried out some interventions per day in order to prevent the need for buses to be returned to depot.

The terminals are congested, and poorly laid out to deal with the volume of bus movements and the high number of routes being operated through them. The study on improving transport recommends that any development of their facilities should be delayed pending restructuring of the route network in response to a scientific travel demand study. Revisions arising from this would probably result in more routes being run through the city center, and less actually being terminated in it.

ACBSE head office building is located at the so called Yeka Depot and has facilities and resources of three depots (Yeka- 97,147sq.m. Shegole-53,996sq.m. & Mekanissa-74,631sq.m.); For parking and the like, 29 check points, 1640 bus stops, Nine (9) specialized big workshops at Yeka & Three (3) smaller garages at Shegole & Mekanissa Depots, totally five (5) vehicles washing bays, Three (3) fuel stations with total capacity of 270,000 liters in the three depots, 2 main stores and 7 satellite stores for spare parts & tickets at depots.

4.4.3. Fleet Size

ACBSE has a fleet size of 1,011 buses regardless of their fleet capacity. Out of this fleet size 80.71% buses are in operational condition. There are three types of bus fleet which are distributed among the depots. These are DAF , rigid and articulated buses. The following figure shows that the distribution of the fleets and fleet operatinal among depots.



	Total Fleet				Operational Fleet			
	DAF	Rigid	Articulated	Total	DAF	Rigid	Articulated	Total
Yeka	202	142	94	438	149	143	75	367
Shegole	167	130	53	350	106	102	53	261
Mekanissa	92	78	53	223	76	73	38	188
Total	461	350	200	1,011	332	318	166	816

Figure 4.1 Anbessa bus fleet size

4.4.4. Spatial Service

ACBSE provides deferent transport services to the Addis Ababa city and Addis Ababa suburb community. It provide three types of Services. These are: Regular Scheduled Service, Premium Service and Special Service.

Currently, 670 daily Operational buses in 124 regular routes & 34 feeder service routes within two shifts from 05:30 a.m.-1:00 a.m. in the morning 1:00 p.m. to 08:30 p.m. in the evening. They transport 500,000 passengers per day & their modal share is 25%.

Figure 4.2 Passengers travelling by bus

The ACBSE gives transport service to population of Addis Ababa city center, boundaries and the suburb cities. The percentage shares service of passenger in Addis Ababa city center is 80.7% of service provided.

Table 4.1 Anbessa bus service routes and performance

City description	Distance range(km)	Total route	Passenger Share (%)
Center	3.8-12	76	80.7
Boundary	12-21	35	15.3
Suburb	21-52	13	4

The bus service provided in the inner city was within the distance range of 5km-12km. The city boundary percentage service is 15.3% within the range of 12km-21km. The area ACBSE provide service to the suburb is 4%. These areas include Chancho, Sendafa, Bushoftu, Sebeta and Holeta. The distance range of suburb area is 21km-52km.

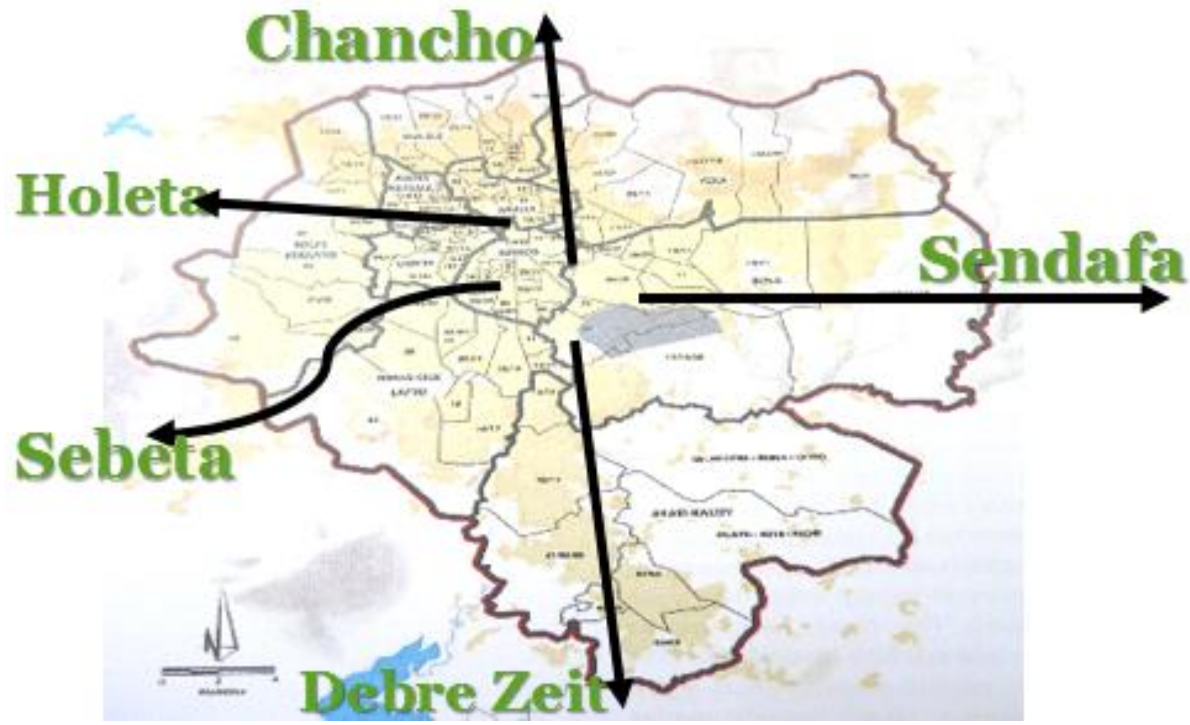


Figure 4.3 Addis Ababa city, boundary and suburb area

Source: ACBSE

4.4.5. Modal Shares

Anbassa city bus Public transport in Ethiopia consists of operations to and from the capital Addis Ababa. The transport modal share in the capital can be broadly spilt as: 15% private car, 25% public transport and 60% walking. Contrary to many other African cities, the role of bicycles in urban transport is largely insignificant due to topographical restrictions and there is no rail transport within the city.

Public transport mainly consists on the one hand of conventional bus services provided by the publicly owned Anbassa City Bus Enterprise and also taxis, and mini and mid- buses operated by the private sector. The large proportion of walking suggests that public transport fares are globally unaffordable for the level of income of the city population. Car ownership among residents is very low, so the majority depends on buses and taxis for their day-to-day mobility in terms of motorized transport.

Until 1992, the right to operate large buses within Addis Ababa was exclusively held by Anbassa while minibus ‘taxi’ services were restricted and regulated on a zonal basis by the public authority.

In 1992, the public transport market was deregulated by a transitional political regime through the ‘Proclamation to Provide for the Regulation of Road Transport’ which limited the conditions for running a public transport activity to only two: proven roadworthiness of the vehicle and qualification of the driver. Once his permit was issued, the carrier was then able to operate throughout the city with no exclusion from routes or areas.

4.4.6. Passengers Waiting Time for Anbessa Bus Transport

Passengers waiting time is the time that the passengers spent until they get the transport services. The amount of passengers waiting time depends on passengers demand, the number of bus assigned, the distance of the routes, the speed of the bus assigned and the dispatching management system of the bus terminals. According to the sample study done by ACBSE the passengers waiting time was shown as the next table:

Table 4.2 Passengers waiting time for bus at inner Addis Ababa city and suburb

Addis Ababa inner city		**Addis Ababa city sub-urban**	
Passengers waiting time	**In percentage**	**Passengers waiting time**	**In Percentage**
More than 45 minutes	34.8	More than 2:00hrs	14.4
45 minutes	20.6	2:00hrs	14.8
30 minutes	13.4	1:30hrs	9.6
20 minutes	8.8	1:00hrs	5.4
Unknown information	22.4	Unknown information	55.8

Table 4.2 shows that the passengers waiting time of the known of inner city of Addis Ababa was more than 45 minutes which holds 34.8 % and indicates most of the passengers of Addis Ababa city waits the bus more than 45 minutes. On the other hand, the Addis Ababa suburban minimum passenger’s waiting time was 60 minute or 1:00hr. But, the maximum passengers waiting time at this area was at least 120 minutes or 2:00hrs.

CHAPTER FIVE

DATA ANALYSIS AND INTERPRETATION

5.1. Data Collection

In this section two types of data was collected. The first data is the demand side data and the second data was the service supplying data. If the supply service and the required demands were not proportional, there would be passenger dissatisfaction or resulted in service supplying organization's (in this case ACBSE) loss. To avoid such problems (enterprise loss and customer dissatisfaction, it is important to increase the customer satisfaction by increasing the service efficiency through optimization that means with the lowest possible number of bus supplied.

Transportation planners and designers setting bus service frequency to increase the service efficiency based on the transport demand required. The Efficiency could be increased through increasing the service by increasing the number of bus, designing effective route, setting and using the schedule and timetable appropriately, and managing and controlling the crew activities.

The frequency of the bus is affected by the speed of the bus, number of bus assigned, the distance of the route, the number of stops per the route distance, the number of demand at the terminals. Even though it is assumed that the speed of the bus dispatched along the same route is the same, in the real world different buses that cannot have the same speed. This shows that there is the speed variation due to different factors. The factors might be traffic congestion, passenger behavior, driver behavior and skill, nature of the road, bus speed capacity, bus design, dispatching management system at terminals and etc. Based on the route wise passenger demand the number of bus is assigned. The number of bus assigned has an effect on the bus head way. Given the origin-destination journey time if the number of bus assigned increases, the bus frequency increases, the bus head way decreases and vice versa. The bus traveling a long distance takes a long time and the bus travelling a short distance take a short period of time to return to its origin. Based on the number of bus assigned and the speed of the bus, the bus traveling a long distance take a long time and resulted in low frequency. The bus which traveling a short distance take a short time and resulted in high frequency.

Therefore to increase bus service frequency and reduce the passenger waiting time it is important to analyses the problems. To analysis this the influencing factors data were collected. The collected data was categorized under two broad category. These category are supplied data and demand or passenger side data.

The supplied data was the interview data and operational data from the organization of ACBSE. The second demand data was the recorded data the resulted from direct observation and the secondary data. Therefore in general, under this section, the interview made, the operational data, passengers flow data, capacity utilization, passengers waiting time and the sample case study was analyzed and presented.

5.2. Interview Analysis

In this section the objective of ACBSE, the fleet capacity available, the methods of assigning the bus, the basic criteria to assign the bus to each routes and how to control the service system were analyzed and discussed.

The objective of the ACBSE was, in short, to serve the public with the minimum cost. The secrete behind this objective intention was to provide the transport service to the poor with the low cost that matches with their level of livelihood.

To achieve their objective the ACBSE increase the number of bus from time to time. Before 3 years the number of bus available was 820 buses. At current time the number of bus was 720 buses in which 520 buses (72.22%) are operational and 200 buses (27.78%) are out of operational. The reduction of the number of buses are fails due to deferent reasons. The causes of the failures was the bus service life and the nature of the road on which the buses provide the services. This can be evaluated from the age of the buses. The age of the buses for DAF was 20 years old and for articulated bus the age was 6 years old.

Figure 5.1 DAF, Bishoftu bus and rigid bus

In other words, to achieve their objective is to assign the bus based on timely based demand profile. In this case the bus was assigned regularly according to the schedule during the rush (peak) hours. The rush hours' time is from 6:30 a.m.-9:00 a.m. and 4:00 p.m. - 6:30 p.m. But, during un-rush (off-peak) hours the bus assignment was different. The bus was assigned based on the demand available along the route without keeping the regular scheduling. The un-rush hours' time is from 9:00 a.m. - 4:00 a.m. and 6:00 p.m.-8:30 p.m.

The bus was assigned based on the route characteristics, number of population, the carrying capacity of the bus, and trip generation. The route characteristics indicate the area where the population density is higher than the others, that means residential area, business area, schools, religious institutions, hospitals, recreational areas and etc. The bus carrying capacity is the volume of the bus to transport mass passengers at the same time. The trip generation is the frequency of the bus from origin to destination or from destination to its origin within a given periods. If there is a high demand the ACBSE responds to this demand by increasing the service frequency or by assigning high volume of the bus which can carry mass passenger at the same time.

But the basic problem is the number of bus assigned and the number of passenger demand along the routes. The bus was assigned based on the passenger demand. But the bus assigned mostly older and the nature of the road was inappropriate to the buses. Therefore during the morning time the buses dispatched the number of buses, mostly, as equal as the number of bus assigned along the routes on schedule basis. After the buses started service the bus started to fail or faces failures and goes to the repairing area. Again from repairing area it returns to service line. This shows that the supply of the bus service is higher during the morning time and become lower and lower during afternoon due to bus failures. This events leads to increase the passengers waiting time from morning to evening. The reason behind to increase passengers waiting time is when the bus fails the bus headway would be changed and as much as the bus fails the headway between the successive bus become more and more.

5.3. Operational Data Analysis

Most public transit systems operate service that has some common characteristics from the supply side. As the bus is one of the public transit system it shares the same characteristic with other public transit. The most prominent of common operation characteristics of the bus are the bus cycle and the bus capacity.

ACBSE provides transport service for 124 routes. These routes service include Addis Ababa city and around Addis Ababa city suburb, Oromia region.

Along these routes the demands and the distance of the transports are vary. These variation creates the utilization of the bus and the headways of the buses assigned to the routes would be vary. The effect of the route distance, travel speed of the bus, travel time, number of stops the number of bus assigned to the route resulted in the variation of passengers waiting time. That means the bus assigned along the long route takes a long time to reach its destination. Therefore the travel time bus of this routes is also long accordingly, and if the route is short the passenger travel time is short. But it depends again on the speed and the number of bus assigned along the route.

Bus operations generally follow the traditional vehicle repeated sequence of events. Operation of each bus is under control of the driver. That driver is responsible for operating the bus safely along the route. In addition the operators manage passenger boarding and alighting at stops along the route as well as manage fare payment on board, and for ensuring passenger safety and security.

The supply data was represent the bus frequency and the bus capacity. The frequency of the bus was the number of trips that the bus travelled within the scheduled period. This data was collected from the ACBSE in the form of number of bus assigned and travel time. This is used to analysis whether the headway is off or on to the schedule to calculate the passenger waiting time bus terminals. The head way also calculated by dividing the bus journey time to the number of bus assigned along the giving routes.

$$\text{Head way} = \frac{\text{Buses Journey Time}}{\text{Fleet Size}} \qquad 5.1$$

The bus capacity was another data represented the supply data. Capacity on a bus route is the product of the route’s rate and the number of passengers on each bus. To get higher capacity, one may rise the frequency of buses or increase the passenger-carrying capability of each bus, or both. The ACBSE provide two types of bus service for public transportation based on their capacity; rigid/DAF which can carry 60 passengers and articulated which contain 100 passengers. This capacity variation causes to passenger waiting time. Based on the passenger demand either the rigid or the articulated one would be assigned to the route. If the passenger demand is higher than the capacity of the bus assigned the passenger would be obligated to wait another bus and vice versa. Therefore in the next section let us analyses in more detail about bus service number of bus assigned, bus capacity and the route wise head way for waiting time optimization model the time tables of bus journey time, bus capacity, bus numbers and the bus service frequency of each route.

5.3.1. Number of Buses Assignment

The primary objective of the bus assignment is to satisfy the passenger demand. The number of bus assigned along the routes is based on the number of passenger demand throughout the routes. If the number passenger demand is higher the number of bus assigned should be proportionally assigned.

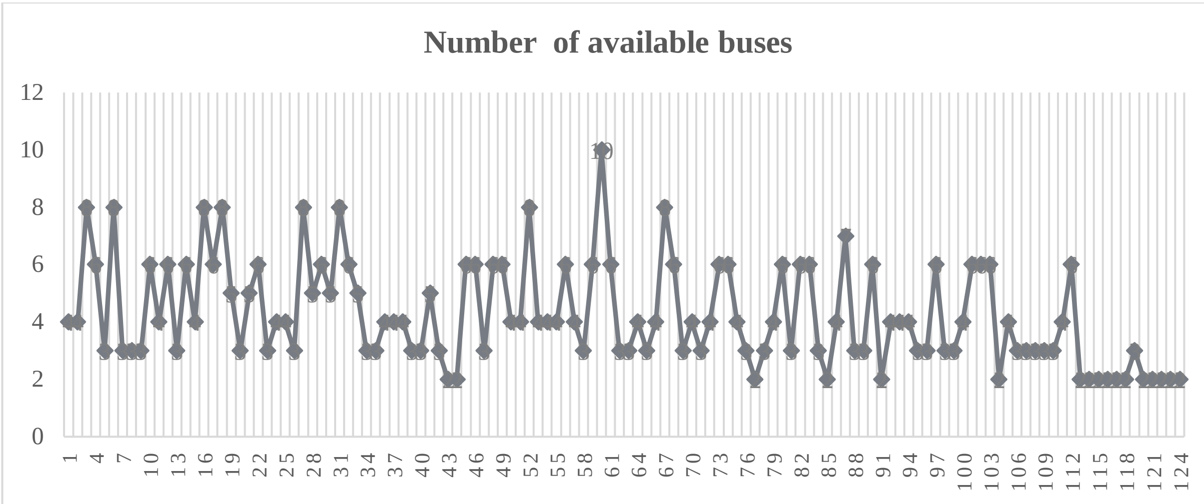


Figure 5.2 Number of available buses

Figure 5.2 indicates that the number of bus service assignment along each route. The maximum bus was 10 to the route of number 60. The minimum bus assigned was 2 to the routes of the number 43, 44, 85, 91, 104, 113, 114, 115, 116, 117, 118, 120, 121, 122, 123 and 124. (Refer appendix-I). The overall average of the buses assigned to each route is 4 buses.

5.3.2. Fleet Capacity

Capacity in transit operations is measured as the maximum number of passengers that can be carried earlier a single point on a fixed route, in a given period of time. The most common measure of capacity is in terms of passengers per hour. With this in mind, the capacity of a transit route is given as the product of the frequency and the maximum number of persons per vehicle.

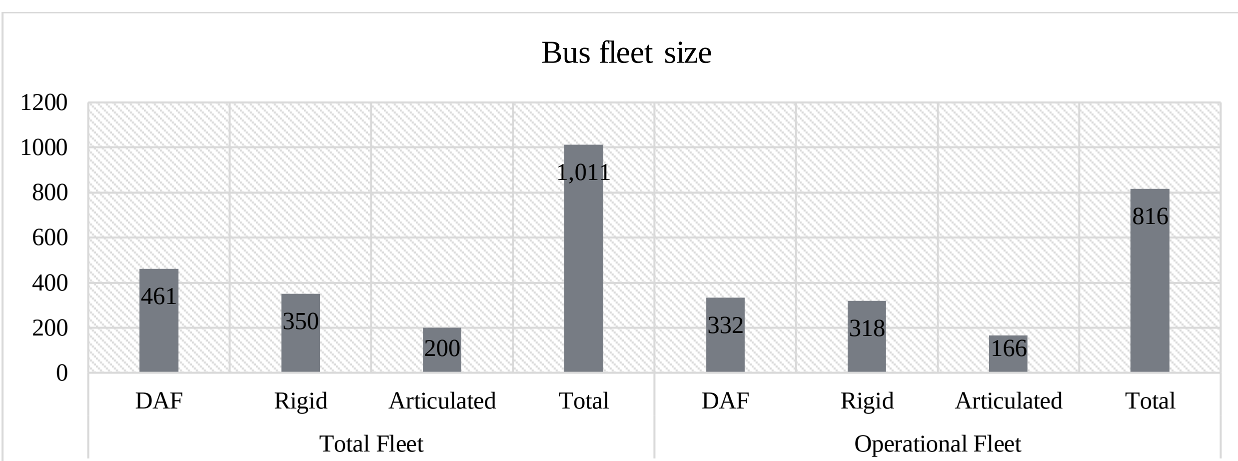


Figure 5.3 Bus fleet size (Source: ACBSE)

Articulated-capacity-100 person per bus was166 which is 20% out of total fleet and 83% was in operational.

DAF-capacity- 60 person per bus was 332 which is 46% out of total fleet and 72% was in operational.

Rigid-caapcity-60 person per bus was 318 which is 35% out of total fleet and 91% was in operational.

5.3.3. The Bus Headway

Headway is an extent of the distance or time between vehicles in a transport system. In transit operations it can be defined as the time between vehicles past a given point as the headway (or time headway), usually in minutes. The opposite of the headway is called the frequency, essentially seizing the number of vehicles per unit time previous a certain point on a route, usually measured in vehicles per hour.

The headway of the bus depends on the distance of the routes, number of bus assigned, the speed of the bus and the number of passengers require the bus public transportation along the routes. If the distance of the route is long and the number of bus assigned along the route was relatively few, the headway of the buses would be relatively long.

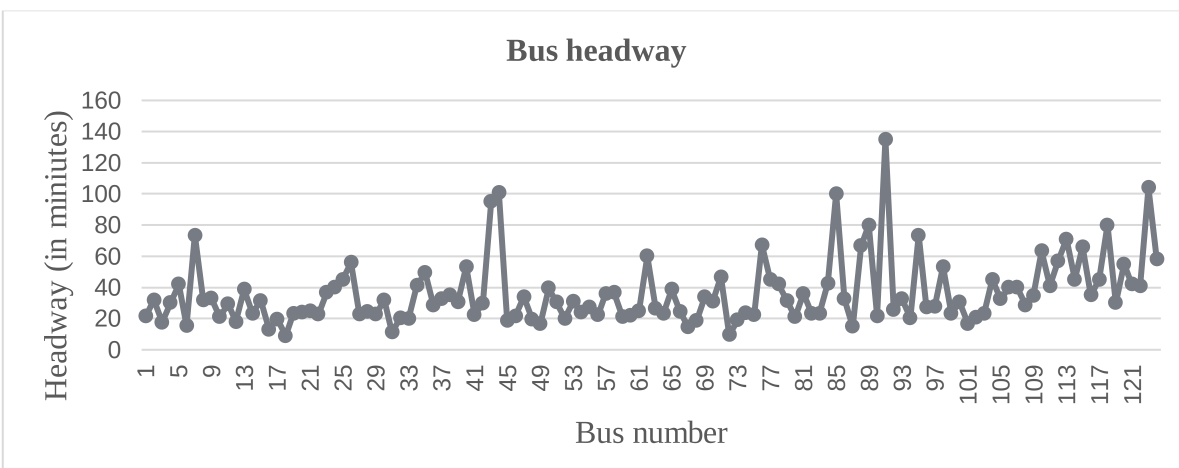


Figure 5.4 Bus headway

On the other hand the number of bus assigned was to serve the number of passengers who needs bus service. That means the demand of passengers who use the bus for their transportation service affects the number of bus which should be assigned to satisfy the passenger's needs.

The average of total bus service headway was 21 minutes. As figure 5.4 indicates that the headways of the buses ranges from 6 minutes to 73 minutes. that means when the passengers of 6 minutes of bus headway waits for 3 minutes for the bus transport to travel to its destination, the passengers of 73 min of bus headway waits the bus for 36.5 minutes to travel to its destination.

5.3.4. Number of Trip/Service Rate

The service rate is the number bus trips per specified time period (hour, day week, month or year) at which the bus provide the services.

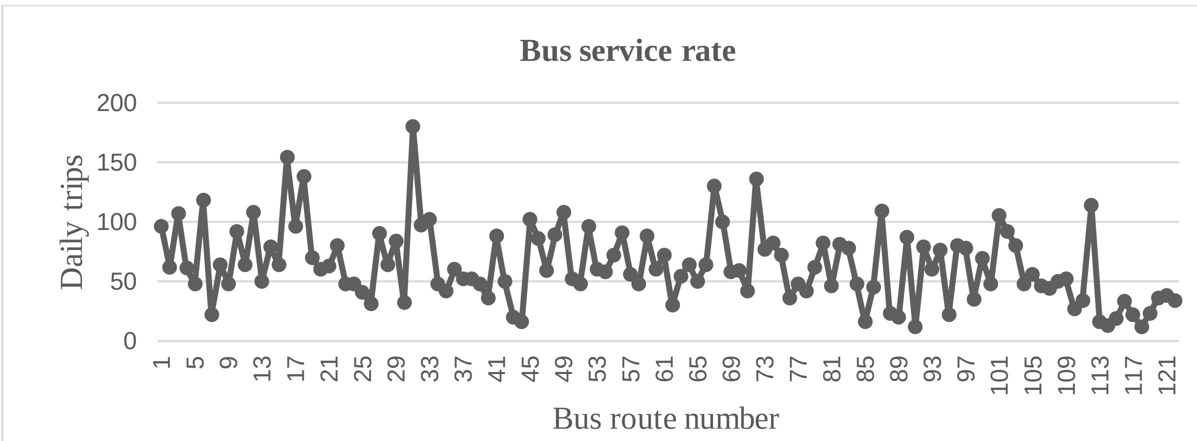


Figure 5.5 Daily bus service rate

Figure 5.5 demonstrates that the ACBSE provide a service rate of 78 trips per day in average with the maximum trips of 180 trips per day (the bus route number 31 from Legahar to Shiromeda) and the minimum travel daily trip was 12 trips per day (bus route number 91 from Addis Ketema to Teji and route number 118 from Merkato to Tateq Kella).

5.3.5. Operational Characteristics

A description of the operational characteristics of Anbessa City Bus Service Enterprise for the month of 2016/2017 is attached as Appendix-I to this report. The subsequent observation is based on an analysis of these data, together with interviews held with the senior management of the enterprise.

5.3.5.1. Routes Operated

At the current time Anbessa operates 124 routes. On all of these routes services are run throughout the operating day within two shifts from 05:30 a.m.-1:00 a.m. in the morning 1:

00a.m. to 08:30 p.m. in the evening. Some of these routes are sub-urban, connecting settlements outside the city boundary that fall within the travel-to-work area. The balance provide services within the conurbation, mostly on radial routes to the central business and commercial areas of the city.

On these routes there are supplementary peak services operated according to vehicle availability and shifting from the low demand to peak demand rotes. The peak services are usually run over a shorter portion of the designated route, but still charge the same fare as for the full service. In this way, they help to provide a more exact match of transport supply to passenger demand.

Anbessa was not able to offer a route map, but it is immediately obvious that there is a high degree of overlap between routes within the network. This predominantly rises from the fare structure, whereby the designated fare depends on the length of the particular route and not on the length of an individual boarding. It is hence in the benefits of the enterprise to deliver services in the corridor that can command higher fares, and not to integrate these with lower fare and shorter services.

5.3.5.2. Scheduled Timetables

All Anbessa services are ran to scheduled timetables, but no information about these is provided at the large majority of stops. Headways on many routes city are extended, and service intervals often fail to provide clock-face regularity.

Addis Ababa city bus enterprise has two types of schedules for operation, i.e. A. basic schedules, where the bus operates for two shifts, about fifteen hours a day, starting from morning 6:15a.m. to evening 8:30 p.m. peak hour services, which operate only for seven to eight hours during a day, utilizing only one set of crew, duly splitting the operation into two spells, one during morning peak hours and second spell during the evening peak.

The schedule of Addis Ababa city bus enterprise shows fixed number of buses throughout the day. During the peak periods most of the buses at every bus routes are highly crowded and sometimes about 150 passengers per bus and during off-peak periods the number of passengers on a bus is very low and increase empty travelling cost or dead mileage. The working time of Addis Ababa city bus enterprise starts at 6:15.a.m. in the morning and end service at 2:30 a.m. in evening. In this working time there is a time table for each route which shows the starting and ending time of all trips to be made on the route. This time table includes tea break and lunch break time. The travel time is assumed to be constant throughout the working day, but the travel time of buses may not be the same during peak hours and off-peak hours due to congestion and traffic lights. And due to this the scheduled time tables is just a time table not the actual time which shows the exact time at which a given bus is on the scheduled destination. The schedule is violated throughout the days and due to this the passenger arrival rate doesn't depends on the time table. Passengers arrive at bus stops independent to the bus schedule and this increase the waiting time.

5.3.5.3. Service Monitoring

Service performance is carried out at the four main terminals and at a further 34 control points in the city designed to capture the large majority of the routes being operated, particularly in relation to schedule and trip achievement. Managers at these points also monitor the correct issues of tickets to passengers.

The checkers show a daily data to the Quality Control Department giving both the scheduled and actual time of operation of each trip. These data are collected and analyzed so as to inform operational management.

The control section strives to ensure that all the revenue is collected by the conductors from passengers and remitted to the enterprise. These controllers are organized into two shifts, and each line controller is expected to check a minimum of twenty four buses during his duty of eight hours. The work of the line controllers is supervised by a special controller, sent at each of the major terminals. All these line controllers are expected to conduct about 50,000 checks on the conductors to prevent any possible mismanagement of revenue. It is therefore clear that such manual collecting mechanisms are subjected to human errors which then cast a negative impact on the efficiency of the services resulted by the city bus enterprise.

5.3.5.4. Bus Terminal Management System

Primary control of the route network is carried out at the four main terminals, Addis Ketema, Leghar and Menelik Square and Megenegna. Terminal controllers adjust services as required to balance the implications of late arrivals and lost trips, and re-allocate vehicles accordingly in order to meet the most pressing levels of demand.

Technicians are also based at the terminals, and carried out some interventions in order to prevent the need for buses to be returned to depot.

The terminals are congested, and poorly laid out to deal with the volume of bus movements and the high number of routes being operated through them. The study on improving transport recommends that any development of their facilities should be delayed pending restructuring of the route network in response to a scientific travel demand study. Revisions arising from this would probably result in more routes being run through the city center, and less actually being terminated in it.

5.3.5.5. The Number of Stops

Bus stops are where passenger boarding and alighting takes place and are linked together to form a route with origin and destination. Each route has different number of bus stops based on their length which is spaced at a distance of 350-500 meters unless policy and topographic restriction exists. There are more than 2573 bus stops currently served by the Addis Ababa city bus service enterprise, (Refer Appendix-I). The routes with less length have more bus stops than the routes with longer distance. This may be due to topographic location the routes, demand characteristics of the route and policy headway of the routes.

Regarding the bus stops along the given routes there are two concepts. The One is the characteristic that is fairly common in bus operations is the concept of “hail-stop” operations. That means a bus needs to stop at a stop or station only if a passenger requirements to board or alight; otherwise, the bus may simply sidestep the stop at running speed. In this characteristics, passengers wishing to board or to alight must indication these intentions to the operator, so that he/she recognizes whether it is necessary to stop at the next stop or station. The second notion is that the bus may stop at all stops; this is more public where the bus has only an inadequate number of stops and/or high capacities of passengers boarding and alighting at these stops. These actions and conducts put a result on the passenger waiting time. That means the operator who tracks the hail-up operation use the time well. But those operators’ stops the bus at every bus stops miss its time and increase passengers waiting time.

5.4. Passenger Flow Data Analysis

The basic assignment of the bus public service is the number of passenger demands along the given routes. The ACBSE dispatches the buses, every day, to their terminal or to their destination to take the passengers from bus destination to the bus terminal and vice versa according to the bus service schedule and timetable. Therefore, any passengers who uses the buses wait the bus at the stops before the bus reach their service area in order, the bus, not to escape them. The passenger board the bus at the terminal or destination alight at any stop, destination or terminals. On the other hand any passenger board at stops along the route can alight at every stops along the route, terminals and destination according to the direction of their journey.

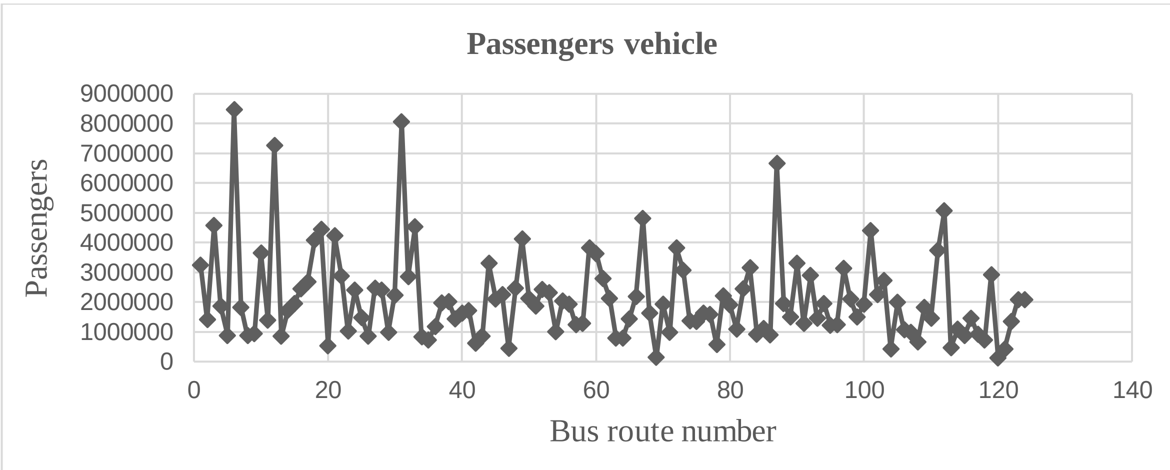


Figure 5.6 Route wise passenger distribution (Source: Appendix–I)

Figure 5.6 defines that the number of passengers vehicle transported by 527 bus in a one year. The maximum demand passengers' vehicle transported is 8,469,043 along the route of number 6. The minimum of demand passengers vehicle transported is 128,448 along the route of number 120. The overall average demand passengers' vehicle transported along each route is 2,120,968 passengers vehicle per year.

5.5. Bus Capacity Utilization

Utilization is a measurement in hours or mileage to indicate how frequently a vehicle or piece of equipment is used within a given time period (i.e. month, quarter, or year). This was used to measure the expected bus performance in case of using the bus size as well as the quantity of the bus which was ready for service.

The quantity of the bus available was indicated on figure 5.3. This figure demonstrates that the total number of bus available, the types of bus and their respective quantities, the operational and non-operational bus and their quantities. Out of the total available buses the operational buses are 80.71% which is 79.66% DAF (rigid Bishoftu) bus and 20.34% articulated bus. The DAF or rigid Bishoftu bus loading capacity is 60 passengers at a time. This was derived from the assumption of bus load factor as the loading capacity was at the crash load. In this case the load factor was 2, which means the number of passengers was two times the seat capacity. The second type of bus was articulated bus which loading capacity was 100 passengers at a time. The loading capacity of the bus used ACBSE was 75 passengers at a time for both rigid and articulated bus. But the actual loading capacity is deferent; less than 75 passengers for DAF or rigid and greater than 75 passengers for articulated bus. To compare the bus utilization the number of bus type assigned to each route was calculated using the bus type percentage. To calculate the expected number of passengers-vehicle the load factor used was 1.5. This is used because of it is approximately equal with the load factor that the ACBSE used. The actual and expected output route performance was indicated on the figure below.

$$\text{Expected passengers} - \text{vehicle} = \text{load factor} * \text{bus seat capacity} * \text{number of}\frac{\text{trip}}{\text{day}} * \frac{365\text{days}}{\text{year}} \quad 5.2$$

On the other hand figure 5.6 indicates that the number of vehicle passengers get served with the available operational bus capacity and quantity. The following figure used to compare the actual passengers get served and the expected number of passengers to get served.

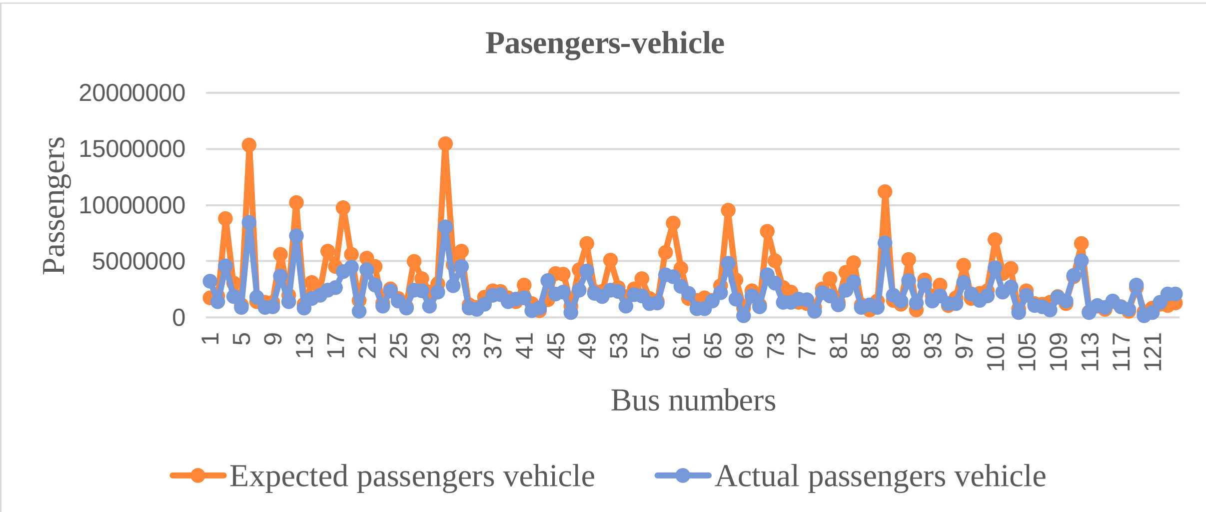


Figure 5.7 Expected and actual passengers-buses

Figure 5.7 indicates that most of the routes couldn't achieve the expected passengers-vehicle per year. The actual efficiency of the service performance was calculated using the expected passengers-vehicle and actual passengers-vehicles. The result shows that the average efficiency the ACBSE performance was about 69% relative to the expected passengers-vehicle. The average gaps between the actual performance and expected passengers vehicle was around 31%. This evaluation indicates that the ACBSE couldn't utilized the available bus capacity. That means the enterprise utilized most of the available capacity, relative to the passengers–vehicle, effectively.

The other performance measurement was the bus service frequency. The bus service frequency describes the number of the bus departed within the specified period. The frequency of the Anbessa bus was described on figure 5.5 as the bus service rate per day. It should be clear that the indicated bus service frequency, as service rate, was the same with the expected frequency. The expected service frequency was compared with the actual calculated bus service frequency to indicate the gap of service designed capacity and the achieved actual performance. This comparison was demonstrated figure 5.8 as the utilized, unutilized and expected bus service frequency.

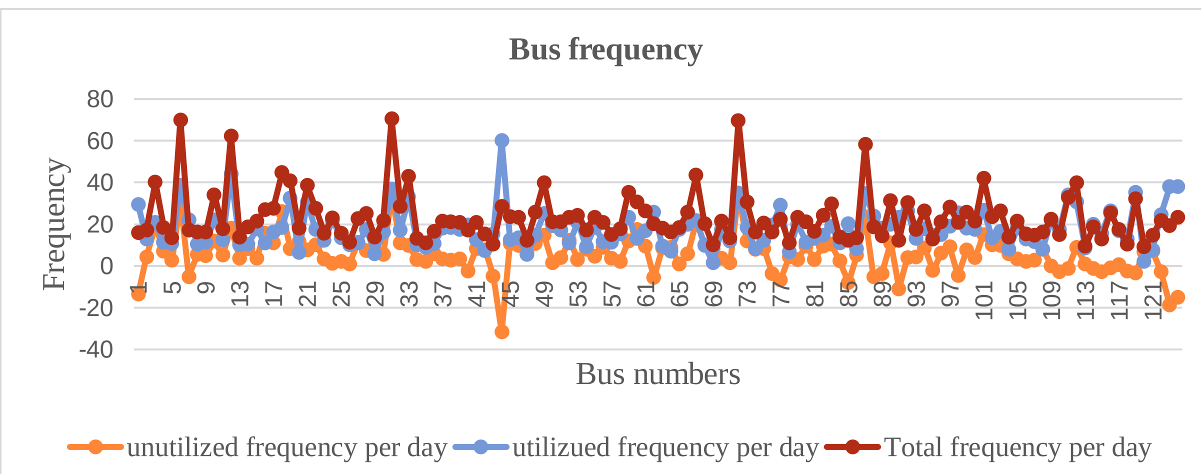


Figure 5.8 Bus frequency utilization

Figure 5.8 demonstrated that the average bus frequency was utilized 18/day and unutilized 5/day, and 76.61% and 23.39% respectively.

From the above two performance evaluation we can summarize that in terms of utilization. The passengers' vehicle utilization was 69% and the frequency utilization was 76.61%. This comparison shows that 7.61% of the service frequency was without transporting passengers. That means equivalent to the empty bus transportation.

5.6. Passengers Waiting Time for Anbessa Bus

In this section the waiting time of the passengers described in terms of utilized headway, calculated from utilized frequency, and calculated even headway from the bus travel cycle time. Waiting time is the time interval for which a passengers has to wait after reaching at the bus stop before the service actually occurs. In this context the two time interval was identified. The first time interval was the bus headway. This is the basic time interval that is used as the standard to compare the deviation of other time interval to see the passengers waiting time. The passengers waiting time of even headway was half of the even headway as used by the most scholars. The second time interval was the utilized headway interval which was calculated from utilized frequency. This interval is associated with the actual performance and it might be more, equal or less than the interval of even headway. When the utilized headway is equal to even headway the deviation of passengers waiting time is zero. That means the service was reliable, otherwise unreliable service. The next figure shows the deference between the utilize headway and even headways.

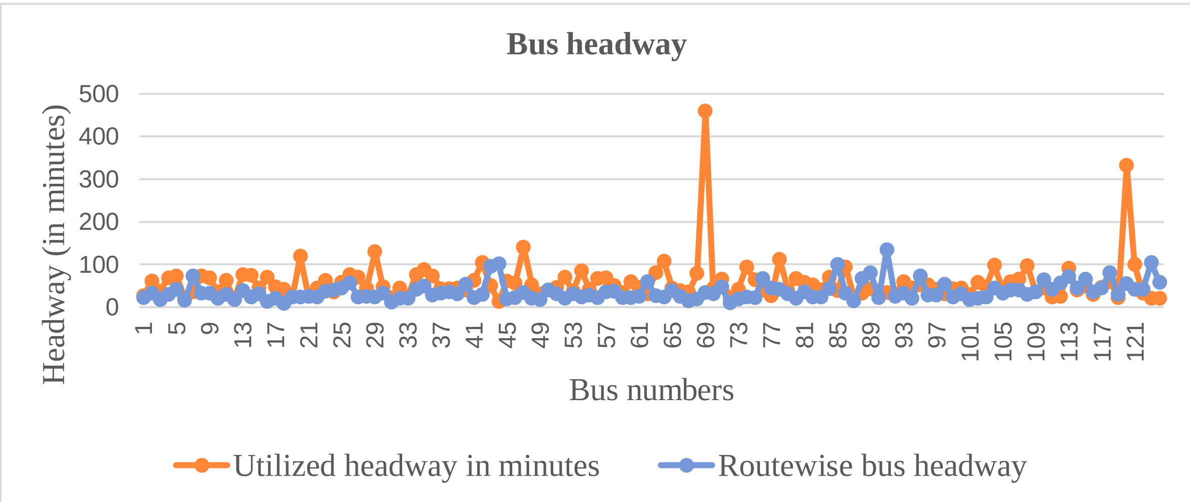


Figure 5.9 The comparison of utilized and unutilized headway

Figure 5.9 shows most of the utilized bus headway was above even headway. As the passengers waiting time is half of the even headway the passengers waiting time of the utilized bus headway is greater than the half of even headway. The average of even headway and utilized headway was 36 minutes and 58 minutes respectively. The average passengers waiting time of even headway is 18 minutes while utilized headway is 29 minutes. That means the average of passengers waiting time of utilized headway is about 1.61 times of the passengers waiting time of an even headway.

5.7. Case Study Data

In this section the number of passengers begin their journey from the terminal, passenger boarding and alighting at every bus stops, number of passengers arrived at the bus destination and passengers waiting time at the bus terminal was analyzed. This was done by attending the bus terminal during study time and just being the passenger of the assigned bus number to the routes.

At the bus terminal the bus service rate and the passengers waiting time was recorded based on the bus number. In this area there is no specified area to identify bus passenger from ordinary person; even passenger of one route from other route. Therefore, to count the number of passengers waiting for service and the number of passenger's arrival rate was counted from the bus boarded passengers at the beginning before the bus leaves the terminals.

The method of bus assignment was based on the route wise passenger demand. To see whether there was a passenger demand or not, or there were a passenger demand but there was no sufficient bus supply, or, there was sufficient bus supply but there were no passenger demand. Therefore, the volume of the passengers along the route was counted at each boarding and alighting stops.

The volume of passengers along the route can be categorized into two types based on the boarding and alighting. The boarding passenger is the passenger who boards the bus at the beginning and along the routes at each bus stop which is called "bus fermata". The alighting passenger is the passengers begin at the start as well as those passengers board at the bus "fermata", and alight at the bus "fermata" and the bus destination of the route.

These category of the passengers is useful to know the demands of passengers along the routes. The volume of demand of the passenger may be high, medium or low at the origin or along the routes up to the bus destination. This decision is helpful to assign the bus according to the passenger demand to improve the service quality they provide to satisfy the passenger demand.

The number of passengers demand at the beginning, along the routes at each fermatas and to each destination of each 13 selected routes are shown on the figure 5.10.

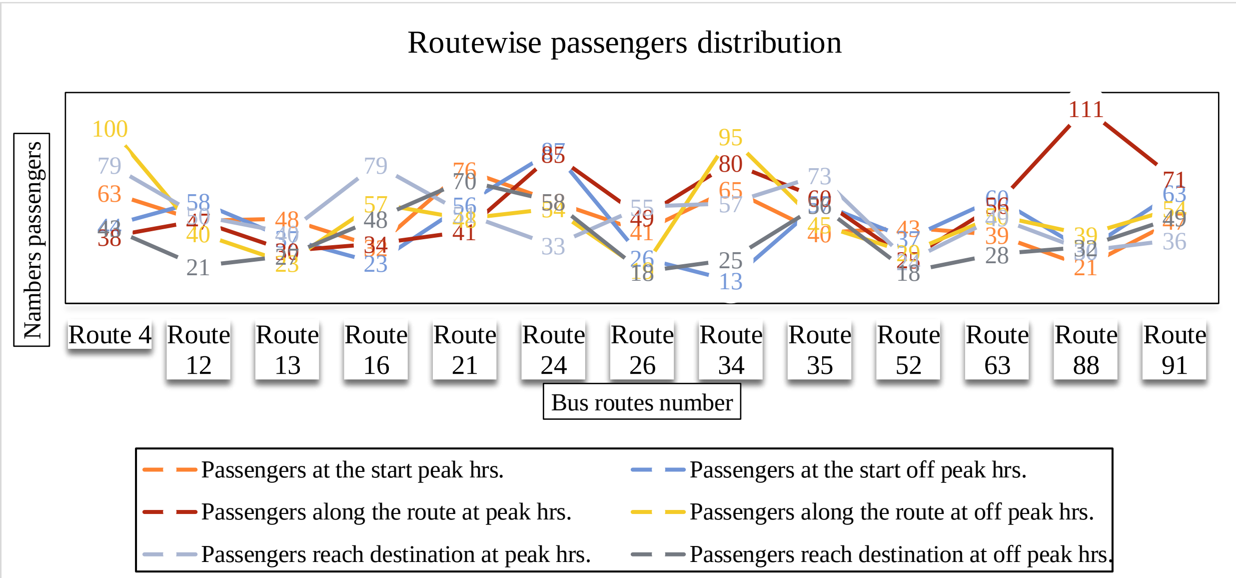


Figure 5.10 Route wise periodicals passenger demand distribution

Figure 5.10 shows that the demand distribution comparison at the bus stop, along each route and reach the bus destination during rush hours and un-rush hours. The comparisons of demand distribution of passengers hours at the bus terminal during the start peak hours and off peak hours shows that the demand route number 12, 24, 35, 63, 88 and 91 the peak hour demand is higher than the demand of off peak hour demand which is 46.15%. The demand of route number 14, 13, 16, 21, 26, 34 and 52 the off peak hour demand is higher than the demand of peak hour demand which is 53.85%.

The demand of the passengers' hour along the routes of the route number 12, 13, 24, 26, 35, 63, 88 and 91 the demand of peak hour is greater than the demand of off peak hour demand which is 61.54%. The demand of the route number 4, 16, 21, 34 and 52 the demand off peak hour demand is higher than the demand of peak hour demand which is 38.46%.

The demand of passengers reach their destination also indicated that the demand route of route number 4, 12, 13, 16, 26, 34, 35, 52, 88 and 91the demand of peak hour is higher than the demand of off peak hour which is 76.92%. The demand of the route number 21, 24 and 63 the demand of peak hour is higher than the demand of peak hour which is 23.08%.

5.7.1. Passenger Arrival Rates

The passenger arrival rate was collected to see the patterns of passenger arrivals and the demand situation along each routes. Due to the dynamic nature of passengers' arrivals the recorded data for a single hour or a single day was not enough to determine the nature of passenger arrivals and the demand situation. To avoid such problems the data was recorded for five days for every sample routes and the average passenger arrivals was used for analyses.

The passenger arrival rates recorded during the day of morning shift and afternoon shifts. During each shifts four hour period was selected to reduce unidirectional passenger flow. That means during this period the passengers can go to its destination as well as they can be returned back to their origin. It was assumed that the bus was busy or free to respond the passenger transport requirements. This time confine both peak and off peak hour periods. The first recording periods started at 7:00 a.m. and ended at 11:00 a.m. during morning time, and the second recording time was started at 2:00 p.m. and ended at 6:00 p.m. afternoon.

Table 5.1 Hourly passenger arrival rates along the routes

Route number	Morning shift				Afternoon shift			
	Peak		Off Peak		Peak		Off Peak	
4	50	44	40	44	48	53	58	51
8	3	3	3	3	3	3	3	3
12	71	80	91	42	81	83	87	77
13	18	24	23	25	21	20	18	19
16	132	126	126	116	108	109	112	109
21	43	73	95	72	51	38	91	65
24	38	49	61	48	36	78	61	50
26	19	39	59	41	26	38	53	36
34	38	58	78	63	47	66	85	62
35	21	20	25	29	25	25	26	22
52	26	35	42	40	51	65	54	36
63	49	56	70	49	42	50	69	54
88	31	26	33	30	26	32	34	28
91	15	13	11	11	11	12	12	12

To determine the hourly passenger arrival rate, the yearly passengers' arrival rate of 2017/2018 was converted into hourly passenger arrival rate. When the yearly passengers' arrival rate converted into hourly passenger arrival rate; the arrival rates was become constant. But in the real world the passenger arrival rates couldn't be constant. Even within the given minute there would be a passenger arrival variation. To see such variation the average passenger arrival rate for a set hour was calculated from the past average data and the recorded data during each hour of the observation.

In similar to table 5.1 to determine the hourly passenger arrival rate at the bus terminal, the yearly passengers' arrival rate of 2017/2018 was converted into hourly passenger arrival rate. When the yearly passengers' arrival rate converted into hourly passenger arrival rate; the arrival rates was become constant. But in the real world the passenger arrival rates couldn't be constant. Even within the given minute there would be a passenger arrival rate variation. To see such variation the average passenger arrival rate for a set hour was calculated from the past average data and the data recorded during each hour of the day of the observation.

Table 5.2 Hourly passenger arrival rate at bus terminals

Route number	Morning shift hourly passenger arrival rate at bus terminals				Afternoon shift hourly passenger arrival rate at bus terminals			
4	68	85	117	82	50	75	93	79
12	115	114	114	127	144	121	104	109
13	18	14	11	13	16	14	12	15
16	33	32	32	31	31	38	44	39
21	34	83	203	94	55	40	25	29
24	28	35	46	46	46	29	20	23
26	41	28	18	28	42	31	22	31
34	28	17	11	15	21	17	13	19
35	21	20	18	16	14	19	25	23
52	26	25	24	21	18	15	13	18
63	32	36	39	38	37	39	42	36
88	34	30	27	27	28	25	22	27
91	9	8	8	8	7	7	7	8

Table 5.2 shows the terminal hourly average passenger arrival rates.

5.7.2. Passengers Arrival Rate Distribution

A pattern of arrivals of passengers at a bus-stop depend upon the time schedule of buses and passengers' knowledge of this, and upon the experience of passengers how well bus keep to their time table. At Addis Ketema terminal, the time of arrivals of passengers, buses and departure of buses have been observed from 7:00 a.m. to 11:00 a.m. and 2:00pm to 6:00 p.m. at every hours without leaving the generality of demand behavior. It's found that passenger arriving at random as because there is not at all specific timetable and information on bus arrivals. The passengers' arrival rates are significantly varied between different times of day, specially, peak and off-peak periods in either direction of flow.

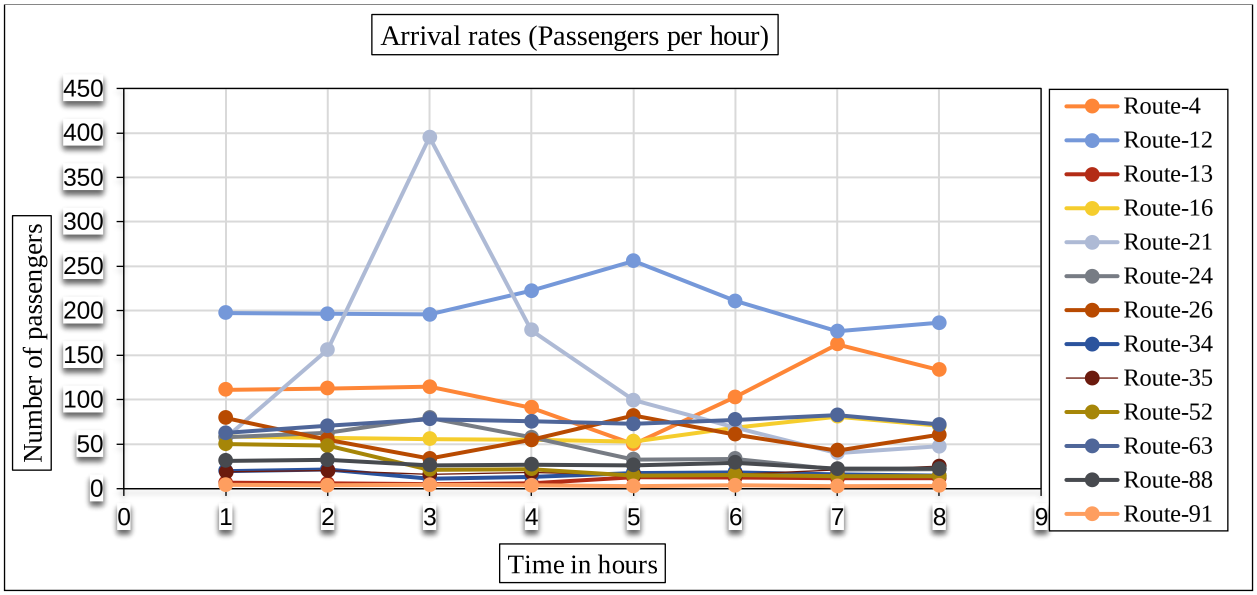


Figure 5.11 Route wise hourly demand flow at terminal

Figure 5.11 shows that the passengers arrival rates varies based on the route direction. There is high demand for some route while low demand for other routes at the same hours. For some routes the passengers demand is almost stable within a given hours, but the passengers demand is very turbulent to some routes at similar hours. To respond for the demand variation based on route direction and hourly variation, it is important to identifying the behavior of the demand distribution.

The number of passengers-vehicle per hour for route bus number 21 is the most fluctuated. This is due to the fluctuation of the bus service frequency (Figure 5.12). At the point, where the service frequency is higher, the number of passengers-vehicle is also higher and vice-versa. On the other hand the passengers-vehicle of route number 91 is stable and low passengers-vehicle. This low passengers-vehicle is resulted from the long bus inter-departure time which is above the hours of the study. That means low passengers-vehicle of route 91 is the result of long bus inter-departure time, (Appendix-II b).

5.7.3. ACBSE Bus Service Rate

One of the major foci in determining transit service is the selection of the most suitable frequency (vehicles/hour) for each route in the system, by time-of-day, day of-week, and day-type. The frequency of the bus is the number of bus departed from the bus station terminal to transport the passengers along the required demand routes. The frequency of the bus is vary based on number of bus assigned, travel distance or journey time, the speed of the bus, number of bus stops, route-wise demand, the drivers behavior and the terminal manager's decisions.

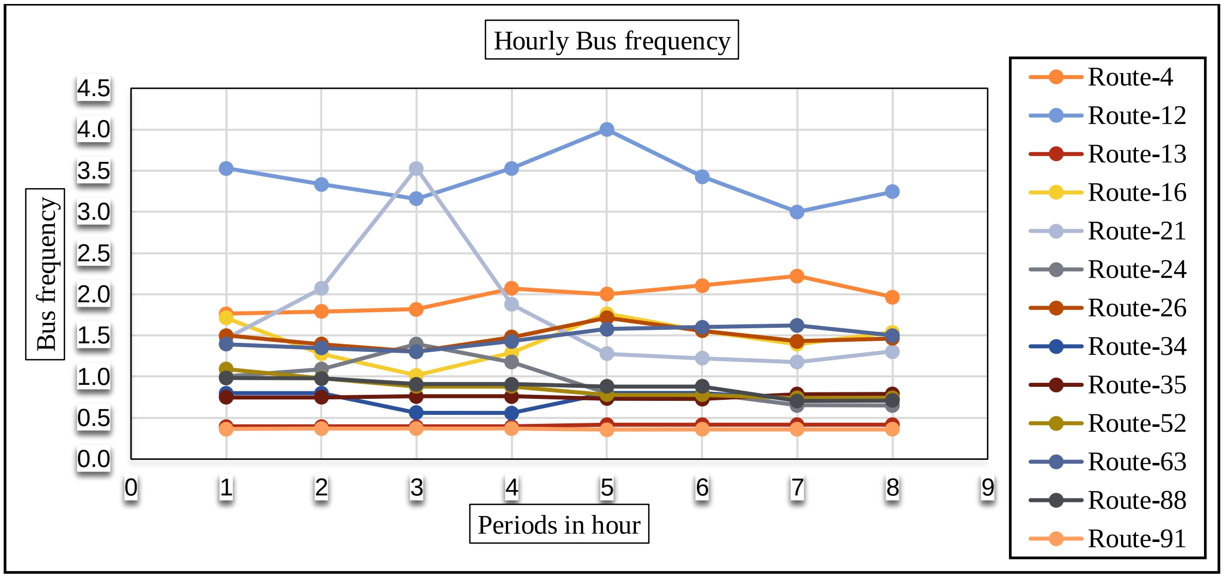


Figure 5.12 Route-wise bus frequency

Figure 5.12 describes that the calculated frequency of the bus from the recorded time of the bus inter-arrival or inter-departure time. The maximum and the minimum frequency of the sample routes is 4 buses per hour (for route number-12) and 0.4 bus (for route number-91) per hour respectively. The frequency of bus route number 12 shows variation in relation to time while the frequency of route number 91 almost stable. This variation and stability of service frequency points out that the frequency of the bus service has direct relationship with the route distance and the number of bus assigned.

5.7.4. Passengers Waiting Time

In regular or even-headway schedules, vehicles arrive and depart at constant intervals. An even-headway schedule can decrease total passenger waiting time when the demand pattern at stations follows some particular distribution, such as a uniform distribution. In contrast, under dynamic demand situations, an even-headway schedule may result in extended passenger waiting times during peak hours due to capacity constraints, or inefficient vehicle capacity utilization during off-peak periods. Not only dynamic demand situation and capacity constraint can extend the bus passengers waiting time, but inappropriate bus assignment also increases passenger waiting time by creating imbalance between the bus required and the demand available.

In order to determine the passengers waiting time of bus departure time is concerned rather than bus arrivals time. However, we recorded bus departure as well as arrivals times to determine the waiting time. The time between the bus arrival and bus departure time is described as bus inter-departure time. The bus inter-departure time was calculated from the bus headway and the waiting time set by ACBSE after the bus arrived at the bus terminals. The average value of the bus waiting time at the bus terminal was 10 minutes. In the headway determination of the bus head way was calculated as the ratio of the bus cycle time to the number of bus assigned along the routes. The cycle time is the time between the sum of the time of the origin to destination and the destination to the origin which consists of journey time plus allowed average bus waiting time at both bus terminal and bus destination route according to shown on Equation 5.3.

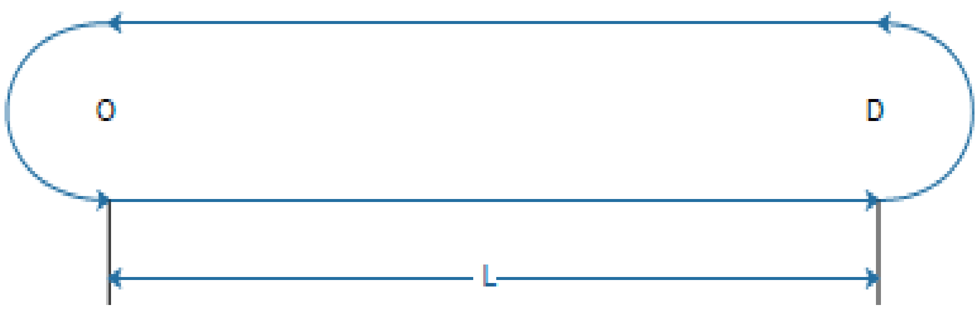


Figure 5.13 Cyclical bus service

Source: H:\Projects\Transit course\Fleet relationships.doc (2006)

Figure 5.13 shows that the diagrammatical representation of the transportation cycle. The bus starts its journey from the origin (O) or the destination (D) and ends at the destination (D) or origin (O). Then, it stops at origin (O) or destination (D) for 10 minutes and does the same thing repeatedly. This process makes the cyclical bus service.

Cycle time is the time for one vehicle to make a complete cycle of the route. It is twice the route length (L) divided by the average speed (S) plus layover times at each end of the route.

$$\text{Cycle time} = \frac{2L}{S} + TO + TD \qquad 5.3$$

$$\text{Number of Vehicles} = \frac{\text{Cycle Time}}{\text{Headway}} \qquad 5.4$$

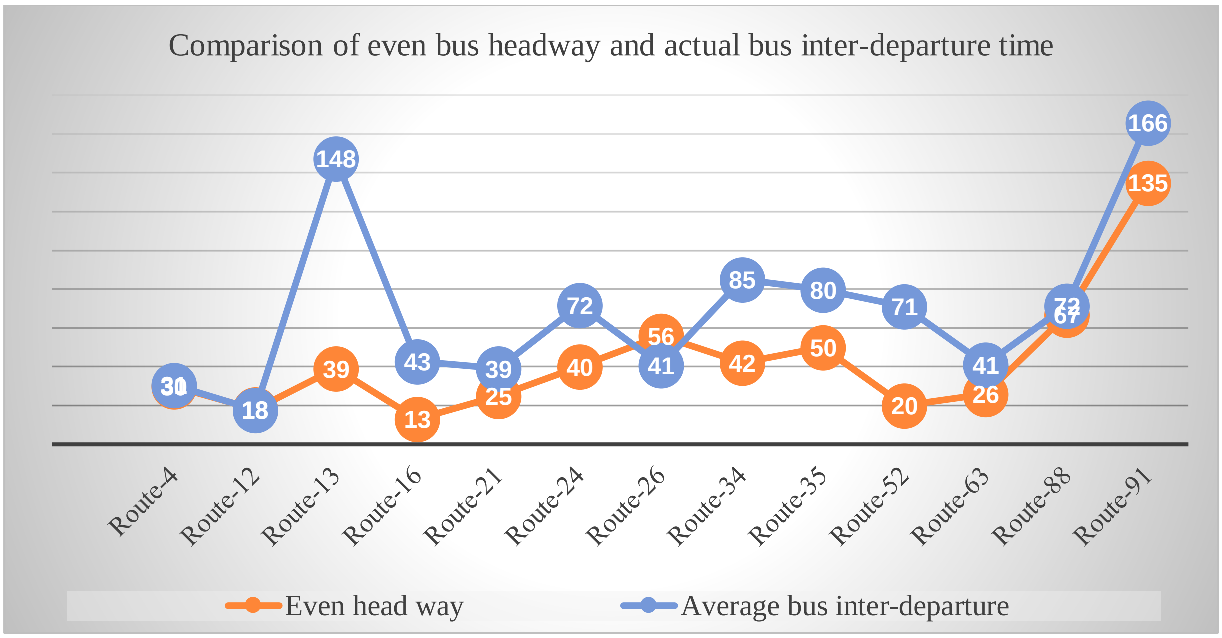


Figure 5.14 Average bus inter departure time and bus headway

Figure 5.14 shows that the ACBSE samples actual bus inter-departure time and regular, or even bus headway times. The average of the total bus headway of the case sample is about 37 minutes and the average of the total bus inter-departure of the case sample is about 65 minutes. The bus inter-departure time is about 1.76 times of regular bus headway times. This indicates that the passengers waiting time is about 1.76 times half of the bus regular headway times.

The bus inter-departure of the route number 4, 12 and 88 is almost equal to the bus regular headway. The bus inter-departure of route 26 is less than the regular bus headway. This means the frequency of the bus route number 26 is higher than the frequency of the regular bus headway. The bus inter-departure time of the bus route number 13 and 91 is higher than the rests of the sample routes. The reason of the higher of the bus route number of 13 is due to the low bus frequency while the higher inter-departure time for the route bus number of 91 is the higher bus even headway.

Summary of Data Analysis and Interpretation

In this section the passengers waiting time was analyzed using the interview data and operational data collected from the organization of ACBSE, and also the sample case study was analyzed and presented.

The interview result shows that the objective of the ACBSE was to provide the transport service to the poor with the low cost that matches with their level of dwellers' livelihood. To achieve their objective the ACBSE increase the number of bus from time to time and assign the bus based on the route characteristics, number of population, the carrying capacity of the bus, and trip generation. But the supply of the bus service is higher during the morning time and become lower and lower during afternoon due to bus failures. As a result the passengers waiting time increases from morning to evening.

The operational data shows that out of the total available buses the operational buses are 80.71% which is 79.66% DAF (rigid Bishoftu) bus and 20.34% articulated bus. The result shows that the average efficiency of the ACBSE performance was about 69% relative to the expected passengers-vehicle. The average gaps between the actual performance and expected passengers vehicle was around 31%. This evaluation indicates that the ACBSE couldn't utilized the available bus capacity. That means the enterprise utilized most of the available capacity, relative to the passengers–vehicle, effectively. The average bus frequency was utilized 18/day and unutilized 5/day, and 76.61% and 23.39% respectively. The passengers' vehicle utilization was 69% and the frequency utilization was 76.61%. This comparison shows that 7.61% of the service frequency was without transporting passengers. That means equivalent to the empty bus transportation. As the passengers waiting time is half of the even headway the passengers waiting time of the utilized bus headway is greater than the half of even headway. The average of even headway and utilized headway was 36 minutes and 58 minutes respectively. The average passengers waiting time of even headway is 18 minutes while utilized headway is 29 minutes. That means the average of passengers waiting time of utilized headway is about 1.61 times of the passengers waiting time of an even headway.

The results of the case study shows that the passengers demand can be higher at the bus terminal and/or along the routes during the peak or off peak hour period. There is high demand, almost stable or very turbulent based on route direction and hourly variation. To respond to the passengers demand determining the most suitable frequency (vehicles/hour) for each route in the system, by time-of-day, day of-week, and day-type, number of bus assigned, travel distance or journey time, the speed of the bus, number of bus stops, route-wise demand, the drivers behavior and the terminal manager's decisions should be taken into consideration.

Providing high frequency (low bus headway) can reduce passengers waiting time. An even-headway schedule can decrease total passenger waiting time when the demand pattern at stations follows some particular distribution, such as a uniform distribution. In dynamic passengers demand situations an even-headway schedule may result in extended passenger waiting times during peak hours due to capacity constraints or inefficient vehicle capacity utilization and inappropriate bus assignment during off-peak periods. The average of the total bus headway of the case sample is about 37 minutes and the average of the total bus inter-departure of the case sample is about 65 minutes. The bus inter-departure time is about 1.76 times of regular bus headway times. This indicates that the passengers waiting time is about 1.76 times half of the bus regular headway times.

In general, in the overall bus capacity utilization, the passengers waiting time is about 1.61 times of the half of even headway. In the case study sample, the passengers waiting time is about 1.76 times of half of the bus regular headway times. The comparison shows that the overall bus capacity utilization passengers waiting time is almost equal to the case study sample's passengers waiting time.

CHAPTER SIX

DESIGN OF OPTIMUM PASSENGERS WAITING TIME

6.1. Introduction

In this section the optimal passenger waiting time would be designed. To design the passengers waiting time, based on the literature and different assumption, the supply bus service rate and the passenger's demand arrival rates were used. Therefore this section provides a mathematical formulation for optimization of average passengers' waiting time problem with the aim of studying the properties of the models. The mathematical models focus on the scientific determinations that are directed toward the minimization of average passengers' waiting time in Anbessa city bus transport services. The analysis of waiting time can be classified into prediction and optimization models. The average waiting time (AWT) of passengers is a well-known measure of quality for a public transportation service.

Passenger waiting times depend on the number of bus, fleet capacity, operational characteristics of the route, and the bus headways. A typical perception is that the greater the number of buses and their capacity, the shorter the passenger waiting time will be. On the other hand, a cost-effective approach to better utilization of the fleet is the adjustment of headways according to request patterns. For this reason, timetabling models with the objective of minimizing the waiting time of passengers in positions are presented in this model. In all the models, the aggregate waiting time of passengers at stations in the bus is proposed as a measure to evaluate the quality of service.

Modelling the waiting time of passengers for public transport is not easy. In everyday speech, the waiting time is referred to time spent at a bus stop waiting. However, this time is not sufficient to include all inconveniences passengers experiences when traveling with public transport, because they are not able to travel whenever they want. In order to cover those inconveniences in the models, the waiting time is defined as half the time between departures.

6.2. Model Assumption

1. The routs where the distribution of high performance and low performance was identified. This identification was used to assign the bus proportional to the passenger demand to avoid passenger waiting time and over uses of the facilities.
2. The disproportional assignment of the bus based on the demand performance shows that the ACBSE has a drawback on assigning the buses to each routes.
3. The passenger arrival rate was considered based on actual passengers' arrival rate. This passengers arrival rates was recorded during data collection and observation process by being at the bus terminal. This is done without affecting the generality of daily demand profiles (peak and off peak demand hours).
4. Un-capacitated and capacitated bus timetabling model under dynamic demand was considered. In un-capacitated bus it enables us to identify if the available capacity can satisfy the demand. In capacitated bus it helps us to know the shortage of the buses to satisfy the required passenger demand along each routes.
5. Improved non-linear formulation with heuristic cuts. This help us to utilize a piecewise linear approximate of the demand function.
6. The speed of the buses traveling in each route may be vary. But in this analysis we assume that the speed of the bus was along the same origin and destination is the same.
7. The assigned bus service is not in a single direction. It is bi-directional. That means when one bus goes to its destination the other bus comes to the terminals. Therefore the bus assigned were equally distributed between the bus terminal to destination, and from the destination to the terminals.
8. The bus provide a service for a single route by considering the cyclical service. But not take into consideration the overlapping routes with other buses. That means the waiting time analyzed for the assigned bus was considered as independent in relation to the other buses which shared common routes.

Parameters	Indices	Decision Variable
λ-arrival rate b-buses BS-bus service T-planning horizon D-total bus service available $\mathbf{H_b}$-the heading between b and (b+1) $\mathbf{H_O}$-the dispatch time of the first time $\mathbf{H_D}$-the last departure j-passengers at station C- bus capacity $\mathbf{b_b}$-on board passengers $\mathbf{w_b}$-number of waiting passengers $\mathbf{h_{min}}$-minimum safety headway time $\boldsymbol{\delta_b}$-number of passengers arriving during the headway $\boldsymbol{\tau}$-time horizon **t**−Divided time periods $\boldsymbol{\lambda^t}$-demand pattern $\boldsymbol{\theta}$-the length of each demand period $\mathbf{d_b}$-departure time $\Delta_\mathbf{b}$ -input flow of passengers between t=0 and the departure time of b[th] bus $\boldsymbol{\delta_o}$-First bus service $\boldsymbol{\delta_D}$-the last bus service $\mathbf{P_t}$-normalizing arrival rates of passengers $\mathbf{y_b^t}$-the assignment of the bus service to the demand period $\boldsymbol{\alpha}$-the division of the length of planning horizon inti equal sized small interval (discretization parameter) $\boldsymbol{\lambda^p}$-passenger arrival rate at period p $\mathbf{x_b^t}$- Number of bus service depart at the beginning of the interval t	b-index of bus t-index of time p-index of period o-index of origin u-index of upper limit l-index of lower limit D-index of departure	x_b^t- Number of bus service depart at the beginning of the interval [t, t + 1] b_t- Number of boarding passengers on the bus that depart at the beginning of the interval [t, t + 1] w_t- Number of passengers waiting for buses at the beginning of the interval [t, t + 1] d_t- Number of passengers arriving at station during the interval [t, t + 1]

6.3. Model Formulation

In this section to solve problems and provide useful insights, a detailed analysis of each mathematical model is provided based on the assumptions and literature reviewed. In the two next sections, two mathematical formulations of the demand-oriented bus timetabling problem are presented. The optimization model determines the departure time of bus services according to the demand profiles. The first set of mathematical optimization models is formulated as MINLPs. The MINLPs are classified according to the demand characteristics dynamic and bus capacity constraint (un-capacitated and capacitated). The second mathematical formulation presented is, MILPs, a time-indexed mixed-integer linear formulation. The mathematical formulation and the structure of the proposed model to minimize the passenger waiting time is illustrated in the following diagram as optimization inputs, optimization model and optimization output:

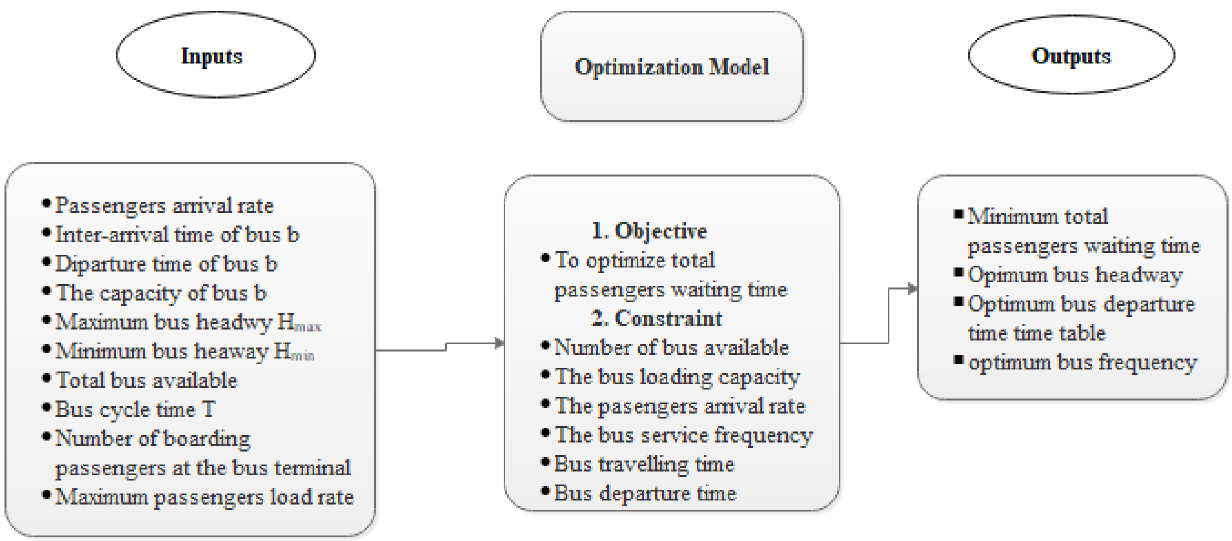


Figure 6.1 The structure of proposed optimization model

6.3.1. Mixed-Integer Non-Linear Formulations of Static Demand

In this section a mathematical formulation for the bus timing problem with the objective of studying the properties of the models was provided. This mathematical models are studied the particular characteristics of the mathematical optimization model according to the assumptions made.

To solve problems and provide useful understandings, a comprehensive analysis of each mathematical model is provided. In the next sections, a mathematical formulations of the demand-oriented bus timing problem are presented. The optimization model determines the departure time of bus services according to the demand profiles. The mathematical formulation presented is a time-indexed mixed-integer linear formulation.

In under static demand model, the basic model assumes a single-station, single-period demand, un-capacitated bus timetabling problem where the inter-arrival time of passengers is constant. Since the passengers demand is static it is represented by an arrival rate (λ). The buses have an infinite capacity to carry passengers. Consider a set of bus services (b ϵ BS) that are required to be scheduled during the planning horizon [0, T]. The total number of available bus services is denoted by D. Let H_b be the headway between b^{th} and $(b+1)^{th}$ bus departures. Thus, H_0 and H_D represent the dispatch time of the first bus and the distance between the end of the period T and the last departure, respectively.

Assume that passengers arrive at a station with fixed and uniform intervals. Therefore, the inter-arrival time of passengers is equal to $(\frac{1}{\lambda})$ and the total number of arriving passengers equals Tλ. The waiting time of the j^{th} passenger at the station is equal to $T-(\frac{1}{\lambda}).j$. With the above notation, the total waiting time w of passengers between t = 0 to t = T is given by the following equations:

$$w = \sum_{j=1}^{\lambda T}\left(T-\left(\frac{1}{\lambda}\right).j\right) = \lambda T^2 - \left(\frac{1}{\lambda}\right).\frac{\lambda T.(\lambda T+1)}{2} = \frac{1}{2}\lambda T^2 - \frac{T}{2} \qquad 6.4$$

$$w = \sum_{j=1}^{\lambda T}\left(T-\left(\frac{1}{\lambda}\right).(j-1)\right) = \frac{1}{2}\lambda T^2 + \frac{T}{2} \qquad 6.5$$

From the above equations 6.4 can be deployed when the first passenger arrives at a moment t = 0 and equation 6.5 can be deployed when the first passenger arrives at a moment $t = (\frac{1}{\lambda})$, respectively, and consequently the term $(\frac{T}{2})$ can be neglected. As a result, total waiting time is equal to $w = \frac{1}{2}\lambda T^2$. With the above description of the total waiting time function, the resulting bus timetabling model is a nonlinear programming (NLP) problem with the following equations:

$$[\text{NLP 1}]: \text{ minimize } z = \frac{1}{2}\lambda \sum_{b \in BS} H_b^2 \qquad 6.6$$

Subject to;

$$\sum_{b \in BS} H_b = T \qquad 6.7$$

$$H_{b \in R^+} \qquad 6.8$$

The measure of the quality of service is defined as the cumulative waiting time of passengers that is the total time that passengers have to wait at the station. The waiting time of passengers for buses is expressed as a product of half the bus headway and the number of passengers coming during the headway. As can be seen, the objective is a quadratic function of the headway. The decision variables are departure times of the bus services. It is highly desirable to design timetables such that departures are as regular as possible. In this regard the total waiting time of passengers is minimized when an even-headway policy is used. The [NLP 1] program has an optimal solution H_b^* with even headway timetable and its optimal objective value is z^*. The even headway time results in minimum waiting time of passengers. Since the summation of headway variables, as equation 6.10, is constant, the objective function is minimized when all the variables are equal $H_b = H_{b+1}$.

The extended model presented in this section assumes a capacitated single-period demand bus timetabling problem. If the capacity of the departing bus is not large enough, some passengers have to stay at the station and wait for the next bus service. Suppose the passenger arrival is stationary with rate λ but capacity constraints are counted in the model.

The bus capacity constraint is modeled as a hard constraint. In order to extend the previous formulation [NLP 1], we need to define the flow-oriented variables. Let b_b and w_b denote the number of on-board passengers of the b^{th} bus and the number of waiting passengers after the departure of b^{th} bus, respectively. Equation 6.11 indicates the technological constraint and signaling system force bus to operate with minimum safety headway time h_{min}. To control the maximum waiting time of passengers, the maximum headway time between bus services is integrated in the formulation. The demand flow conservation constraint is presented in Equation

6.12. The number of arrived passengers during the headway is calculated by Equation 6.13. Equation 6.14 states the bus capacity constraint. Finally, the capacitated bus timetabling problem [NLP 2] is presented in the following NLP program:

$$[\text{NLP 2}]: \text{minimize } z = \sum_{b\epsilon BS} (w_b + \frac{1}{2}\delta_b)H_b \quad 6.9$$

Subject to:

$$\sum_{b\epsilon BS} H_b = T \quad 6.10$$

$$h_{min} \leq H_b \leq h_{max}, b\epsilon TS \quad 6.11$$

$$w_b = w_{b-1} + \delta_{b-1} - b_b, b\epsilon TS \quad 6.12$$

$$\delta_b = H_b\lambda, b\epsilon TS \quad 5.13$$

$$b_b = C, b \in TS \quad 6.14$$

$$w_0 = b_0 = 0 \quad 6.15$$

$$w_b, \delta_b, b_b, H_b \in R^+ \quad 6.16$$

The most important aspect of the [NLP 2] program is that its optimal solution is dependent on the utilization rate which is defined as the bus capacity-to-arrival ratio $(\frac{C}{\lambda})$. The optimal solution of the [NLP 2] program is a regular-headway timetable H^* obtained from the un-capacitated model [NLP 1] if and only if $\lambda. H^* \leq C$. In this case $\lambda H^* \leq C$ the capacity of the buses is large enough to accommodate all travel demand through the even-headway timetable and there are no waiting passengers $w_b = 0$. As a result, by replacing $\delta_b = H_b\lambda$ in Equation 6.13, the objective function of the [NLP 2] program is equivalent to the objective function of [NLP 1]. Therefore, the optimal solution of the [NLP 2] program is obtained by a regular-headway timetable.

The optimal solution of the [NLP 2] program is a semi-regular headway schedule (H'^*) with the following equations if and only if $\lambda H^* > C$ where, H^* is the ratio of cycle time to the total number of buss assigned to each route:

$$H'^*_b = \min\left\{h_{max}, \max\left\{h_{min}, \frac{C}{\lambda}\right\}\right\} \quad b = 0, 1, 2, 4 \ldots D - 1 \quad 6.17$$

$$H'^{*} = T - \sum_{b \in BS \setminus D} H_b^{*} \tag{6.18}$$

For the case when $\lambda H^{*} > C$ the regular headway is still a near-optimal solution for the [NLP 2] program. If the headway time between two successive departures is $(\frac{C}{\lambda})$ then the buses dispatch at full capacity. No improvement in the objective function value can be made by decreasing the headway. On the other hand, an increase in the headway results in passengers who have been left behind. Therefore, the optimal headways are determined according to the minimum and maximum allowed headways regarding the ratio $(\frac{C}{\lambda})$.

6.3.2. Mixed-Integer Non-Linear Formulations of Dynamic Demand

In a real-world situation arrival rate fluctuations need to be considered. In this study, a piecewise linear approximation of the demand function is utilized. In other words, in the following extended models, it would be assumed that travel demand is period-dependent. The study time horizon is divided into a number of time periods ($t \in T$) that correspond to different demand patterns (λ^t). The length of each demand period is θ and consequently the start time of the t^{th} period is $\theta.(t-1)$. The arrival process of passengers is assumed to be homogeneous uniform for each period. As demand is dynamic, the even-headway policy may be sub-optimal in this case. The decision variables are departure time of bus services at each period with the aim of minimizing total waiting time of passengers.

Since bus capacity is not limited, all passengers can board the first arriving bus ($w_b = 0$). The binary variables (y_b^t) are included in the formulation to represent the assignment of the bus services to the demand periods. The variable (y_b^t) takes a value of one if b^{th} bus runs at period t, and takes a value of zero otherwise. This variable is linked with the departure time variables (d_b) through constraint (6.22). The introduction of the binary variables into the modeling make the problem a MINLP and consequently finding the optimal solution to this class of problems is strongly NP-complete. The total number of passengers arriving between two consecutive bus b and b + 1 (δ) is dependent not only on the headway time but also the departure times of bus services. The relationship between departure times and binary variable is presented in Equation (6.22). Equation (6.23) ensures that each bus service must be scheduled in a specific time period. The input flow of passengers between t = 0 and the departure time of the b^{th} bus is denoted by

Δ_b. With this notation, Equation (6.24) calculates the passenger flows between two consecutive departures.

Assume that the b^{th} bus departs at period t. In order to calculate Δ_b we should count the number of arrival passengers at periods t' = 1, 2. . .t − 1. As a result, Δ_b is equal to $\sum_{t' \in \tau}\left(1 - \sum_{p=1}^{t'} y_b^p\right). \theta. \lambda^{t'}$. The second part of Δ_b includes the number of passengers arriving at the beginning of the period t calculated through $d_b - \theta.(t-1)).\lambda^t$.

The formulae for the number of passengers arriving before the first bus service (δ_o) and after the last bus service (δ_D) are presented in Equations (6.27)–(6.30). As stated previously, we assume that the inter-arrival time of passengers is constant at each period, and the bus have infinite capacity. Consequently the total waiting time of passengers is presented in equation (6.19) is presented as follows;

$$[\text{MINLP 1}]: \text{minimize } z = \sum_{b \in BS} \frac{1}{2} \delta_b H_b \qquad 6.19$$

Subject to:

$$\sum_{r \in TS} H_b = T \qquad 6.20$$

$$h_{min} \le H_b \le h_{max}, b \in BS \backslash \{D\} \qquad 6.21$$

$$\theta.(t-1) - M.(1 - y_b^t) \le d_b < \theta.t + M.(1 - y_b^t) \quad b \in BS \;\; t \in \tau \qquad 6.22$$

$$\sum_{t \in \tau} y_b^t = 1 \quad b \in BS \qquad 6.23$$

$$\delta_b = \Delta_{b+1} + \Delta_b \quad b \in BS \backslash \{0, D\} \qquad 6.24$$

$$\Delta_b \le \sum_{t' \in \tau}\left(1 - \sum_{p=1}^{t'} y_b^p\right).\theta.\lambda^{t'} + \left(d_b - \theta.(t-1)\right).\lambda^t + M.(1 - y_b^t) \;\; b \in BS \backslash \{0\}, t \in \tau \qquad 6.25$$

$$\Delta_b \ge \sum_{t' \in \tau}\left(1 - \sum_{p=1}^{t'} y_b^p\right).\theta.\lambda^{t'} + \left(d_b - \theta.(t-1)\right).\lambda^t + M.(1 - y_b^t) \;\; b \in TS \backslash \{0\}, t \in \tau \qquad 6.26$$

$$\delta_0 \leq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_1^p\right). \theta. \lambda^{t'} + \left(d_1 - \theta. (t-1)\right). \lambda^t + M. (1 - y_1^t) \quad t \in \tau \tag{6.27}$$

$$\delta_0 \geq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_1^p\right). \theta. \lambda^{t'} + \left(d_1 - \theta. (t-1)\right). \lambda^t + M. (1 - y_1^t) \quad t \in \tau \tag{6.28}$$

$$\delta_D \leq \sum_{t' \in \tau} \left(1 - \sum_{p=t'}^{NT} y_D^p\right). \theta. \lambda^{t'} + (\theta. t - d_D). \lambda^t + M. (1 - y_D^t) \quad t \in \tau \tag{6.29}$$

$$\delta_D \geq \sum_{t' \in \tau} \left(1 - \sum_{p=t'}^{NT} y_D^p\right). \theta. \lambda^{t'} + (\theta. t - d_D). \lambda^t + M. (1 - y_D^t) \quad t \in \tau \tag{6.30}$$

$$d_b, \delta_b, \Delta_b, H_b \in R^+ \qquad y_b^t \in \{0,1\} \tag{6.31}$$

In this section assume a capacitated single-period demand bus timetabling problem. If the capacity of the departing bus is not large enough, some passengers have to stay at the station and wait for the next bus service. The most general mathematical programming model presented in this study assumes that each service accommodates a maximum number of passengers according to the bus capacity constraint under a period-dependent arrival rate of passengers. This problem can be expressed as a MINLP with the following equations:

$$[\text{MINLP 2}]: \text{minimize } z = \sum_{b \in BS} \left(w_b + \frac{1}{2}\delta_b\right). H_b \tag{6.32}$$

Subject to:

$$w_b = w_{b-1} + \delta_{b-1} - b_b \quad b \in BS \tag{6.33}$$

$$b_b \leq C \quad b \in BS \tag{6.34}$$

$$w_0 = b_0 = 0 \tag{6.35}$$

$$\theta. (t-1) - M. (1 - y_b^t) \leq d_b < \theta. t + M. (1 - y_b^t) \quad b \in BS \;\; t \in \tau \tag{6.36}$$

$$\sum_{t \in \tau} y_b^t = 1 \quad b \in BS \tag{6.37}$$

$$\delta_b = \Delta_{b+1} + \Delta_b \quad b \in BS\backslash\{0, D\} \qquad 6.38$$

$$\Delta_b \leq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_b^p\right) . \theta . \lambda^{t'} + \left(d_b - \theta . (t-1)\right) . \lambda^t + M . (1 - y_b^t) \quad b \in BS\backslash\{0\}, t \in \tau \qquad 6.39$$

$$\Delta_b \geq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_r^p\right) . \theta . \lambda^{t'} + \left(d_b - \theta . (t-1)\right) . \lambda^t + M . (1 - y_b^t) \quad b \in BS\backslash\{0\}, t \qquad 6.40$$

$$\delta_0 \leq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_1^p\right) . \theta . \lambda^{t'} + \left(d_1 - \theta . (t-1)\right) . \lambda^t + M . (1 - y_1^t) \quad t \in \tau \qquad 6.41$$

$$\delta_0 \geq \sum_{t' \in \tau} \left(1 - \sum_{p=1}^{t'} y_1^p\right) . \theta . \lambda^{t'} + \left(d_1 - \theta . (t-1)\right) . \lambda^t + M . (1 - y_1^t) \quad t \in \tau \qquad 6.42$$

$$\delta_D \leq \sum_{t' \in \tau} \left(1 - \sum_{p=t'}^{NT} y_D^p\right) . \theta . \lambda^{t'} + (\theta . t - d_D) . \lambda^t + M . (1 - y_D^t) \quad t \in \tau \qquad 6.43$$

$$\delta_D \geq \sum_{t' \in \tau} \left(1 - \sum_{p=t'}^{NT} y_D^p\right) . \theta . \lambda^{t'} + (\theta . t - d_D) . \lambda^t + M . (1 - y_D^t) \quad t \in \tau \qquad 6.44$$

$$d_b, \delta_b, \Delta_b, b_b, w_b, H_b \in R^+ \qquad y_b^t \in \{0,1\} \qquad 6.45$$

6.3.3. Mixed-Integer Linear Formulation

The model above has a non-linear objective function and linear constraints. As noted from equation 6.2, 6.3 and 6.4, minimizing passenger waiting time is a non-linear nonconvex objective function and it is to all purposes mathematically intractable. One main difficulty is due to the non-linearity nature of the objective function. On the other hand, the complexity of the approximate non-linear models remains and it is difficult to solve them efficiently by commercially available solvers.

In what follows, a linear time-index formulation of the bus timetabling problem is proposed which offers a new definition of decision variables with the aim of minimizing the waiting time of passengers. In the proposed MILP model, the index t $(t \in \tau)$ is used to display the time intervals that buses are authorized to dispatch. Thus the length of the planning horizon is divided into equal-sized small time intervals of length α (e.g. minutes or seconds) and bus dispatch only at discrete time points. Particularly, the discretization parameter (α) is introduced to determine the range so that the MILP model is computationally tractable. With the above notation of the decision variables, the passenger flow variables are defined at each time interval (appendix-II b). A common and important characteristic of the travel demand profile is the existence of some peak points (local maximum) over time. Demand peaks are related to rush hours and normally condensed to two points per day. In our approach to passenger demand, the piece-wise linear approximation of the demand function is considered which enables capturing the demand profile with different shapes and patterns. The arrival rate of passengers at period $p \in P$ is denoted by λ^p. The p^{th} period of demand is denoted by $[t_p, t_{p+1}]$.

Table 6.1 Decision variables of the MILP model.

Symbol	Description
x_b^t	The number of bus service depart at the beginning of the interval [t, t + 1]
b_t	The number of boarding passengers on the bus that depart at the beginning of the interval [t, t + 1]
w_t	The number of passengers waiting for buses at the beginning of the interval [t, t + 1]
δ_t	The number of passengers arriving at station during the interval [t, t + 1]

The proposed general form of demand approximation is helpful in reducing the number of binary decision variables in the MINLP model. Without losing the generality of the modeling approach, it can be assumed that the set of arrival rate periods is a subset of the time interval allowed for dispatching buses$(p \subseteq \tau)$. For modeling the problem, the binary decision variables x_r^t is defined where the value of 1 means the dispatch of b^{th} bus at the beginning of the interval [t, t + 1].

Note that the variables related to the flow of passengers (number of passengers waiting at the station, number of boarding passenger and the number of passengers entering the station) are calculated at any time t and therefore the objective function can be expressed as a linear function. Constraints (6.50) and (6.51) describe the assignment of bus services to time intervals. Equation (6.52) calculates the number of passengers arriving at the station during interval [t, t + 1] according to the arrival rate. Equation (6.53) establishes the relationship between the passenger flow variables. Equation (6.54) also states that if a bus is dispatched at time t, then the number of passengers boarding the bus is up to the capacity of that bus.

$$\text{[MILP]: minimize } z = \sum_{t\in\tau} \alpha\left(w_t + \frac{1}{2}\delta_t\right) \quad 6.46$$

Subject to:

$$\sum_{b\in BS} H_b = T \quad 6.47$$

$$h_{min} \leq H_b \leq h_{max}, b \in BS\setminus\{D\} \quad 6.48$$

$$d_b = \sum_{t\in\tau} \alpha(t-1)\,.\,x_b^t, b \in BS \quad 6.49$$

$$\sum_{t\in\tau} x_b^t \leq 1\,, \quad b \in BS \quad 6.50$$

$$\sum_{b\in BS} x_b^t \leq 1\,, \quad t \in \tau \quad 6.51$$

$$\delta_t = \alpha\lambda^p, \frac{t_p + \alpha}{\alpha} \leq t < \frac{t_{p+1} + \alpha}{\alpha}, \quad t \in \tau, p \in P \quad 6.52$$

$$w_t = w_{t-1} + \delta_{t-1} - b_t\,, \quad t \in \tau \quad 6.53$$

$$b_t \leq \sum_{b\in TS} x_b^t\,.\,C, \quad t \in \tau \quad 6.54$$

$$d_b, H_b, \delta_t, b_t, w_t, \in R^+\,, \quad x_b^t \in \{0,1\} \quad 6.55$$

6.4. Running the Model

In this chapter the three types of models was developed. The first model developed was non-linear programming formulation for both capacitated and un-capacitated bus time table to optimize passenger waiting time. The second model developed In order to maintain solution feasibility, the initial lower and upper limits of service frequencies are incorporated in the formulations. Then the heuristic cuts are generated. The third model was about linearization of non-linear programming model to liner programming model to reduce the complexity of the non- linear programming to enable us solve efficiently with commercial software solvers. Therefore the model developed was run using lingo 17.0 version to solve the model. The result of the solved model was illustrated according to appendix-III.

6.5. Solve the Waiting Time Model

The linear programming (LP) model developed was solved. The model was develop by considering hourly passengers arrival rates without affecting the daily demand profiles (maximum and minimum passengers demand) and the bus service frequency at bus terminals.

6.6. Model Input and Their Values

The inputs for the LP model are standard passenger carrying capacity of buses, operational number of buses available for schedule, passenger demand in one hour, passenger's arrival rates and bus head ways. The standard capacity of buses are 60 and 100 for bus rigid (Bishoftu bus and DAF) and articulated bus respectively based on the international allowable capacity of buses with their dimension.

6.6.1. Bus Frequency and Bus Headway

Policy headway serves as a lower bound for scheduling service frequency and is usually used by transit operators in low-demand routes to ensure that passengers would be able to receive desired level of service.

Headway is the amount of time between two vehicles passing through a given point in transportation systems**.** It is a measurement of the distance or time between vehicles in a transit system. The minimum headway is the shortest such distance or time achievable by a system without a reduction in the speed of vehicles. In Addis Ababa city Anbessa bus transport there is no specific route wise set maximum and minimum bus headway allowed. But there is generic fixed time to depart the bus after arriving the bus terminal. Therefore the maximum and minimum of bus headway was determined route wisely based on the passenger demand between the times of departure time.

In this case before calculating the bus headway, as the headway is the inverse of frequency, the bus frequency was calculate based on the passengers demand within the time of between bus arrival to bus departure. By having this in mind;

$$\text{Bus frequency} = \frac{\text{The average maximum number of passengers (max load)}}{\text{The bus seat capacity}} \qquad 6.56$$

Table 6.2 Calculated bus frequency using max load method

Route number	Origin	Destination	Articulated bus		DAF or rigid bus	
			Minimum frequency	Maximum frequency	Minimum frequency	Maximum frequency
4	Kaliti	Addis Ketema	1	1	1	2
12	Gurara Ferensay Kela	Addis Ketema	1	1	2	2
13	Italy Embassy	Addis Ketema	1	1	2	2
16	Kidanimihret	Addis Ketema	1	1	1	2
21	Felidoro	Addis Ketema	1	2	1	4
24	Dire Sololiya	Addis Ketema	1	2	2	3
26	Addis Ketema	Sebeta	1	1	1	2
34	German Squar	Addis Ketema	1	1	1	2
35	Lebu Muziqa Sefer-	Addis Ketema	1	1	1	2
52	Gerji	Addis Ketema	1	1	1	2
63	Addis Ketema	Mikililand	1	1	2	2
88	Addis Ketema	Chancho	1	1	2	2
91	Addis Ketema	Teji	1	1	1	2

$$\text{Bus Headway} = \frac{1}{\text{bus frquency}} \qquad 6.57$$

Headway variation also deteriorates the quality of the customer experience by increasing the average waiting time for buses. If headways are constant the average waiting time is h/2 where h is the headway.

Table 6.3 Minimum and maximum bus headway (in minutes)

Route number	Origin	Destination	Articulated bus		DAF or rigid bus	
			Minimum headway	Maximum headway	Minimum headway	Maximum headway
4	Kaliti	Addis Ketema	41	120	25	72
12	Gurara Ferensay Kela	Addis Ketema	47	54	28	32
13	Italy Embassy	Addis Ketema	46	54	28	32
16	Kidanimihret	Addis Ketema	52	100	31	60
21	Felidoro	Addis Ketema	27	88	16	53
24	Dire Sololiya	Addis Ketema	34	53	21	32
26	Addis Ketema	Sebeta	57	115	34	69
34	German Squar	Addis Ketema	56	79	33	47
35	Lebu Muziqa Sefer-	Addis Ketema	50	81	30	49
52	Gerji	Addis Ketema	59	86	35	51
63	Addis Ketema	Mikililand	50	67	30	40
88	Addis Ketema	Chancho	45	52	27	31
91	Addis Ketema	Teji	65	88	39	53

6.6.2. Bus Carrying Capacity and Number of Bus Assigned Data

There is considerable diversity in the size, capacity and configuration of transit buses among cities in the world. A general applicable approach to the estimation of bus capacity is:

Vehicle Capacity = number of seats + area available for standing/area per standee (set as a standard)

For planning purposes, the standee density standard would be the amount of space each standee would be assigned to allow an acceptable level of crowding across an average peak hour. In either case, this is a policy standard that reflects social norms and available resources. It also reflects the type of service provided and the nature of the market. The longer that people must stand the more space generally assigned to each standing passenger.

According to the available data the ACBSE owns four types of bus. These are DAF, rigid Bishoftu bus, articulated and double-deck bus (which is newly introduced in 2018). These buses are assigned according to their passengers' carrying capacity and the route appropriateness based on the route wise passengers' demand. The bus carrying capacity for DAF and rigid Bishoftu bus is 60 passengers (number of seat plus standees). The carrying capacity of the articulated and double-deck bus is 100 passengers and more respectively. Therefore in this case study the study is not focuses on double-deck bus transport.

The response to the available demand could not be satisfied by assigning the bus of high carrying capacity. Increasing the number of bus is another option to respond to the passenger demand when the demand is very high and reducing the number of bus when the demand is very low, see appendix-I.

6.6.3. Passengers Flow Data

In public transportation systems, travel demand is characterized by peak and off-peak fluctuations. In the investigated case, the transport demand is characterized by an hourly arrival rate of passengers (ϴ= 60 minutes). Passenger arrival rates at Addis Ketema terminals in hourly for each thirteen routes are shown in Figures 5.11.

Each demand represents a particular pattern observed during a specific five days for a single routes. The actual demand data are found from the automatic passenger count method. The difference between hourly travel demand scenarios lies in the computational effort needed for the optimization models, although the models presented are capable of handling any travel demand pattern observed during the study period of 7:00 a.m-11:00 a.m. and 2:00 p.m.-6:00 p.m. of day.

6.7. Computation Procedure

The model developed for determining the optimal passengers waiting time required for a given routes during a given time period was solved by using LINGO software. LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratic Constrained, Second Order Cone, Semi-Definite, Stochastic**,** and Integer optimization models faster, easier and more efficient**.** LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, a full featured environment for building and editing problems, and a set of fast built-in solvers.

LINGO help to cut development time. It was designed to formulate linear, nonlinear and integer problems quickly in a highly readable form. LINGO's modeling language allows to express models in a straightforward intuitive manner using summations and subscripted variables much like would with pencil and paper. Models are easier to build, easier to understand, and, therefore, easier to maintain.

LINGO allows to build models that pull information directly from databases and spreadsheets and, can output solution information right into a database or spreadsheet making it easier to generate reports in the application of user choice. Due to this appropriateness the model was developed on notepad window and taken to LINGO software for solution.

6.8. LINGO code for LP model

In this section the model developed was converted to the LINGO code. For 13 samples bus routes similar model was developed and solved similarly by LINGO software. The next LINGO model is the model of bus route number-4 of both shift for DAF or Rigid Bishoftu bus.

DAF or Rigid Bishoftu bus

Shift-1

```
MODEL:
 [_1] MIN= W1 + W2 + W3 + W4 + 0.5 * Q1
+ 0.5 * Q2 + 0.5 * Q3 + 0.5 * Q4;
 [_2] H0 + H1 + H2 + H3 + H4 + H5 = 180;
 [_3] H0 <= 72;
 [_4] H1 <= 72;
 [_5] H2 <= 72;
 [_6] H3 <= 72;
 [_7] H4 <= 72;
 [_8] H5 <= 72;
 [_9] H0 >= 25;
 [_10] H1 >= 25;
 [_11] H2 >= 25;
 [_12] H3 >= 25;
 [_13] H4 >= 25;
 [_14] H5 >= 25;
 [_15] X02 + 2 * X03 + 3 * X04 - D0 = 0;
 [_16] X12 + 2 * X13 + 3 * X14 - D1 = 0;
 [_17] X22 + 2 * X23 + 3 * X24 - D2 = 0;
 [_18] X32 + 2 * X33 + 3 * X34 - D3 = 0;
 [_19] X42 + 2 * X43 + 3 * X44 - D4 = 0;
 [_20] X52 + 2 * X53 + 3 * X54 - D5 = 0;
 [_21] X01 + X11 + X21 + X31 + X41 + X51
<= 1;
 [_22] X02 + X12 + X22 + X32 + X42 + X52
<= 1;
 [_23] X03 + X13 + X23 + X33 + X43 + X53
<= 1;
 [_24] X04 + X14 + X24 + X34 + X44 + X54
<= 1;
 [_25] X02 + X03 + X04 + X01 <= 1;
 [_26] X12 + X13 + X14 + X11 <= 1;
 [_27] X22 + X23 + X24 + X21 <= 1;
 [_28] X32 + X33 + X34 + X31 <= 1;
 [_29] X42 + X43 + X44 + X41 <= 1;
 [_30] X52 + X53 + X54 + X51 <= 1;
 [_31] Q1 = 63;
 [_32] Q2 = 63;
 [_33] Q3 = 63;
 [_34] Q4 = 88;
 [_35] W1 - W0 - Q0 + B1 = 0;
```

Shift-2

```
MODEL:
 [_1] MIN= W1 + W2 + W3 + W4 + 0.5 * Q1
+ 0.5 * Q2 + 0.5 * Q3 + 0.5 * Q4;
 [_2] H0 + H1 + H2 + H3 + H4 + H5 = 180;
 [_3] H0 <= 72;
 [_4] H1 <= 72;
 [_5] H2 <= 72;
 [_6] H3 <= 72;
 [_7] H4 <= 72;
 [_8] H5 <= 72;
 [_9] H0 >= 25;
 [_10] H1 >= 25;
 [_11] H2 >= 25;
 [_12] H3 >= 25;
 [_13] H4 >= 25;
 [_14] H5 >= 25;
 [_15] X02 + 2 * X03 + X04 - D0 = 0;
 [_16] X12 + 2 * X13 + X14 - D1 = 0;
 [_17] X22 + 2 * X23 + X24 - D2 = 0;
 [_18] X32 + 2 * X33 + X34 - D3 = 0;
 [_19] X42 + 2 * X43 + X44 - D4 = 0;
 [_20] X52 + 2 * X53 + X54 - D5 = 0;
 [_21] X01 + X11 + X21 + X31 + X41 + X51
<= 1;
 [_22] X02 + X12 + X22 + X32 + X42 + X52
<= 1;
 [_23] X03 + X13 + X23 + X33 + X43 + X53
<= 1;
 [_24] X04 + X14 + X24 + X34 + X44 + X54
<= 1;
 [_25] X02 + X03 + X04 + X01 <= 1;
 [_26] X12 + X13 + X14 + X11 <= 1;
 [_27] X22 + X23 + X24 + X21 <= 1;
 [_28] X32 + X33 + X34 + X31 <= 1;
 [_29] X42 + X43 + X44 + X41 <= 1;
 [_30] X52 + X53 + X54 + X51 <= 1;
 [_31] Q1 = 50;
 [_32] Q2 = 98;
 [_33] Q3 = 146;
 [_34] Q4 = 68;
 [_35] W1 - W0 - Q0 + B1 = 0;
```

```
[_36] - W1 + W2 - Q1 + B2 = 0;
[_37] - W2 + W3 - Q2 + B3 = 0;
[_38] - W3 + W4 - Q3 + B4 = 0;
[_39] 60 * X01 + 60 * X11 + 60 * X21 +
60 * X31 + 60 * X41 + 60 * X51 - B1 >=
0;
[_40] 60 * X02 + 60 * X12 + 60 * X22 +
60 * X32 + 60 * X42 + 60 * X52 - B2 >=
0;
[_41] 60 * X03 + 60 * X13 + 60 * X23 +
60 * X33 + 60 * X43 + 60 * X53 - B3 >=
0;
[_42] 60 * X04 + 60 * X14 + 60 * X24 +
60 * X34 + 60 * X44 + 60 * X54 - B4 >=
0;
[_43] D0 >= 0;
[_44] D1 >= 0;
[_45] D2 >= 0;
[_46] D3 >= 0;
[_47] D4 >= 0;
[_48] D5 >= 0;
[_49] H0 >= 0;
[_50] H1 >= 0;
[_51] H2 >= 0;
[_52] H3 >= 0;
[_53] H4 >= 0;
[_54] H5 >= 0;
[_55] Q1 >= 0;
[_56] Q2 >= 0;
[_57] Q3 >= 0;
[_58] Q4 >= 0;
[_59] B1 >= 0;
[_60] B2 >= 0;
[_61] B3 >= 0;
[_62] B4 >= 0;
[_63] W1 >= 0;
[_64] W2 >= 0;
[_65] W3 >= 0;
[_66] W4 >= 0;
[_67] X0 <= 1;
[_68] X1 <= 1;
[_69] X2 <= 1;
[_70] X3 <= 1;
[_71] X4 <= 1;
[_72] X5 <= 1;
[_73] X0 >= 0;
[_74] X1 >= 0;
[_75] X2 >= 0;
[_76] X3 >= 0;
[_77] X4 >= 0;
[_78] X5 >= 0;
END
```


```
[_36] - W1 + W2 - Q1 + B2 = 0;
[_37] - W2 + W3 - Q2 + B3 = 0;
[_38] - W3 + W4 - Q3 + B4 = 0;
[_39] 60 * X01 + 60 * X11 + 60 * X21 +
60 * X31 + 60 * X41 + 60 * X51 - B1 >=
0;
[_40] 60 * X02 + 60 * X12 + 60 * X22 +
60 * X32 + 60 * X42 + 60 * X52 - B2 >=
0;
[_41] 60 * X03 + 60 * X13 + 60 * X23 +
60 * X33 + 60 * X43 + 60 * X53 - B3 >=
0;
[_42] 60 * X04 + 60 * X14 + 60 * X24 +
60 * X34 + 60 * X44 + 60 * X54 - B4 >=
0;
[_43] D0 >= 0;
[_44] D1 >= 0;
[_45] D2 >= 0;
[_46] D3 >= 0;
[_47] D4 >= 0;
[_48] D5 >= 0;
[_49] H0 >= 0;
[_50] H1 >= 0;
[_51] H2 >= 0;
[_52] H3 >= 0;
[_53] H4 >= 0;
[_54] H5 >= 0;
[_55] Q1 >= 0;
[_56] Q2 >= 0;
[_57] Q3 >= 0;
[_58] Q4 >= 0;
[_59] B1 >= 0;
[_60] B2 >= 0;
[_61] B3 >= 0;
[_62] B4 >= 0;
[_63] W1 >= 0;
[_64] W2 >= 0;
[_65] W3 >= 0;
[_66] W4 >= 0;
[_67] X0 <= 1;
[_68] X1 <= 1;
[_69] X2 <= 1;
[_70] X3 <= 1;
[_71] X4 <= 1;
[_72] X5 <= 1;
[_73] X0 >= 0;
[_74] X1 >= 0;
[_75] X2 >= 0;
[_76] X3 >= 0;
[_77] X4 >= 0;
[_78] X5 >= 0;
END
```

6.9. Output of the LINGO Model Considering Maximum Demand

The LINGO model is developed on Window 10, Intel (R) core(TM) i3-5005U CPU @ 2.00GHZ and RAM 4.00GB Laptop computer. The output of the model shows the total passengers waiting time over the specified study period of planning horizon by considering the passenger's arrival rates or passengers demand rates over the two shifts, morning shift and after noon shift as well as the load capacity, DAF and rigid Bishoftu bus, and articulated bus whose loading capacity is 60 and 100 passengers per bus total passengers waiting time model was solved. The demand of this shifts are categorized as hourly demand. Thus the results of the model shows that the optimized waiting time is the total of passengers' waiting time of the hourly passengers' arrival rates. The sample output of the LINGO model is as follows: (Appendix-III).

6.10. Sensitivity Analysis

In this section, a sensitivity analysis is conducted to find the suitable bus capacity, headway and the number of bus required. By fixing the number of bus and the passenger demand as it was, the sensitivity analysis of the route performance, in relation to bus headway, was evaluated by varying the value of parameter α. It is clear that when the number of passengers increase the total passengers waiting time increases. In addition, when the headway is longer the total passengers waiting time also higher. In this case, even, when the number of passenger demand was lower the total passengers waiting time might be longer due to the longer bus headways.

The second sensitivity analysis made was the relation of the bus headway and the bus capacity. The effect of the headway on the bus capacity as the bus headway increase was evaluated. The deference between total passengers waiting time of rigid or DAF and articulated bus was compared. The result shows that as the bus headway increasing the deference between the total passengers waiting time of both bus capacity tends to zero. This indicates that the bus capacity should be taken into consideration when the bus headway was shorter and it doesn't matter when the headway is longer.

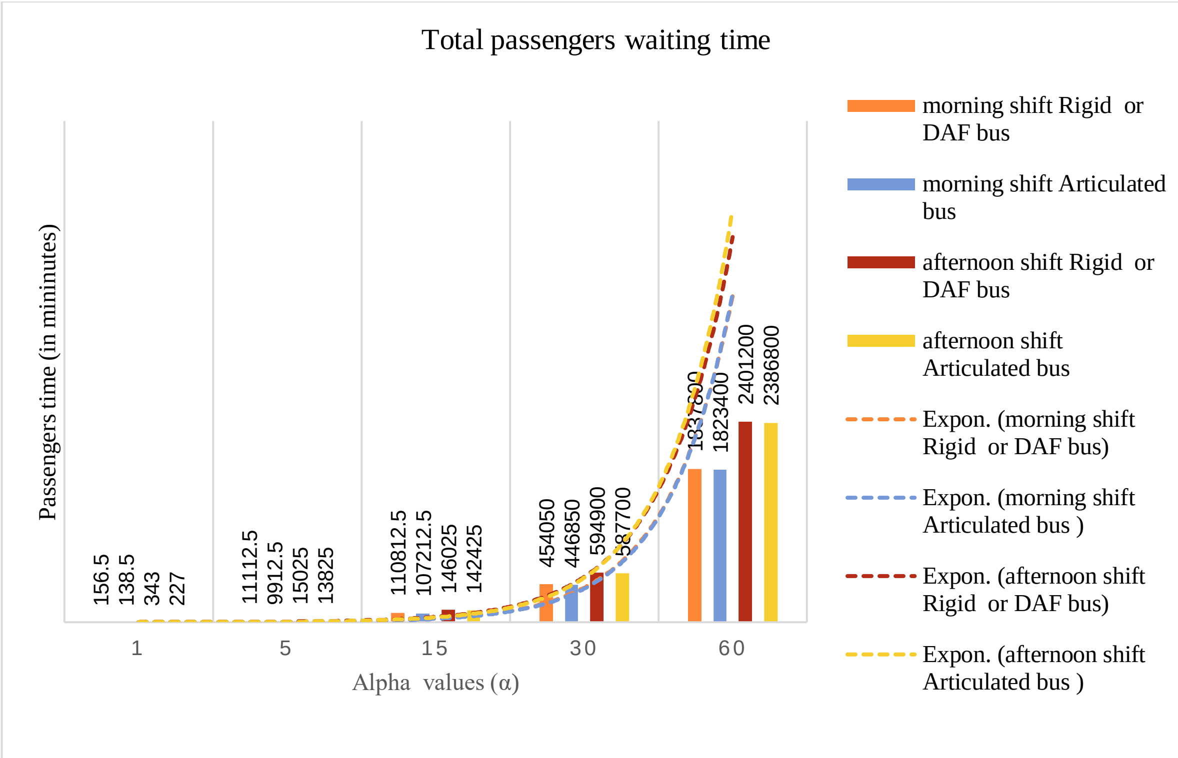


Figure 6.2 Total passengers waiting time

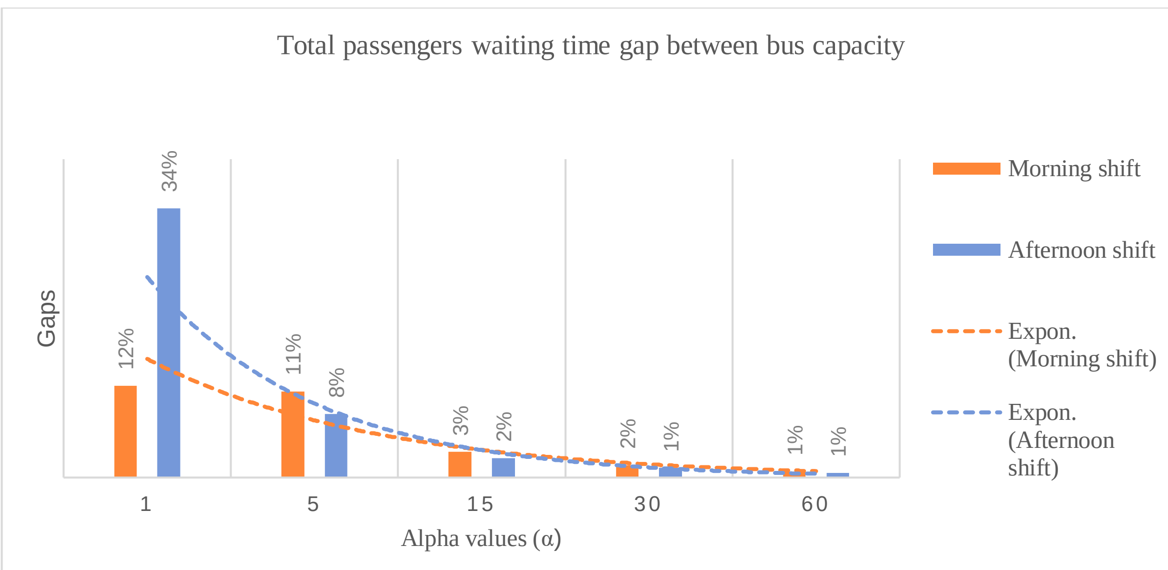


Figure 6.3 Gap between total passengers waiting time

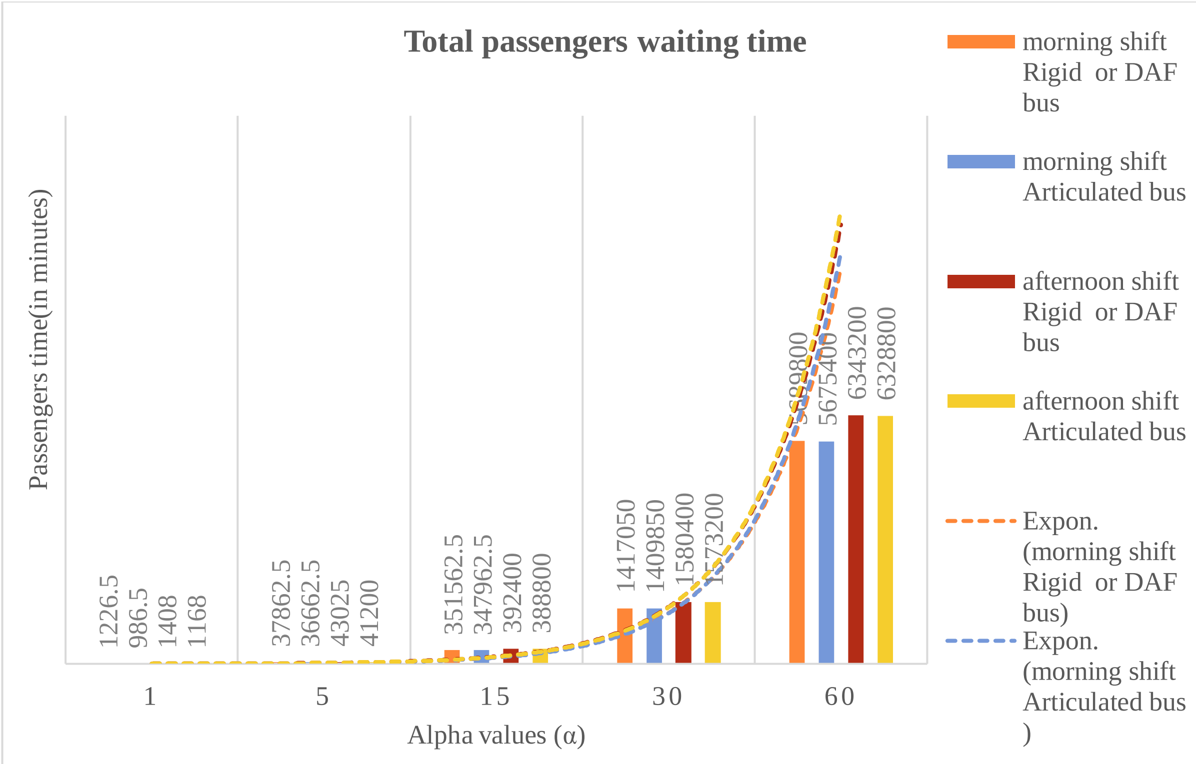


Figure 6.4 Total passengers waiting time

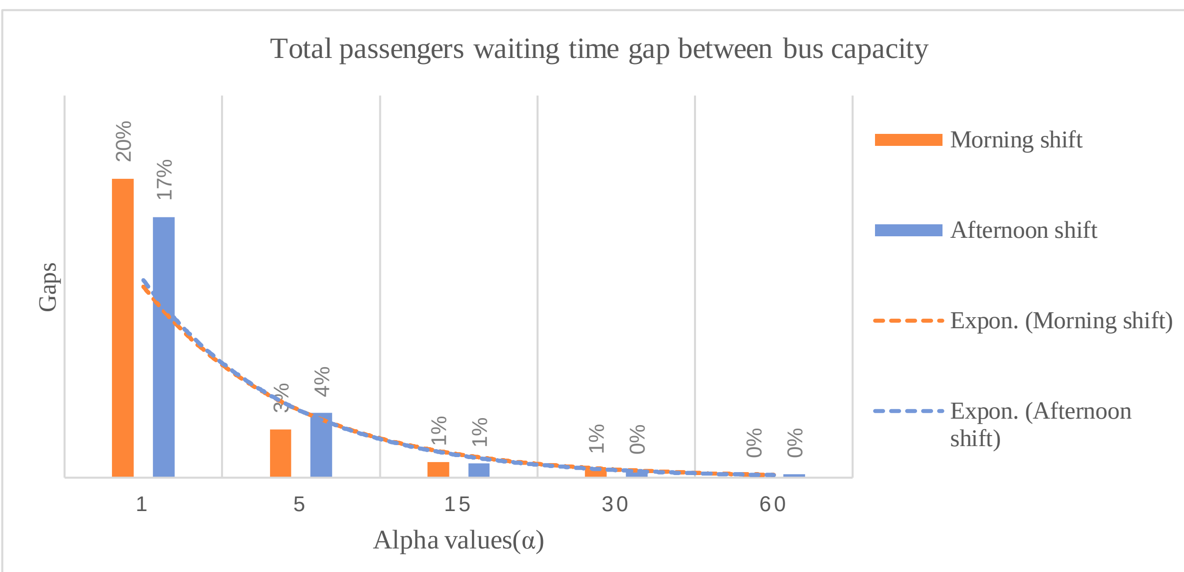


Figure 6.5 Gap between total passengers waiting time

Figure 6.2 and 6.4 shows that the sensitivity analysis by varying the value of α for bus route 4 and 12 for shift 1 and 2 respectively. This figure shows that as the value of α increases the total passengers waiting time increases exponentially. In contrary, figure 6.3 and 6.5 indicate that the gap between the total passengers waiting time between the bus capacities was decreases exponentially as the bus headway increases.

6.11. Model Evaluation and Validation

In the following sections, the output of the model is validated using different parameters. The model output is evaluated in terms of bus headway, bus frequency, bus capacity, and number of bus required, number of boarding passengers and the bus departure time by considering the numbers of passengers arrived during the successive bus inter-arrival time or the time between bus arrivals and departure time. Then, the validation is done by comparing the parameters results with the existing parameters values. The validation of the optimization model solution are summarized as follows.

6.11.1. Bus Head way and Bus Inter-Departure Time

Bus head way is the scheduled time between bus arrivals and departure time which is called regular or even headway. The bus inter-departure time is the time between successive bus departure times.

In this section two types of bus headway and the bus inter-departure was compared. The fist headway is the headway calculated from the bus cycle time and the available bus assigned along each routes. The calculation was represented as the following equation.

$$\text{Bus head way} = \frac{\text{Bus cycle time}}{\text{Number of bus availble}} \qquad 6.58$$

The second headway was the headway calculated from the frequency of the bus. The frequency of the bus was calculated based on the passenger demand and the available bus capacity. This method was used to determine the maximum and minimum bus headway. The formula of calculating the bus frequency and bus headway based on the passenger demand was as equation 6.57 and 6.58 respectively.

The inter-departure time is the time recorded during the observation field study. This time is deferent from the bus headway. It might be longer or shorter than the scheduled headway based on the principles of the terminal managers follow. They might allow more buses to the higher demand and allow less buses to the lower demand.

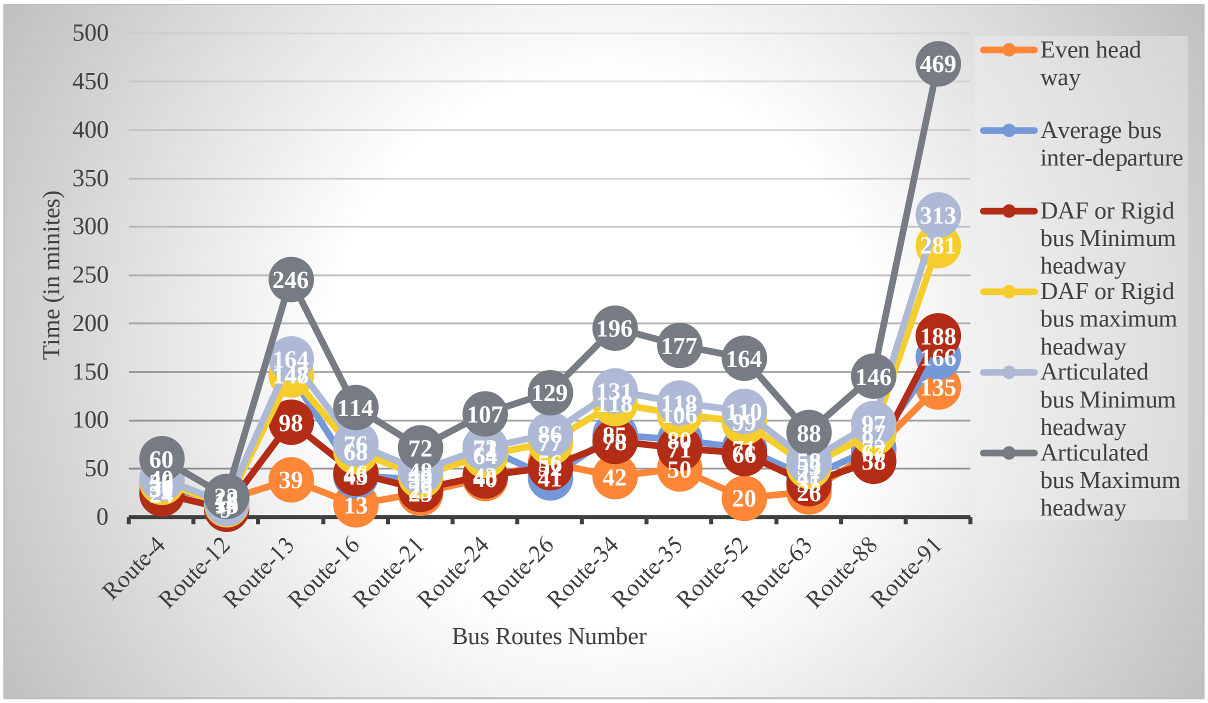


Figure 6.6 Even headway, bus inter-departure time, and minimum and maximum calculated bus headway

Figure 6.6 shows that articulated bus maximum headway is the maximum of the all headways. Then, articulated bus minimum headway. Next, DAF or Rigid bus maximum headway. But, DAF or Rigid minimum headway, average bus inter-departure time and even headway shows lower, equal or higher than each other.

In general the average of the bus departure time before optimization is 53 minutes. The bus departure time after optimization was 32 minutes for DAF or rigid Bishoftu bus and 33 minutes for articulated bus. This result shows that the overall average bus departure time reduction is 39.62% and 37.74% for DAF or rigid Bishoftu bus and articulated bus.

6.11.2. Bus Frequency Before and After Optimization

The bus transport service frequency indicates the number of bus per time within a specified time period. Table 6.5 shows that the comparison of actual bus frequencies and the frequencies obtained from the optimization model output. The actual bus frequency for each shift was obtained from the bus transport timetable developed using the inter-departure time as indicated on appendix-IV a. To determine the frequency after optimization the bus headway output from the model was used to develop the time table. Using the developed time table the new bus frequency after optimization was set and shown on appendix-IV b. This table displays that the actual number of bus frequency of each shifts and for both types of bus.

Table 6.4 Comparison of the actual bus frequency with the model output frequency

Route Number	**Origin**	**Destination**	**Frequency before optimization**		**Frequency after optimization**		**Improved frequency**	
			Shift	**Frequency**	**DAF or rigid bus**	**Articulated bus**	**DAF or rigid bus**	**Articulated bus**
4	Kaliti	Addis Ketema	1	7	9	9	2	2
			2	6	9	9	3	3
12	Gurara Ferensay Kela	Addis Ketema	1	13	13	13	0	0
			2	12	13	13	1	1
13	Italy Embassy	Addis Ketema	1	1	6	6	5	5
			2	1	6	6	5	5
16	Kidanimih ret	Addis Ketema	1	5	13	13	8	8
			2	6	13	13	7	7
21	Felidoro	Addis Ketema	1	8	9	9	1	1
			2	5	9	9	4	4
24	Dire Sololiya	Addis Ketema	1	5	6	5	1	0
			2	4	6	5	2	1
26	Addis Ketema	Sebeta	1	5	5	5	0	0
			2	4	5	5	1	1
34	German Squar	Addis Ketema	1	3	5	5	2	2
			2	3	5	5	2	2
35	Lebu Muziqa Sefer	Addis Ketema	1	4	4	4	0	0
			2	4	4	4	0	0
52	Gerji	Addis Ketema	1	3	12	12	9	9
			2	2	12	12	10	10
63	Addis Ketema	Mikililan d	1	5	9	9	4	4
			2	4	9	9	5	5
88	Addis Ketema	Chancho	1	3	3	3	0	0
			2	2	3	3	1	1
91	Addis Ketema	Teji	1	1	1	1	0	0
			2	1	1	1	0	0
Total				117	190	188	73	71
Average				4.5	7.31	7.23	2.81	2.73

Table 6.4 demonstrate the bus frequency sample routs before and after optimization. The frequency of the bus before optimization was the same because of the assumption that the speed of the bus along the route is the same and the number of types along a single route was not

identified. The frequency of the bus after optimization was different for different bus type as the bus assigned might be pure rigid or DAF which is the smaller loading capacity, the mix of the rigid and articulated bus and/or pure articulated bus which was the maximum loading capacity. The loading capacity of the buses would be in between the minimum loading capacity and maximum loading capacity. Therefore this analysis focus on both buses; but not all about the mix size. Having this in mind the total sample route average frequency of actual frequency is 4.5 bus per shift. In actual bus frequency the available buses are considered as similar buses. In after optimization bus frequency both bus types were considered. The total average of bus frequency for DAF or Bishoftu rigid bus is 7.31 buses, and 7.23 buses per shift for articulated buses.

The general average frequency improved for DAF or rigid and bus is 2.81 which is 62.44% of actual bus frequency. The average frequency improved for articulate bus frequency was 2.73 which is 60.67% of the actual bus frequency.

6.11.3. Bus Capacity and Number of Bus Required

Bus capacity is the ability of the bus to transport the passenger from its origin to its destination. During this transportation time the capacity of the bus assigned to the route might be greater than the passenger demand, less than the demand or almost optimum to the passenger demand. To balance the imbalanced passenger demand and the service supplied the capacitated bus transport was used to respond to the demand greater than the bus assigned by increasing the number of bus or by assigning the larger bus which has the more carrying capacity relatively while un-capacitated bus transport was assigned to the low passenger demand route. In this case the service capacity is greater than the passenger demand and the passengers do not wait for transport.

In this model the two limiting bus capacity was used. The first and second 60 passengers (seat + standee) and 100 passengers (seat + standee) respectively. DAF or Bishoftu rigid bus which can carry 60 passengers (seat + standee) was grouped as the first type. This capacity is the minimum bus capacity that assigned to the routes. The second type of bus is an articulated bus that has a carrying capacity of 100 passengers (seat + standee) per bus.

As it can be seen from appendix-IIIa the capacity if the bus has had an effect on passengers waiting time. When the DAF and Bishoftu rigid bus were compared with an articulated bus, the articulated bus has almost two times than the rest one. But, in articulated bus transport, due to the high carrying capacity the passenger waiting time was lower than the rest of the bus. The total average passengers waiting, regardless of the routes, for the DAF and Bishoftu was 1.0803 times of the passengers waiting time for articulated. That means the passengers waiting time for the DAF and Bishoftu bus was 8.03% more than the passengers waiting time for articulated bus. Importantly this should be noted that this process might happen along the routes of high passenger demand.

6.12. Evaluating the Effect of Waiting Time over the Bus Service Performance

The performance of the bus was classified under three categories. These categories are UCL, CL and LCL (as it was indicated in chapter 3). The high service performance is might be due to the high demand but lower frequency or high bus frequency but lower passenger demand and vice versa. Similarly, the low service performance might be lower frequency and low demand or high demand and low frequency or low demand high frequency. The basic indication message of frequency in relation to waiting time is the higher frequency is the low passengers waiting time and the lower frequency is the higher passengers waiting time. Therefore, in this section, the performance of the bus service evaluated with service frequency is to indicate the effect of passengers waiting time or in other words the bus service delay.

From the case study table 6.4 it easy to understand that the routes which was above UCL use the required frequency 84.38% and 87.10% for DAF or Rigid and articulated bus respectively. The routes below the LCL use the required frequency 50% for both bus types. Route 35 utilized the maximum bus frequency for both bus type, but it is grouped under the class of below LCL. This indicates that along this route there is low passengers demand and high service rate. In general, this evaluation tells that the long passengers waiting time and the passengers low demand reduces the performance of the bus public transport service.

CHAPTER SEVEEN

CONCLUSION, RECOMMENDATION AND FUTURE WORK

7.1. Conclusion

In public bus transport service minimization of passenger waiting time in a mixed traffic networks with higher demand route is becomes more and more necessary. In order to increase the efficiency and superior utilization of fleet capacity in bus transport systems, it is compulsory to use optimization methods. This approach optimizes the bus services to satisfy the passenger demand with the bus service operational constraints. To optimize the passenger demands with the bus service supply mixed-integer linear MILP and non-linear programming MINLP models has been presented in this thesis. Mixed-integer linear MILP model was improved, and developed from non-linear programming MINLP models by discretizing the length of the planning horizon into equal-sized small time intervals of length α (in minutes) and bus dispatch only at discrete time points to make the model to be tractable.

The main contribution of this study was introducing the demand-oriented mathematical modeling formulation for bus transportation service in Addis Ababa. Afterwards Addis Ketema bus terminal as a case study and 13 bus routes samples were selected. The even headways were obtained by calculating from the bus journey cycle time.

The minimization of passengers waiting time model was developed to minimize total passengers waiting time at the bus terminals. The model developed was mixed integer linear programming MILP and it was solved by LINGO 17.0 version software. The result was evaluate in terms of bus headway, bus frequency, bus capacity, and number of bus required.

Then the result of the model evaluated by the headway revels that the overall average bus headway reduction is 39.62% and 37.74% for DAF or rigid Bishoftu bus and articulated bus respectively. Improved average frequency for DAF or rigid and articulate bus is 62.44% and 60.67% of actual bus frequency. The total average passengers waiting time, regardless of the routes, for the DAF and Bishoftu was 1.0803 times of the passengers waiting time for articulated. That means the passengers waiting time for the DAF and Bishoftu bus was 8.03% more than the passengers waiting time for articulated bus.

The sensitivity was analyzed in two ways. First the sensitivity of passengers waiting time was evaluated by varying the value of parameter α fixing the number of bus and the passenger demand in relation to bus headway. When the headway is longer the total passengers waiting time also higher. In this case, even, when the number of passenger demand was lower the total passengers waiting time might be longer due to the longer bus headways. The second sensitivity analysis made was the relation of the bus headway and the bus capacity. The effect of the headway on the bus capacity as the bus headway increase the deference between total passengers waiting time of rigid or DAF and articulated bus tends to be zero. This indicates that the effect of the bus capacity doesn't matter when the headway is longer. But it should be taken into consideration when the bus headway was shorter.

In conclusion, minimizing the total passengers waiting time is the most important to increase the transportation service quality and satisfy the passenger demand. The minimization process was done by considering the demand variation and operational constraint. Therefore, providing efficient transport service is possible by supplying the available bus based on the required passenger demand.

7.2. Recommendation

In general increasing the service quality to satisfy the passenger demand of the public transport is very important. To increase the efficiency of bus service and increase the customers' satisfaction it is critical to reduce passengers waiting time. To reduce passengers waiting time;

1. Increase the bus service frequency by increasing the number of bus. This doesn't mean buying a new bus to increase the number of bus. But, reducing the bus from the routes of low demand and adding to the routes of high demand. In this case it is important to understand the side effect of the bunching effect and it should be taken into considerations.
2. Increase the bus service frequency by assigning the fastest bus to the routes of higher demand.
3. Vary the bus headway based on timely demand with the available bus. Reduce headway as much as the passengers demand during the high demand time and increasing the headway during low demand to avoid the loss of both directions.

4. Utilize the bus loading capacity. Assign the high loading bus capacity to the routes of high demand and low bus capacity to the routes of low demand.
5. Use articulated bus for the shorter bus headway and DAF or rigid Bishoftu bus for longer bus headway. Because articulated bus is effective over shorter bus headway than longer bus headway to minimize passengers waiting time. The effect of the volume of the bus as the headway increases became insignificant over the total passengers waiting time.

7.3. Future Work

Concerning future research, the prediction of passenger demand is essential in the planning of bus transport system. In real-time operations, some types of disruption may make unexpected change in passenger demand. In this situation, implementing a demand based re-scheduling method could be an effective approach for the management of these alterations. From an application viewpoint, applying the proposed mathematical optimization model for on-line bus rescheduling during a significant unexpected passenger demand disturbance is very important. Therefore a further interesting research direction would be to study the costs of passengers waiting time and the operational costs.

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APPENDIX-I

Bus network route information of passenger transport of 2009 E.C (2017 G.C)

Route Number	Origin	Destination	Number of buses	Distance (Km)	Travel time Per	Average Speed, Km/hr.	Number of stops	Travelled Passengers Per year	Travelled Passengers Per day	Trip Travelled per day	Waiting time, min
1	Megenagna	Karalo	4	7.7	33	14.00	14	3233769	8860	118.13	10
2	Kore Mekanissa	Addis Ketema	4	11.1	54	12.33	17	1410183	3864	51.52	10
3	Ayer Tena	Menelik Squar	8	10.8	60	10.80	18	4577765	12542	167.23	10
4	Kaliti	Addis Ketema	6	19.4	80	14.55	32	1872932	5132	68.43	10
5	Kore Mekanissa	Menelik Squar	3	12.7	53	14.38	22	881376	2415	32.20	10
6	Kera	Semen Gebeya Squar	8	9.9	52	11.42	19	8469043	23203	309.37	10
7	Megenagna	Aleltu	3	49	100	29.40	41	1830821	5016	66.88	10
8	Kechene	Addis Ketema	3	9.4	38	14.84		872859	2392	31.89	10
9	Bole Brass Clinic	Piassa	3	10.5	39	16.00	19	932256	2555	34.07	10
10	Kotebe College	Piassa	6	12.7	53	14.38	23	3661572	10032	133.76	10
11	Kolfe Efoyeta	Menelik Hospital	4	10	49	12.24	18	1387294	3801	50.68	10
12	Gurara Ferensay Kela	Addis Ketema	6	9.9	44	13.50	15	7267791	19912	265.49	10
13	Italy Embassy	Addis Ketema	3	9.9	48	12.38	15	846506	2320	30.93	10
14	Saris Abo	Menelik Squar	6	12.3	60	12.30	20	1711537	4690	62.53	10
15	Megenagna	Addis Ketema	4	10.4	53	11.77	17	1954987	5357	71.43	10
16	Kidanimihret	Addis Ketema	8	7.9	42	11.29	17	2449539	6712	89.49	10
17	Kusqum	Addis Ketema	6	9.1	49	11.14	16	2688997	7368	98.24	10
18	Keraniyo	Addis Ketema	8	7.3	26	17.00	15	4077805	11173	148.97	10
19	Sansusi	Piassa	5	12.8	48	16.00	20	4458017	12214	162.85	10
20	Dil Ber	Addis Ketema	3	8.6	26	19.85	15	537285	1473	19.64	10
21	Felidoro	Addis Ketema	5	8.6	52	9.92	15	4232927	11598	154.64	10
22	Summit	Legehar	6	14.3	58	14.79	30	2874670	7876	105.01	10
23	Lamberet	Addis Ketema	3	12	45	16.00	24	1020279	2796	37.28	10
24	Dire Sololiya	Addis Ketema	4	15.9	70	13.63	30	2402667	6583	87.77	10

25	Legehar	Akaki	4	19	80	14.25	35	1485454	4070	54.27	10
26	Addis Ketema	Sebeta	3	25.5	74	20.68	35	846170	2319	30.92	10
27	Legehar	Kaliti	8	14.9	82	10.94	24	2460608	6742	89.89	10
28	Asko Sansuzi	Addis Ketema	5	11.1	51	13.06	17	2399071	6573	87.64	10
29	Saris Addisu Sefer	Addis Ketema	6	12.7	58	13.14	19	986908	2704	36.05	10
30	Sululta	Addis Ketema	5	25.8	70	22.11	29	2239943	6137	81.83	10
31	Legehar	Shiro Meda	8	7.4	35	12.69	12	8066267	22100	294.67	10
32	Hana Mariam	Legehar	6	10.6	51	12.47	22	2856036	7825	104.33	10
33	Kotebe Gebriel	Arat Kilo	5	11.4	40	17.10	23	4529110	12409	165.45	10
34	German Squar	Addis Ketema	3	9.8	52	11.31	22	843165	2311	30.81	10
35	Lebu Muziqa Sefer-	Addis Ketema	3	15	64	14.06		729383	1999	26.65	10
36	Kara Kore	Legehar	4	11.7	47	14.94	19	1176118	3223	42.97	10
37	Keraniyo	Menelik Squar	4	12	55	13.09	17	1981714	5430	72.40	10
38	German Squar	Sidist Kilo	4	11	60	11.00	24	2027692	5556	74.08	10
39	Bole School	Addis Ketema	3	9.6	36	16.00	18	1436151	3935	52.47	10
40	Karalo	Addis Ketema	3	17.9	70	15.34	29	1628111	4461	59.48	10
41	Eyesus	Addis Ketema	5	8.5	46	11.09	13	1725423	4728	63.04	10
42	Megenagna	Legehar	3	9.8	35	17.00	28	612009	1677	22.36	10
43	Menagesha	Addis Ketema	2	30.2	85	21.32	40	846892	2321	30.95	10
44	Legedadi	Addis Ketema	2	30.4	91	20.04	41	3297574	9035	120.47	10
45	Legehar	Dil Ber	6	8.6	46	11.22	16	2108889	5778	77.04	10
46	Gerji	Arat Kilo	6	11.2	55	12.22	23	2252973	6173	82.31	10
47	Yenegew Fire School	Addis Ketema	3	6	41	8.78	13	455366	1248	16.64	10
48	Bole Michael	Menelik Sq;	6	10.9	49	13.35	19	2458254	6735	89.80	10
49	Chefe Ayate;	Megenagna	6	11	40	16.50	20	4132609	11323	150.97	10
50	Ayer Tena	Megenagna	4	14.9	69	12.96		2122253	5815	77.53	10
51	Bethel Hospital	Addis Ketema	4	10.9	51	12.82	19	1876275	5141	68.55	10
52	Gerji	Addis Ketema	8	14.1	70	12.09	26	2430285	6659	88.79	10
53	Bole Michael	Shiro Meda	4	11.5	52	13.27	22	2308952	6326	84.35	10
54	Lafto	Legehar	4	9.5	38	15.00	18	1006222	2757	36.76	10

55	Legehar	Gurara Ferensay Kella	4	9.5	45	12.67	15	2038536	5586	74.48	10
56	Saris Abo	Shiro Meda	6	14.2	57	14.95	26	1937351	5308	70.77	10
57	Kara	Legehar	4	14.4	62	13.94	26	1240833	3400	45.33	10
58	Legehalr	Alem Bank	3	12	45	16.00	20	1276113	3497	46.63	10
59	Bethel Hospital	Menelik Squar	6	11.5	54	12.78	20	3827269	10486	139.81	10
60	Debr Zeit	Legehar	10	47.2	100	28.32	47	3631321	9949	132.65	10
61	Chefe Ayate	Legehar	6	18	65	16.62	32	2797047	7664	102.19	10
62	Sebeta	Legehar	3	23.8	80	17.85	35	2127709	5830	77.73	10
63	Addis Ketema	Mikililand	3	9.1	30	18.20	16	793923	2176	29.01	10
64	Sidist Kilo	Megenagna Gorf Aswegaj	4	9.5	36	15.83		790818	2167	28.89	10
65	Addis Ketema	Alem Bank	3	11	48	13.75	20	1444394	3958	52.77	10
66	Addis Ketema	Kara Qorre	4	10.5	39	16.15	18	2191526	6005	80.07	10
67	Legehar	Jemmo Mekanissa	8	10.6	48	13.25	19	4818337	13201	176.01	10
68	Menelik Hospital	Tore Hailoch	6	10.2	46	13.30	17	1638810	4490	59.87	10
69	Lome Meda	Merkato	3	5.9	41	8.63	7	139577	383	5.11	10
70	Aware Square	Ayer Tena	4	12	52	13.85	20	1941900	5321	70.95	10
71	Gerji	Balcha Hospital	3	10.9	60	10.90	19	979906	2685	35.80	10
72	Hana Mariam	Sari Abo	4	4.9	9	32.67	8	3826196	10483	139.77	10
73	Legehar	Ring Road Vis Winget	6	10.2	47	13.02	19	3061367	8388	111.84	10
74	Cmc Square	Addis Ketema	6	14.2	61	13.97	28	1365121	3741	49.88	10
75	Sidist Kilo	Qera	4	10.4	35	17.83	17	1345603	3687	49.16	10
76	Megenagna	Kaliti	3	18.2	91	12.00	24	1631525	4470	59.60	10
77	Ayer Tena	Kera	2	5	35	8.57	21	1595734	4372	58.29	10
78	Megenagna	Gofa Condiminium	3	12.4	53	14.04	13	569610	1561	20.81	10
79	Arat Kilo	Semit Condiminium	4	14.7	53	16.64	25	2200722	6030	80.40	10
80	Semen Gebeya Squar	Megenagna	6	12.4	53	14.04	22	1902620	5213	69.51	10
81	Sidist Kilo	Sansusi	3	11.1	44	15.14	24	1098312	3010	40.13	10
82	Goro Adebabay	Balcha Hospital	6	14.6	59	14.85	27	2445509	6701	89.35	10
83	Chefe Ayate	Sidist Kilo	6	18	60	18.00	33	3164885	8671	115.61	10

84	Kolfe Efoyta	Legehar	3	9.5	54	10.56	18	923436	2530	33.73	10
85	Addis Ketema	Holeta	2	45	90	30.00	32	1110261	3042	40.56	10
86	Ayer Tena	Korki	4	12.3	55	13.42	26	904824	2479	33.05	10
87	Winget Vis Ring Road	Ayer Tena	7	10.5	42	15.00	19	6667590	18268	243.57	10
88	Addis Ketema	Chancho	3	40	90	26.67	39	1962090	5376	71.68	10
89	Addis Ketema	Sendafa	3	44	110	24.00	47	1491009	4085	54.47	10
90	Betel Hospital	Legehar	6	10	55	10.91	18	3302370	9048	120.64	10
91	Addis Ketema	Teji	2	52	125	24.96	55	1276843	3499	46.65	10
92	Hana Mariam Ring Road	Balcha	4	9.6	41	14.05	21	2897527	7939	105.85	10
93	Bole Bulbula	Megenanga	4	15.2	55	16.58	22	1455389	3988	53.17	10
94	Piassa	Mikililand	4	9.9	31	19.16	17	1949590	5342	71.23	10
95	Addis Ketema	Addis Alem	3	47	100	28.20	41	1228027	3365	44.87	10
96	Megenagna	Goro Sefera	3	9.2	31	17.81	15	1247214	3418	45.57	10
97	Megenagna	Legetafo Mission	6	15.8	73	12.99	31	3130672	8578	114.37	10
98	Dukem	Saris Abo	3	26.3	70	22.54	36	2093123	5735	76.47	10
99	Ayer Tena	Alem Gena Michael	3	9.4	25	22.56	17	1495456	4098	54.64	10
100	Addis Ketema	Jemo	4	14.5	51	17.06	18	1939160	5313	70.84	10
101	Megenagna	Aba Kirros Sq.	6	12	40	18.00	23	4410934	12085	161.13	10
102	Kara	Legehar	6	13.7	52	15.81	23	2243409	6147	81.96	10
103	Jemo	Piassa	6	12.2	59	12.41	23	2721284	7456	99.41	10
104	Werku Sefer	Kera	2	8.3	35	14.23		434949	1192	15.89	10
105	Anfo Meda	Legehar	4	12	55	13.09	13	2005458	5495	73.27	10
106	Goro Adebabay	Sammit Megenagna	3	10.8	50	12.96		1067922	2926	39.01	10
107	Saris Abo	Akaki Qorqoro	3	11.4	50	13.68	12	976130	2675	35.67	10
108	Asko Addisu Sefer - 18 Sq.	Menelik Sq.	3	9.3	33	16.91		662582	1816	24.21	10
109	Saris Abo	Tulu Dimetu Square	3	12	42	17.14	15	1828352	5010	66.80	10
110	Sidist Kilo	Tulu Dimetu Square	3	24.9	85	17.58	34	1450832	3975	53.00	10
111	Dire Sololiya	Piassa	4	16.6	72	13.83	32	3740270	10248	136.64	10

112	Circular Route With In Ring Road	4 Turning Points	6	47.3	161	17.63		5066707	13882	185.09	10
113	Kaliti Total	Feche Koye	2	8.1	61	7.97	11	468947	1285	17.13	10
114	Gelan Condiminium	Saris Abo	2	7.9	35	13.54	33	1092143	2993	39.91	10
115	Lebu Muziqa Bet	Mexico Square	2	9.4	56	10.07		869534	2383	31.77	10
116	Mekanissa Michael Sq	Jemo No_ 2	2	5.6	25	13.44	10	1451023	3976	53.01	10
117	Kotari Condiminnium	Mexico Square	2	9.2	35	15.77	14	928748	2545	33.93	10
118	Merkato	Tateq Kella	2	18	70	15.43	20	717138	1965	26.20	10
119	Megenagna	Summit Condiminnium	3	9.2	35	15.77	21	2915468	7988	106.51	10
120	Burayu Keta	Tore Hiloch	2	12.1	45	16.13	20	128448	352	4.69	10
121	Jemo Qedus Gebreal	Mexico Square	2	10	32	18.75	21	427585	1172	15.63	10
122	Arat Kilo	Entoto Mariam	2	16.6	31	32.13	24	1341976	3677	49.03	10
123	Megenagna	Yeka Abado	2	23.6	94	15.06	19	2087157	5719	76.25	10
124	Megenagna	Tulu Dimtu	2	12	48	15.00		2087157	5719	76.25	10
Total			527	1813.9	6831	1920.27	2573	263000062	2573	9608.15	1240
Avarage			4.25	14.628	55	15.49	20.75	2120968.2	5811.38	77.49	10

APPENDIX-II

a. Passengers arrival rate

Route Number	Origin	Destination	Number of buses	distance (Km)	Travel time /single trip, min	Average Speed, Km/hr.	Recorded average passenger arrival rate at terminals							
							Morning shift				Afternoon shift			
4	Kaliti	Addis Ketema	6	19.4	80	15	63	63	63	44	25	49	73	68
12	Gurara Ferensay Kela	Addis Ketema	6	9.9	44	14	56	59	62	63	64	62	59	58
13	Italy Embassy	Addis Ketema	3	9.9	48	12	17	15	13	15	31	29	30	28
16	Kidanimihret	Addis Ketema	8	7.9	42	11	34	45	55	43	30	44	58	46
21	Felidoro	Addis Ketema	5	8.6	52	10	39	76	112	95	78	56	34	37
24	Dire Sololiya	Addis Ketema	4	15.9	70	14	58	58	57	49	41	42	33	34
26	Addis Ketema	Sebeta	3	25.5	74	21	53	40	26	37	48	39	30	42
34	German Squar	Addis Ketema	3	9.8	52	11	25	27	20	24	22	23	22	20
35	Lebu Muziqa Sefer-	Addis Ketema	3	15	64	14	25	27	21	24	21	22	27	32
52	Gerji	Addis Ketema	8	14.1	70	12	46	49	24	25	19	20	19	19
63	Addis Ketema	Mikililand	3	9.1	30	18	45	53	60	53	46	49	51	48
88	Addis Ketema	Chancho	3	40	90	27	32	33	29	30	30	33	32	32
91	Addis Ketema	Teji	2	52	125	25	12	10	12	10	8	10	8	9

b. Bus inter-departure time

Route Bus number	Bus inter-departure time using clock								Bus inter-departure time (in minutes)							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
4	00:34:00	00:34:00	00:33:00	00:29:00	00:30:00	00:29:00	00:27:00	00:31:00	34	34	33	29	30	29	27	31
12	00:17:00	00:18:00	00:19:00	00:17:00	00:15:00	00:18:00	00:20:00	00:19:00	17	18	19	17	15	18	20	19
13	02:31:00				02:24:00				151				144			
16	00:35:00	00:47:00	00:59:00	00:47:00	00:34:00	00:39:00	00:43:00	00:39:00	35	47	59	47	34	39	43	39
21	00:41:00	00:29:00	00:17:00	00:32:00	00:47:00	00:49:00	00:51:00	00:46:00	41	29	17	32	47	49	51	46
24	01:00:00	00:55:00	00:43:00	00:51:00	01:15:00		01:32:00		60	55	43	51	75		92	
26	00:40:00	00:43:00	00:46:00	00:41:00	00:35:00	00:39:00	00:42:00	00:41:00	40	43	46	41	35	39	42	41
34	01:15:00		01:47:00		01:15:00		01:22:00		75		107		75		82	
35	01:20:00		01:19:00		01:22:00		01:16:00		80		79		82		76	
52	00:56:00	01:00:00	01:08:00		01:17:00		01:21:00		55	61	68		77		81	
63	00:43:00	00:45:00	00:46:00	00:42:00	00:38:00	00:38:00	00:37:00	00:40:00	43	45	46	42	38	38	37	40
88	01:01:00		01:06:00		01:18:00		01:25:00		61		66		68		85	
91	02:44:00				02:48:00				164				168			

APPENDIX-III

a. Objective value

Route number	Shifts	Bus type	Alpha value (in minutes)				
			1	5	15	30	60
4	Shift 1	Rigid or DAF bus	156.5	11112.50	110812.5	454050	1837800
		Articulated bus	138.5	9912.5	107212.5	446850	1823400
	Shift 2	Rigid or DAF bus	343	15025	146025	594900	2401200
		Articulated bus	227	13825	142425	587700	2386800
12	Shift 1	Rigid or DAF bus	1226.5	37862.5	351562.5	1417050	5689800
		Articulated bus	986.5	36662.5	347962.5	1409850	5675400
	Shift 2	Rigid or DAF bus	1408	43025	392400	1580400	6343200
		Articulated bus	1168	41200	388800	1573200	6328800
13	Shift 1	Rigid or DAF bus	30	1300	22500	100800	424800
		Articulated bus	30	750	18900	93600	410400
	Shift 2	Rigid or DAF bus	59	4200	48600	205200	842400
		Articulated bus	59	3000	45000	198000	828000
16	Shift 1	Rigid or DAF bus	88.5	6587.5	70087.5	291150	1186200
		Articulated bus	88.5	5387.5	66487.5	283950	1171800
	Shift 2	Rigid or DAF bus	89	6325	67725	281700	1148400
		Articulated bus	89	5125	64125	274500	1134000
21	Shift 1	Rigid or DAF bus	872	27425	257625	1041300	4186800
		Articulated bus	752	26225	254025	1034100	4172400
	Shift 2	Rigid or DAF bus	134.5	10262.5	103162.5	423450	1715400
		Articulated bus	102.5	9050	99562.5	416250	1701000
24	Shift 1	Rigid or DAF bus	122.5	9937.5	100238	411750	1448100
		Articulated bus	122.5	8737.5	96637.5	404550	1433700
	Shift 2	Rigid or DAF bus	75	6075	65475	272700	977400
		Articulated bus	75	4875	61875	265500	963000
26	Shift 1	Rigid or DAF bus	78	6775	71775	297900	1213200
		Articulated bus	78	5575	68175	290700	1198800
	Shift 2	Rigid or DAF bus	79.5	6487.5	69187.5	287550	1171800
		Articulated bus	79.5	5287.5	65587.5	280350	1157400
34	Shift 1	Rigid or DAF bus	46	3075	38475	164700	680400
		Articulated bus	46	1875	34875	157500	666000

	Shift 2	Rigid or DAF bus	44.5	2662.5	34762.5	149850	621000
		Articulated bus	44.5	1462.5	31162.5	142650	606600
35	Shift 1	Rigid or DAF bus	48.5	3162.5	39262.5	167850	693000
		Articulated bus	48.5	1962.5	35662.5	160650	678600
	Shift 2	Rigid or DAF bus	51	2825	36225	155700	644400
		Articulated bus	51	1625	32625	148500	630000
52	Shift 1	Rigid or DAF bus	72	6500	69300	288000	1173600
		Articulated bus	72	5300	65700	280800	1159200
	Shift 2	Rigid or DAF bus	38.5	2062.5	29362.5	128250	534600
		Articulated bus	38.5	962.5	25762.5	121050	520200
63	Shift 1	Rigid or DAF bus	79	8310	82290	399600	1625400
		Articulated bus	79	6990	78570	390600	1607400
	Shift 2	Rigid or DAF bus	73	7750	77610	376200	1596600
		Articulated bus	73	6430	73890	367200	1513800
88	Shift 1	Rigid or DAF bus	62	4525	51525	216900	889200
		Articulated bus	62	3325	47925	209700	892800
	Shift 2	Rigid or DAF bus	64.5	4512.5	51412.5	216450	887400
		Articulated bus	64.5	3312.5	47812.5	209250	873000

b. Constraints value

Variable	Route number 4				Route number 12				Route number 13				Route number 16				Route number 21				Route number 24			
	Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100	
	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2
	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
w1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
w2	3	0	0	0	0	4	0	0	5	0	0	0	0	0	0	0	0	18	0	0	0	27	0	0

w3	6	0	0	0	0	6	0	0	6	0	0	0	0	0	0	0	16	14	0	0	0	46	0	0
w4	9	13	0	0	2	5	0	0	2	0	0	0	0	0	0	0	68	0	12	0	0	56	0	0
δ1	63	25	63	25	56	64	56	64	65	60	65	60	34	30	34	30	39	78	39	78	58	87	58	87
δ2	63	49	63	49	59	62	59	62	61	59	61	59	45	44	45	44	76	56	76	56	58	79	58	79
δ3	63	73	63	73	62	59	62	59	56	57	56	57	55	58	55	58	112	34	112	34	57	70	57	70
δ4	44	68	44	68	63	58	63	58	58	61	58	61	43	46	43	46	95	37	95	37	72	64	72	64
H0	25	25	30	30	18	18	18	18	39	39	38	54	13	13	13	13	53	53	53	24	40	40	53	53
H1	25	25	30	30	18	18	18	18	39	39	38	34	13	13	13	13	23	23	23	24	40	40	39	39
H2	25	25	30	30	18	18	18	18	38	38	40	28	13	13	13	13	16	16	16	24	40	40	34	34
H3	25	25	30	30	18	18	18	18					13	13	13	13	16	16	16	24	40	40	34	34
H4	25	25	30	30	18	18	18	18					13	13	13	13	16	16	16	28				
H5	55	55	30	30	18	18	18	18					13	13	13	13								
H6													13	13	13	13								
H7													13	13	13	13								
x02	0	0	0.37	0.25	0	0	0.38	0.41	0	0.67	0.65	0.6	0	0	0	0	0	0.2	0	0.66	0.83	0	0.58	0.51
x03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x04	1	1	0.63	0.73	1	1	0.62	0.59	1	0.93	0.35	0.4	0.17	0.23	0.1	0.14	1	0.8	1	0.34	0.91	1	0.42	0.49
D0	3	1	2.26	2.44	3	3	2.24	2.18	3	2.87	1.7	1.8	0.5	0.7	0.3	0.42	3	2.6	3	1.68	2.83	3	1.84	1.98
x12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x13	1	0.86	0.63	0.49	0.98	1	0.59	0.62	1	0.98	0.61	0.59	0	0	0	0	1	1	0.76	0.56	0.97	1	0.58	0.79
x14	0	0	0	0	0	0	0	0	0	0.17	0.21	0.17	0	0	0	0	0	0	0	0	0.33	0	0.15	0.21
D1	2	1.63	1.26	0.98	0.98	2	1.18	1.24	2	2.02	1.85	1.69	0	0	0	0	2	2	1.52	1.12	2.03	2	1.61	2.21
x22	0	0	0	0	0	0	0	0	1	0.93	0	0	0	0	0	0	0	0	0	0	0.88	1	0	0.36
x23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

D2	0	0	0	0	0	0	0	0	1	0.93	0	0	0	0	0	0	0	0	0	0	0.88	1	0	0.36
x32	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
x33	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
x34	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0
x42	1	0.42	0.26	0	0.93	1	0.18	0.23					0	0	0	0	0.65	0.8	0.39	0.12				
x43	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0				
x44	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0				
D4	1	0.42	0.26	0	0.93	1	0.18	0					0	0	0	0	0.65	0.8	0.39	0.12				
x52	0	0	0	0	0	0	0	0					0	0	0	0								
x53	0	0	0	0	0	0	0	0					0	0	0	0								
x54	0	0	0	0	0	0	0	0					0	0	0	0								
D5	0	0	0	0	0	0	0	0					0	0	0	0								
x62													0	0	0	0								
x63													0	0	0	0								
x64													0	0	0	0								
D6													0	0	0	0								
x72													0	0	0	0								
x73													0	0	0	0								
x74													0	0	0	0								
D7													0	0	0	0								
x01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x31	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0	0	0	0	0

x41	0	0	0	0	0	0	0	0					0	0	0	0	0	0	0	0				
x51	0	0	0	0	0	0	0	0					0	0	0	0								
X61													0	0	0	0								
X71													0.75	0.73	0.45	0.44								
w0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
δ0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	60	25	63	25	56	60	56	64	60	60	65	60	34	30	34	30	39	60	39	78	58	60	58	87
B3	60	49	63	49	59	60	59	62	60	59	61	59	45	44	45	44	60	60	76	56	58	60	58	79
B4	60	60	63	73	60	60	62	59	60	57	56	57	55	58	55	58	60	48	100	34	57	60	57	70

variable	Route number 26				Route number 34				Route number 35				Route number 52				Route number 63				Route number 88			
	Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100		Load capacity 60		Load capacity 100	
	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2	Shift 1	Shift 2	Shift 1	Shift-2
	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
w1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
w2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	3	0	0
w3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	7	0	0
w4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12	0	0
δ1	53	48	53	48	54	47	54	47	54	37	54	37	46	40	46	40	45	46	45	46	67	63	67	63
δ2	40	39	40	39	49	43	49	43	51	49	51	49	49	38	49	38	53	49	53	49	63	64	63	64
δ3	26	30	26	30	43	38	43	38	47	60	47	60	51	35	51	35	60	51	60	51	58	65	58	65
δ4	37	42	37	42	45	46	45	46	42	57	42	57	46	41	46	41	53	48	53	48	61	66	61	66

H0	69	69	56	56	47	47	41	41	50	50	49	49	20	20	20	20	26	26	26	26	67	67	67	67
H1	65	65	56	56	44	44	41	41	50	50	49	49	20	20	20	20	26	26	26	26	67	67	67	67
H2	64	64	56	56	33	33	42	42	48	48	50	50	20	20	20	20	28	28	28	28	66	66	66	66
H3													20	20	20	20								
H4													20	20	20	20								
H5													20	20	20	20								
H6													20	20	20	20								
H7													20	20	20	20								
x02	0.88	0.8	0.53	0.48	0.87	0.65	0.54	0.47	0.37	0.188	0.54	0.37	0.15	0.42	0.46	0.4	0.12	0.33	0.45	0.46	0	0	0.67	0.63
x03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x04	0.12	0.2	0.26	0.3	0.53	0.35	0.43	0.38	0.63	0.82	0.46	0.6	0.85	0.58	0.51	0.35	0.88	0.67	0.55	0.51	1	1	0.33	0.37
D0	1.23	1.4	1.31	1.38	2.1	1.7	1.83	1.61	2.67	2.63	1.92	2.17	2.7	2.27	1.99	1.45	2.77	2.33	2.1	1.99	3	3	1.66	1.74
x12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x13	0.67	0.65	0.4	0.39	0.82	0.72	0.49	0.43	0.85	0.82	0.51	0.49	0.82	0.63	0.49	0.38	0.88	0.82	0.53	0.49	1	1	0.63	0.64
x14	0.32	0.3	0	0	0.18	0.28	0	0	0.15	0.18	0.1	0	0	0	0	0	0.12	0.18	0.5	0	0	0	0.25	0.28
D1	2.23	2.2	0.8	0.78	2.18	2.28	0.98	0.86	2.15	2.18	1.05	0.98	1.63	1.27	0.98	0.76	2.12	2.18	1.21	0.98	2	2	2.01	2.12
x22	0	0	0	0	0.43	0.13	0	0	0.53	0.43	0	0	0	0	0	0	0.63	0.43	0	0	2	2	0	0
x23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0.43	0.133	0	0	0.53	0.43	0	0	0	0	0	0	0.63	0.43	0	0	1	1	0	0
x32													0	0	0	0								
x33													0	0	0	0								
x34													0	0	0	0								
D3													0	0	0	0								

x42													0	0	0	0								
x43													0	0	0	0								
x44													0	0	0	0								
D4													0	0	0	0								
x52													0	0	0	0								
x53													0	0	0	0								
x54													0	0	0	0								
D5													0	0	0	0								
x62													0	0	0	0								
x63													0	0	0	0								
x64													0	0	0	0								
D6													0	0	0	0								
x72													0.62	0	0	0								
x73													0	0	0	0								
x74													0	0	0	0								
D7													0.62	0	0	0								
x01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x31													0	0	0	0								
x41													0	0	0	0								
x51													0	0	0	0								
X61													0	0	0	0								
X71													0	0	0	0								
w0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

δ0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B2	53	48	53	48	54	47	54	47	54	37	54	37	46	40	46	40	45	46	45	46	60	60	67	63
B3	40	39	40	39	49	43	49	43	51	49	51	49	49	38	49	38	53	49	53	49	60	60	63	64
B4	26	30	26	30	43	38	43	38	47	60	47	60	51	35	51	35	60	51	60	51	60	60	58	65

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a. Old or actual time table from recorded data

	start	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**						
	07:00:00	**07:34:00**	**08:08:00**	**08:41:00**	**09:10:00**	**09:44:00**	**10:18:00**	**10:51:00**	**11:20:00**						
4	**02:00:00**	**02:30:00**	**02:59:00**	**03:26:00**	**03:57:00**	**04:27:00**	**04:56:00**	**05:23:00**							
	start	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
	07:00:00	**07:17:00**	**07:35:00**	**07:54:00**	**08:11:00**	**08:28:00**	**08:46:00**	**09:05:00**	**09:22:00**	**09:39:00**	**09:57:00**	**10:16:00**	**10:33:00**	**10:50:00**	**11:08:00**
12	**02:00:00**	**02:30:00**	**02:45:00**	**03:03:00**	**03:23:00**	**03:38:00**	**03:56:00**	**04:16:00**	**04:35:00**	**04:50:00**	**05:08:00**	**05:28:00**	**05:47:00**	**06:02:00**	
	start	**1**	**2**												
	07:00:00	**09:31:00**	**12:02:00**												
13	**02:00:00**	**04:24:00**	**06:48:00**												
	start	**1**	**2**	**3**	**4**	**5**	**6**	**7**							
	07:00:00	**07:35:00**	**08:22:00**	**09:21:00**	**10:08:00**	**10:43:00**	**11:30:00**								
16	**02:00:00**	**02:34:00**	**03:13:00**	**03:56:00**	**04:35:00**	**05:16:00**	**05:45:00**	**06:02:00**							
	start	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**					
	07:00:00	**07:41:00**	**08:10:00**	**08:27:00**	**08:59:00**	**09:40:00**	**10:09:00**	**10:26:00**	**10:58:00**	**11:45:00**					
21	**02:00:00**	**02:47:00**	**03:36:00**	**04:27:00**	**05:13:00**	**06:00:00**									
		1	**2**	**3**	**4**										
	07:00:00	**08:00:00**	**08:55:00**	**09:38:00**	**10:29:00**	**11:44:00**									
24	**02:00:00**	**03:15:00**	**03:15:00**	**04:30:00**	**06:02:00**										
	start	**1**	**2**	**3**	**4**	**5**	**6**								
	07:00:00	**07:40:00**	**08:23:00**	**09:09:00**	**09:50:00**	**10:25:00**	**11:04:00**								
26	**02:00:00**	**02:35:00**	**03:14:00**	**03:56:00**	**04:37:00**	**05:12:00**									
		1	**2**	**3**	**4**										
	07:00:00	**08:15:00**	**08:15:00**	**10:02:00**	**11:17:00**										
34	**02:00:00**	**03:15:00**	**03:15:00**	**04:37:00**	**05:52:00**										

	start	1	2	3	4										
	07:00:00	08:20:00	08:20:00	09:39:00	10:59:00	12:18:00									
35	02:00:00	03:22:00	03:22:00	04:38:00	06:00:00										
	start	1	2	3	4										
	07:00:00	07:56:00	08:56:00	10:04:00	11:12:00										
52	02:00:00	03:17:00	04:38:00	05:55:00											
	start	1	2	3	4	5	6								
	07:00:00	07:43:00	08:28:00	09:14:00	09:56:00	10:39:00	11:24:00								
63	02:00:00	02:38:00	03:16:00	03:53:00	04:33:00	05:11:00									
	start	1	2	3	4										
	07:00:00	08:01:00	09:07:00	10:08:00	11:09:00										
88	02:00:00	03:18:00	04:36:00	06:01:00											
	start	1	2												
	07:00:00	09:44:00	12:28:00												
91	02:00:00	04:48:00	07:36:00												

b. New (developed) time table from optimized headway.

Bus route	Types of bus	Shifts	Start	1	2	3	4	5	6	7	8	9	10
4	DAF or Rigid	shift-1	7:00 AM	7:25 AM	7:50 AM	8:15 AM	8:40 AM	9:05 AM	9:30 AM	9:55 AM	10:20 AM	10:45 AM	11:10 AM
		shift-2	02:00:00	2:25 AM	2:50 AM	3:15 AM	3:40 AM	4:05 AM	4:30 AM	4:55 AM	5:20 AM	5:45 AM	
	Articulated	shift-1	07:00:00	7:25 AM	7:50 AM	8:15 AM	8:40 AM	9:05 AM	10:00 AM	10:25 AM	10:50 AM	11:15 AM	
		shift-2	02:00:00	2:25 AM	2:50 AM	3:15 AM	3:40 AM	4:05 AM	5:00 AM	5:25 AM	5:50 AM	6:15 AM	

			start	1	2	3	4	5	6	7	8	9	10	11	12	13	14
12	DAF or Rigid	shift-1	7:00 AM	7:18 AM	7:36 AM	7:54 AM	8:12 AM	8:30 AM	8:48 AM	9:06 AM	9:24 AM	9:42 AM	10:00 AM	10:18 AM	10:36 AM	10:54 AM	11:12 AM
		shift-2	2:00 AM	2:18 AM	2:36 AM	2:54 AM	3:12 AM	3:30 AM	3:48 AM	4:06 AM	4:24 AM	4:42 AM	5:00 AM	5:18 AM	5:36 AM	5:54 AM	
	Articulated	shift-1	7:00 AM	7:18 AM	7:36 AM	7:54 AM	8:12 AM	8:30 AM	8:48 AM	9:06 AM	9:24 AM	9:42 AM	10:00 AM	10:18 AM	10:36 AM	10:54 AM	11:12 AM
		shift-2	2:00 AM	2:18 AM	2:36 AM	2:54 AM	3:12 AM	3:30 AM	3:48 AM	4:06 AM	4:24 AM	4:42 AM	5:00 AM	5:18 AM	5:36 AM	5:54 AM	

			start	1	2	3	4	5	6	
13	DAF or Rigid	shift-1	7:00 AM	7:39 AM	8:18 AM	8:56 AM	9:35 AM	10:14 AM	10:53 AM	11:31 AM
		shift-2	2:00 AM	2:39 AM	3:18 AM	3:56 AM	4:34 AM	5:12 AM	5:51 AM	
	Articulated	shift-1	07:00:00	7:38 AM	8:16 AM	8:56 AM	9:34 AM	10:12 AM	10:50 AM	11:30 AM
		shift-2	02:00:00	2:54 AM	3:28 AM	3:56 AM	4:50 AM	5:44 AM	6:18 AM	

			start	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
16	DAF or Rigid	shift-1	7:00 AM	7:13 AM	7:26 AM	7:39 AM	7:52 AM	8:05 AM	8:18 AM	8:31 AM	8:44 AM	8:57 AM	9:10 AM	9:23 AM	9:36 AM	9:49 AM	10:02 AM	10:15 AM	10:28 AM	10:41 AM	10:54 AM	11:07 AM
		shift-2	2:00 AM	2:13 AM	2:26 AM	2:39 AM	2:52 AM	3:05 AM	3:18 AM	3:31 AM	3:44 AM	3:57 AM	4:10 AM	4:23 AM	4:36 AM	4:49 AM	5:02 AM	5:15 AM	5:28 AM	5:41 AM	5:54 AM	6:07 AM
	Articulated	shift-1	7:00 AM	7:13 AM	7:26 AM	7:39 AM	7:52 AM	8:05 AM	8:18 AM	8:31 AM	8:44 AM	8:57 AM	9:10 AM	9:23 AM	9:36 AM	9:49 AM	10:02 AM	10:15 AM	10:28 AM	10:41 AM	10:54 AM	11:07 AM

		shift-2	2:00 AM	2:13 AM	2:26 AM	2:39 AM	2:52 AM	3:05 AM	3:18 AM	3:31 AM	3:44 AM	3:57 AM	4:10 AM	4:23 AM	4:36 AM	4:49 AM	5:02 AM	5:15 AM	5:28 AM	5:41 AM	5:54 AM	6:07 AM
21			start	1	2	3	4	5	6	7	8	9										
	DAF or Rigid	shift-1	7:00 AM	7:53 AM	8:16 AM	8:32 AM	8:48 AM	9:04 AM	9:57 AM	10:50 AM	11:13 AM	11:29 AM										
		shift-2	2:00 AM	2:53 AM	3:16 AM	3:32 AM	3:48 AM	4:04 AM	4:57 AM	5:50 AM	6:13 AM	6:29 AM										
	Articulated	shift-1	7:00 AM	7:24 AM	7:48 AM	8:12 AM	8:36 AM	9:04 AM	9:28 AM	9:52 AM	10:16 AM	10:40 AM	11:08 AM									
		shift-2	2:00 AM	2:24 AM	2:48 AM	3:12 AM	3:36 AM	4:04 AM	4:28 AM	4:52 AM	5:16 AM	5:40 AM	6:04 AM									
24			start	1	2	3	4	5	6													
	DAF or Rigid	shift-1	7:00 AM	7:40 AM	8:20 AM	9:00 AM	9:40 AM	10:20 AM	11:00 AM													
		shift-2	2:00 AM	2:40 AM	3:20 AM	4:00 AM	4:40 AM	5:20 AM	6:00 AM													
	Articulated	shift-1	7:00 AM	7:53 AM	8:32 AM	9:06 AM	9:40 AM	10:33 AM	5:33 PM													
		shift-2	2:00 AM	2:53 AM	3:32 AM	4:06 AM	4:40 AM	5:33 AM	6:26 AM													
26			start	1	2	3	4	5														
	DAF or Rigid	shift-1	7:00 AM	8:09 AM	9:14 AM	10:18 AM	11:27 AM															
		shift-2	2:00 AM	3:09 AM	4:14 AM	5:18 AM	6:27 AM															

	Articulated	shift-1	7:00 AM	7:56 AM	8:52 AM	9:48 AM	10:44 AM	11:40 AM							
		shift-2	2:00 AM	2:56 AM	3:52 AM	4:48 AM	5:44 AM	6:40 AM							
34			start	1	2	3	4	5	6						
	DAF or Rigid	shift-1	7:00 AM	7:47 AM	8:31 AM	9:04 AM	9:51 AM	10:38 AM	11:22 AM						
		shift-2	2:00 AM	2:47 AM	3:31 AM	4:04 AM	4:51 AM	6:51 AM							
	Articulated	shift-1	7:00 AM	7:41 AM	8:22 AM	9:04 AM	9:45 AM	10:26 AM	11:08 AM						
		shift-2	2:00 AM	2:41 AM	3:22 AM	4:04 AM	4:45 AM	11:45 AM							
35			start	1	2	3	4	5							
	DAF or Rigid	shift-1	7:00 AM	7:50 AM	8:40 AM	9:28 AM	10:18 AM	11:08 AM							
		shift-2	2:00 AM	2:50 AM	3:40 AM	4:28 AM	5:18 AM								
	Articulated	shift-1	7:00 AM	7:49 AM	8:38 AM	9:28 AM	10:17 AM	11:06 AM							
		shift-2	2:00 AM	2:49 AM	3:38 AM	4:28 AM	5:17 AM								
52			start	1	2	3	4	5	6	7	8	9	10	11	12

	DAF or Rigid	shift-1	7:00 AM	7:20 AM	7:40 AM	8:00 AM	8:20 AM	8:40 AM	9:00 AM	9:20 AM	9:40 AM	10:00 AM	10:20 AM	10:40 AM	11:00 AM
		shift-2	2:00 AM	2:20 AM	2:40 AM	3:00 AM	3:20 AM	3:40 AM	4:00 AM	4:20 AM	4:40 AM	5:00 AM	5:20 AM	5:40 AM	6:00 AM
	Articulated	shift-1	7:00 AM	7:20 AM	7:40 AM	8:00 AM	8:20 AM	8:40 AM	9:00 AM	9:20 AM	9:40 AM	10:00 AM	10:20 AM	10:40 AM	11:00 AM
		shift-2	2:00 AM	2:20 AM	2:40 AM	3:00 AM	3:20 AM	3:40 AM	4:00 AM	4:20 AM	4:40 AM	5:00 AM	5:20 AM	5:40 AM	6:00 AM
63			start	1	2	3	4	5	6	7	8	9			
	DAF or Rigid	shift-1	7:00 AM	7:26 AM	7:52 AM	8:20 AM	8:46 AM	9:12 AM	9:40 AM	10:06 AM	10:32 AM	11:00 AM			
		shift-2	2:00 AM	2:26 AM	2:52 AM	3:20 AM	3:46 AM	3:46 AM	3:46 AM	4:12 AM	4:38 AM	5:06 AM			
	Articulated	shift-1	7:00 AM	7:26 AM	7:52 AM	8:20 AM	8:46 AM	9:12 AM	9:40 AM	10:06 AM	10:32 AM	11:00 AM			
		shift-2	2:00 AM	2:26 AM	2:52 AM	3:20 AM	3:20 AM	3:46 AM	4:12 AM	4:40 AM	5:06 AM	5:32 AM			
88			start	1	2	3	4								
	DAF or Rigid	shift-1	7:00 AM	8:07 AM	9:14 AM	10:20 AM	11:27 AM								
		shift-2	2:00 AM	3:07 AM	4:14 AM	5:20 AM	6:27 AM								
	Articulated	shift-1	7:00 AM	8:07 AM	9:14 AM	10:20 AM	11:27 AM								
		shift-2	2:00 AM	3:07 AM	4:14 AM	5:20 AM	6:27 AM								

APPENDIX-V

Interview Questionnaire for Aneesa City Bus Service Enterprise (ACBE)

The purpose of this survey is to **analysis and optimization of passenger waiting time; in case Ambessa city bus** for transporting people to and from work. In public transport passenger demand and public transport enterprise interests are a pair of contradictions, that is, the interests of the enterprise are sacrificed if the demands of passengers are to be met, and not providing enough service capacity causes the waiting time to become excessively long. To compromise this two contradict interests, the ultimate goal is to optimize the passengers waiting time based on the passengers' dynamic demand and the constraints of the supply service.

Costs, **operational constancy**, and employee satisfaction are typical objectives in optimization problems in public transportation. These criteria are traditionally simply merged into a single objective. So thank you for your cooperation with me by answering and supporting with your company's data associated with the following interviews.

1. Formal interview questionnaire
    1.1. What are the objective of your organizations?
    1.2. To achieve your objective what are the level of your capacity (number of buses)?
    1.3. How do you assign thes buses to each routes?
    1.4. What are the basic criteria to assign the buses to each route?
    1.5. Do you think your customers are satisfied with your current bus assignment system?
    1.6. If your answer question no. 1.5 is no what are the main challenges that makes your enterprise un satisfy your customers?
    1.7. How do you control the transportation system of your enterprise whether they are fulfilling or not their responsibility?
    1.8. How do you evaluate your customer satisfaction?
    1.9. If there is some additional information ...

    Thank you for your cooperation!