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Addis Ababa Institute Of Technology School Of Civil And
Environmental Engineering

Assessment of Improvement Areas for Optimizing the
Capacity of Addis Ababa LRT

By

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Abstract

Recently, railway traffic has increased considerably in the different parts of the world; moreover, it is expected that railway transportation will further grow for both passenger and freight transportation. These developments create needs to optimize both the utilization of the infrastructure and the coordination tasks inside the railway company.

Investments in railway infrastructure are expensive and already constructed railway infrastructure is not easily adjusted or changed. Dimensioning and constructing railway lines and networks therefore require extensive knowledge of future operation and demand. As the experience shows that the traffic often develops differently than expected. This means that railway infrastructure has to be designed flexibility, for different operational conditions.

There are many approaches that are used to model and implement the evaluation of railway capacity. In this thesis reviewing previous relevant literature and available data, analytical method UIC 405 is being used. This method tries to calculate the theoretical capacity in order to evaluate the railway line capacity and from that practical capacity has been determined.

First step for railway planning is to determine the demand passenger. To analyze the passenger demand and the number of train needed, a modal split is used to forecast the demand. The developed models are applicable to passengers railway network like Addis Ababa LRT.

Based on the different analysis made for both on North-South and East-West LRT route, the results show that 34 trains has to be operate for both routes which can respond and satisfy the passenger demand for the current year. Thus the Ethiopian Railway Corporation (ERC) to revise the railway planning by considering the growth population and increase the number of trains.

Key word: railway capacity, analytical method, UIC 405

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NOMENCLATURE

LRT: light rail transit

AA LRT: Addis Ababa Light rail transit

UIC: The International Union of Railways

CN: Canadian National

ERC: Ethiopian Railways Corporation

E-W: East- West

N-S: North- South

AREMA: American Railway Engineering and Maintenance of way Association

C: capacity of the line

T: period

T_{fm}: average of minimum train headways

tr: running time margin

T_{zu} : addition time

H_{min}: Minimum headway (minutes)

t: Minutes to travel between sidings

N: Number of directions run on a single track

C_p: Practical line segment capacity

C_t : Theoretical line segment capacity

H_n: Maximum gross headway in N directions.

E: Dispatching efficiency for line segment

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CHAPTER ONE: INTRODUCTION

1.1: Background

Railway is an attractive mode of transportation with a wide range of applications. It is used to provide high capacity local transportation of passengers in large cities and to connect cities by comfortable high speed services offering short travel times from city centre to city centre, and so on. Nowadays, given the growing pressure from the public transportation, it can be noted that improving railway capacity is significant to meet requirements of different customers.

The current population in Ethiopia is 103,998,005 in 2017, based on the latest United Nations estimates. Ethiopia is currently one of the fastest growing countries in the world, with a growth rate of 3.02%, the population of Addis Ababa was 3, 86 million which accounted for 32.27% of the total urban of population of the country. Addis Ababa's fast growth and to enable the transport sector to play its required role and to effectively solve the problem of urban transportation, especially that of the downtown area, the government of Ethiopia decides to build a light rail in the city of Addis Ababa. Currently this project has planned two lines, the east-west line and the south-north line. About 2.86 km is the shared section, which has the greatest passenger flow. The demand for railway transportation is steadily increasing around the world like Addis Ababa. The increase in demand generates increase in traffic load.

With the increase in travel demand and traffic management problems, travel demand forecasting models are being employed increasingly to make informed decisions about the operational improvements to the existing transportation system (Hannibal Bwire, 2008). For that assessing and optimizing the capacity of railway are of primary importance.

Therefore study about the analysis of railway capacity is indispensable to make the city transportation system modern and efficient. But analyzing and describing the railway capacity transportation involves several complex systems, e.g. railway infrastructure, rolling stock, timetable and human behaviour. Some of the factors influencing capacity are: number of tracks connecting the stations, station track layout, signalling system, train performance, speed difference between train services, market demand, reliability and delay acceptance of railway customers.

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1.2. Statement of the Problem

In Addis Ababa the transport demand is more than the transport supply can handle because of the fact that population growth is faster than that of transport facility. Thus long waiting for long time in every station especially at peak hours are becoming affects working time. This shows that the actual available 15 trains per day (ERC) might not be enough for the LRT passenger. So deploying train transport system without efficiently upgraded the railway network; the problem may not be solved. So that the transportation planning should be done first and it is achieved by estimating the current and future possible passenger demand.

Therefore it is important doing on the analysis for the railway capacity in Addis Ababa light rail transit to identify the problem. But the most common problems for railway capacity that can be studied in this thesis are the operation and infrastructure conditions.

An efficient utilization of the existing railway infrastructure is an essential component of a high quality transportation system and has become a central task for management of railway infrastructure. Hence, this thesis attempts to figure out the optimized way of capacity utilization approach at AALRT.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is to assess and analyze the capacity utilization at AA LRT and to provide an optimized capacity improvement approach.

1.3.2 Specific Objectives

- ✓ To investigate an appropriate analytical method to calculate the theoretical capacity in this line.
- ✓ To identify the sub city closest to the LRT routes.
- ✓ To determine and then forecast the passenger demand for current and next years.
- ✓ Analyzing and calculating operation capacities in order to improve the performance of railway
- ✓ To assess the impact of changes to the railway network more quickly.

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1.4: Research of Methodology

1.4.1 Analytical method

In this research analytical method is applying because they are a good starting point to identify bottlenecks, improve railway capacity and can give a good result. They are often used to find optimal or near-optimal solutions to given problems. Analytical methods are often mathematically demanding, but do not require much input.

The analytical computation is usually performed to obtain a first indication on the railway capacity in a preliminary state. They are designed to model the railway environment by means of mathematical formulae or algebraic expression. However, analytical results vary from one method to another depending on what type of parameters they model. Furthermore, analytical models are very sensitive to parameter input and train mix variation.

They can be conducted without software developed for railroad applications, such as Microsoft Excel, but there is also analytical capacity tools specifically developed for rail applications. Figure 1.1 presents the different levels of analytical approach and how complexity can be added to the process to provide more detailed results.

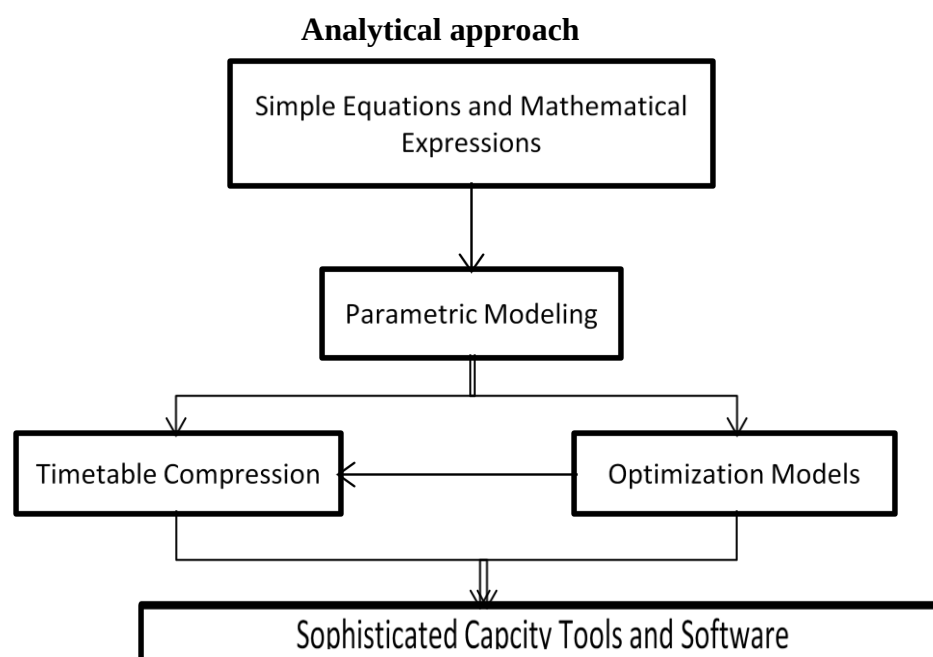


Figure 1.1: Levels of analytical approaches for capacity analysis

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1.5 Research Questions

As the purpose of this study is to improve the area and optimize the capacity of Addis Ababa LRT, these following questions will be answered throughout this thesis.

- How does the LRT use the available capacity?
- What are the possible capacity improvement methods that are more sensible to AA LRT Case?

1.6 Scope of the research

This study concerns railway operation in Ethiopia, focusing on passengers in Addis Ababa railway transportation. The initial phase of the project is 34 km length and expected to extend up to 74 km length in the long term plan. It consists two main line which is East-west line from Ayat to Torhailoch with 16.68 km length and north-south line from Menilik II square to Kality which extend to 19.01.

The researches mainly focus on providing railway capacity analysis. The scopes and tasks of this work are described as follows.

- A survey of method to evaluate railway capacity
- To perform an analytical and empirical capacity analysis
- Analyze the effect of different parameter on railway capacity

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1.7 Study area

The area on the figure is the first railway built in the capital of Ethiopia, Addis Ababa. The green line indicates the East - West and the blue one the North - South. So this research tries to study and improve the performance of the railway capacity.

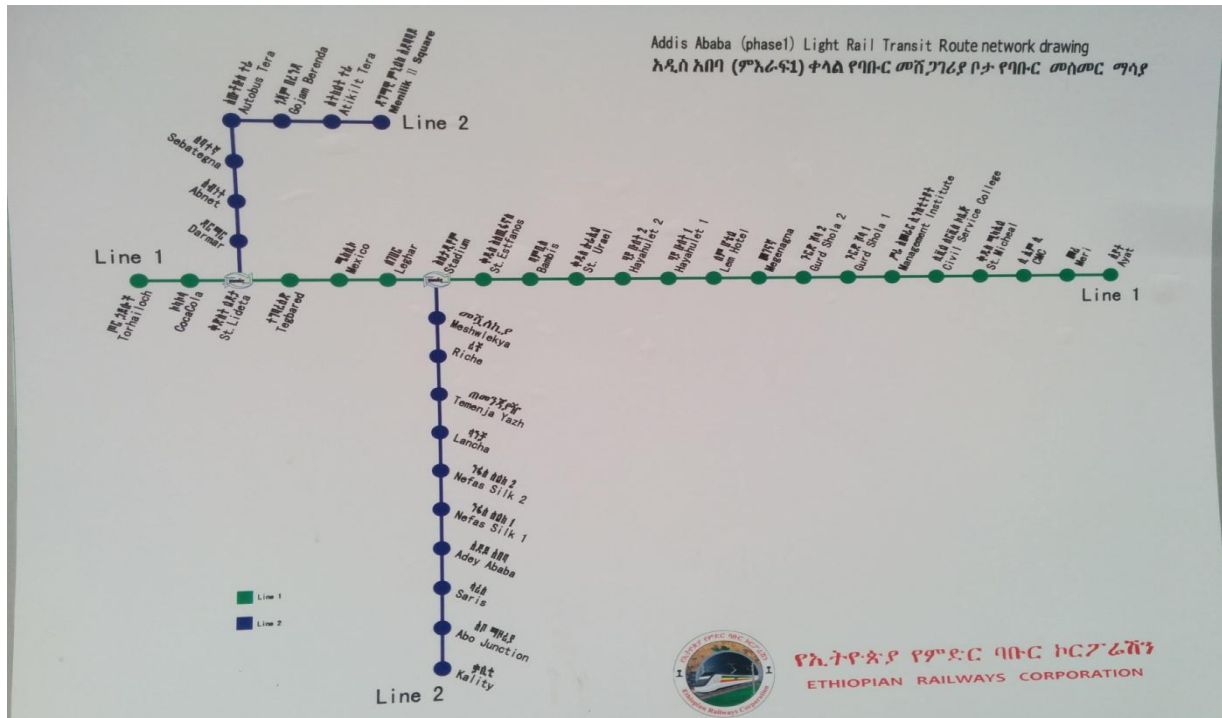


Figure 1.2: Addis Ababa Light Rail Transit system network along both corridors (ERC)

1.8. Organization of the thesis

This thesis presents its work in five chapters

- Chapter one contains the introduction and background of the thesis, statement of the problem, objective, methodology and scope.
- Chapter two includes the literature review and mainly focuses on the overview regarding railway capacity Evaluation. It also includes the definitions and main parameters affecting railway capacity, followed by a presentation of evaluation methods for the railway capacity.
- Chapter three presents the methodology of the study.
- Chapter four establishes the data collection, presentation and analysis.
- Chapter five includes the discussion, conclusion and recommendation based on the findings either for further research or for considerations for making the results more acceptable and understandable.

CHAPTER TWO: LITTERATURE REVIEW

2.1 Introduction

In order to provide a reliable railway transportation service, optimizing the railway capacity should be taken at the right time. Hence, it is necessary to carry out analysis to set a higher stability of capacity.

In (Abril M, et al , 2008) the authors classify three separated methodologies, but in some way complementary, for carrying out capacity assessment, distinguishing them in analytical, optimization and simulation methods. The article (Kontaxi E., Ricci S, 2009) goes into depth giving a wide overview of different techniques developed along years for capacity evaluation, making comparisons among them, underlying advantages and drawback of their applications. Furthermore, both sources introduced to the complexity of a railway system. They explain how capacity is close dependent by several factors that are often interconnected defining such complexity. Specifically those elements are classified into infrastructure, traffic and operational factors. Moreover in (Abril M, et al , 2008), authors studied in several Spanish railway lines how capacity is affected by train speed, commercial stops, train heterogeneity, block length and timetable robustness.

By different researchers, the term capacity has numerous meanings and for which numerous definitions have been given will be listed, the several factors affecting railway capacity had been identified and also method to optimize the stability of railway capacity had been developed. These will be seen in the next subtopics.

2.2. Definition

Capacity in a general sense is the “capability to perform or produce” (Barber, F et al., 2007). This is relevant, albeit imprecise. In the context of railway transportation, the capacity of a railway is often used to mean the number of trains that can travel over a given section of line during a given period of time. When referring to a rail context, it can be described as follows:

The International Union of Railways’ (UIC) Code 406 *Capacity*, which aims to establish a harmonised understanding of and to enable calculations of available railway infrastructure

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capacity, defines the capacity of any railway infrastructure as “the total number of possible paths in a defined time window. Since the railway capacity is a dynamic concept influenced by several factors, in UIC Code 406 (Cai, X., Goh, C., 1994) is written:

“Capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilised.”

Other recent analyses of the railway capacity concept include those by Landex and Abril.

Abril et al. similarly define theoretical capacity as “the number of trains that could run over a route, during a specific time interval, in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum headway” (Cai, X., Goh, C., 1994). From this definition of theoretical capacity, Abril et al. derive practical capacity, used capacity and available capacity.

Thus it can be seen in a number of European sources that railway capacity is commonly defined as the number of trains in a given period and as a function of various traffic parameters.

In North America, in a review by the Canadian Transport Commission of the state of the art in defining and measuring railway capacity, Khan defines capacity at the corporate level as “the ability of the carrier to supply as required the necessary services within acceptable service levels and costs so as to meet the present and projected demand” i.e. a relationship between capacity, quality and cost.

Krueger of Canadian National (CN) describes capacity in general terms: “Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan. This could mean anything from the number of tons moved, speed of trains, on-time performance, available track maintenance time, service reliability, or maximum number of trains per day that the subdivision can handle”.

For the purpose of the study, capacity is understood as the maximum number of trains that can be operated in a railway line or section, given the railway infrastructure, the timetable and the operation performance goals. This is usually called the **Practical Capacity**, since it is a realistic measure of railway capacity, with realistic assumptions regarding the train mix

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(different average speeds) and the expected operating quality. In railways it is also common to distinguish Theoretical Capacity, Used Capacity and Available Capacity. **Theoretical Capacity** gives an upper limit on the maximum number of trains, if operated in ideal conditions. The **Used Capacity** is the traffic volume that runs on a railway line or section. Finally, the **Available Capacity or Unused Capacity** is the difference between Practical Capacity and Used Capacity. Since not all Available Capacity can be used for additional train paths due to heterogeneity of trains, the Available Capacity is composed by a **Useful Capacity**, if new train paths can be added, and **Lost Capacity**, otherwise (Abril et al. 2007).

2.3. Review of parameters affecting railway capacity

Railway capacity is not static. It is extremely dependent on how it is used. The physical and dynamic variability of train characteristics makes capacity dependent on the particular mix of trains and the order in which they run on the line. Furthermore, it varies with changes in infrastructure and operating conditions. These are some of the fundamental factors that affect it:

2.3.1. Infrastructure parameters:

Block and signaling system: The signals help extend the train driver's visibility, so it allows greater speeds. The role of signalling is to keep trains at a safe distance. There are two types of systems: fixed and moving block signaling. In a fixed block signaling system, the position of each train is known only by the block section(s) that it occupies. The separation between trains is maintained by imposing the restriction that each block section be occupied by at most one train at a time. Block section lengths, train speeds, and train lengths are, therefore, important parameters. In a moving block signalling system, which is a modern technology, the position of each train is known continuously, thus permitting better regulation of the relative distances. This requires an efficient communication system between line signals, cabs, and control centers. In addition, speeds that can be achieved by trains can be limited in practical situations by different factors other than track geometry and signalling, such as catenary or power traction constraints.

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Single/double tracks: This has a major impact on capacity. It is not as simple as multiplying the number of tracks: two tracks usually have around four times more capacity than a single track; however, a four track line rarely increases capacity by more than 50% over a double line (Kittelson and Associates, 2003). Furthermore, adding a second track may not eliminate the problem because the station is the real bottleneck. Auxiliary tracks at crossing stations also increase the capacity of a single track because they allow trains to carry out crossings and over takings.

Definition of lines, routes: In assessing the line capacity, the railway line itself must be defined, namely the list of stations and halts along the line and their characteristics. The line capacity should develop into a network capacity problem as soon as other parallel routes are available to provide the same kind of services. This is specifically the case of freight transport on some main international corridors. In this case, the total capacity can be estimated by summing up the contribution of independent lines and finding alternate route sections to overcome bottleneck problems that are detected on the main line.

Track structure and speed limits: The condition of the rails, ties, and ballast dictate the weight and type of equipment that can be used on the line, as well as the speeds allowed on the line. They have an important influence on the capacity. The speed limits are regulated by means of speed profiles, which take into account physics, safety, comfort, train types, etc.

Network effects: A single line cannot be considered as a fully independent part of the whole network due to crossing and overlapping lines, which can be true bottlenecks. As a consequence, the capacity of a line cannot be defined without considering what happens on the interfering lines.

2.3.2: Traffic parameters

New or existing lines: The solution is generally different when new (i.e., to be designed) or current (i.e. available) lines are considered. In the second case, which is by far the most common, several constraints are already set, and the traffic to be accommodated often becomes an available capacity problem, which is more constrained.

Train mix: Railway capacity is very much dependent on traffic mix. The ideal case is when all trains are the same or have the same speed. As the mixture of different trains increases,

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more interferences are generated. Thus, trains require over takings and crossings, and the mixture reduces the traffic flow. Besides maximum speed, other rolling stock characteristics such as acceleration and deceleration are also important.

Regular timetables: A specific target of the line planning and train scheduling problems is the construction of periodic timetables, which means train services of the same class departing at fixed intervals. It often represents a strong commercial constraint for train scheduling.

Traffic peaking factor: It is a measure of concentration of traffic within a short time frame. It has a significant impact on capacity because it can result in traffic levels that are higher than the network could reliably sustain. When this occurs, the effects are felt for considerable time periods into the future as the system recovers from the overload.

Priority: The priorities of trains play a vital role. Train priorities decrease capacity because priority trains are given preferential treatment over lower priority trains, which results in increased delays. This basically allows the priority traffic to move as if it were the only traffic in the network. As a rule, the greater the number of priority classes, the less capacity is available.

2.3.3. Operating parameters

Track interruptions: These can be planned events (maintenance times, commercial stops, etc.) and unplanned events (train failures, broken rails, etc.) that take a track out of service. These interruptions affect the capacity of a line because they directly reduce the number of hours available in the day to move trains. Track outages usually occur due to maintenance, which is scheduled to minimize train impact; however, it can also be attributed to infrastructure and train failures such as broken rails, accidents, etc.

Train stop time: This parameter accounts for the amount of time trains spend stopped on a line. It is a delay that directly increases the amount of time a train takes to traverse a subdivision.

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Maximum trip time threshold: This parameter represents the upper limit of acceptable trip time. It affects capacity because it restricts the number and/or length of the train stops.

Time window: The interval or unit of time that is taken as a reference for computing the desired line capacity should be defined. Traditionally, this is set either to one hour or to the whole working day.

2.4. An overview of railway transportation

Railway transportation is a public mode of transportation which is mainly characterized by steel wheels that run on steel rails. Early uses of this concept were found in mines which later on evolved for the transportation of passenger and freight. Table 1 summarises the main strengths and weaknesses of railway transportation.

Major turning points in the early development of railways were the invention of the edge rail by William Jessop in 1789 and the building of the first steam locomotive by Richard Trevithick in 1804 (Westwood, j, 2009). The first public steam-operated railway opened for Traffic on 27 September 1825 between Darlington and Stockton (Rangwala, 1998). Since then, railways have spread all around the world as an energy-efficient and sustainable mode of transportation.

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Table 2.1: Railway transportation: Strengths and weaknesses

	Item	Main reasons
Strengths	Safety	Restriction in movement to just one axis - Very controlled
	Energy efficiency	Low friction due to steel wheels running on steel rail - Higher passenger/freight km per kilo equivalent of petrol
	Environment friendly	Low CO ₂ emissions due to higher passenger/freight km per kilo equivalent of petrol – Low friction and adhesion
	Load handling	Enormous traction power and energy efficiency
	Less land use	High carrying capacity per square metre of infrastructure
Weaknesses	Not door-to-door	Not practical
	Capital intensive industry	Rolling stock, signalling and infrastructure are expensive.
	Extreme dependency on the infrastructure	Trains can only go where the rails go and only have one degree of freedom for movement along the rails.
	Long braking distance	Low friction due to steel wheels running on steel rails
	Noise	Steel wheels running on steel rails

2.5. Railway capacity challenge

Many railways have witnessed huge growth in passenger and freight demand over the last decade. Road congestion, higher fuel costs, rising incomes, privatisation of railways along with concern for sustainability of transport have resulted in enormous growth in rail passenger and freight in the last decade. Growth in railway demand is one side of the coin; the other side of the coin is limited railway infrastructure. Many railways around the world are facing a challenge to accommodate necessary train services on their infrastructure (Association of Train Operating Companies, 2008). Although in some cases double, triple or quadruple tracks have been built, the capacity of infrastructure in total has not increased proportionately to keep up with the pace of demand. Therefore, a so-called “railway capacity challenge” has emerged which is schematically depicted in Figure 2.1.

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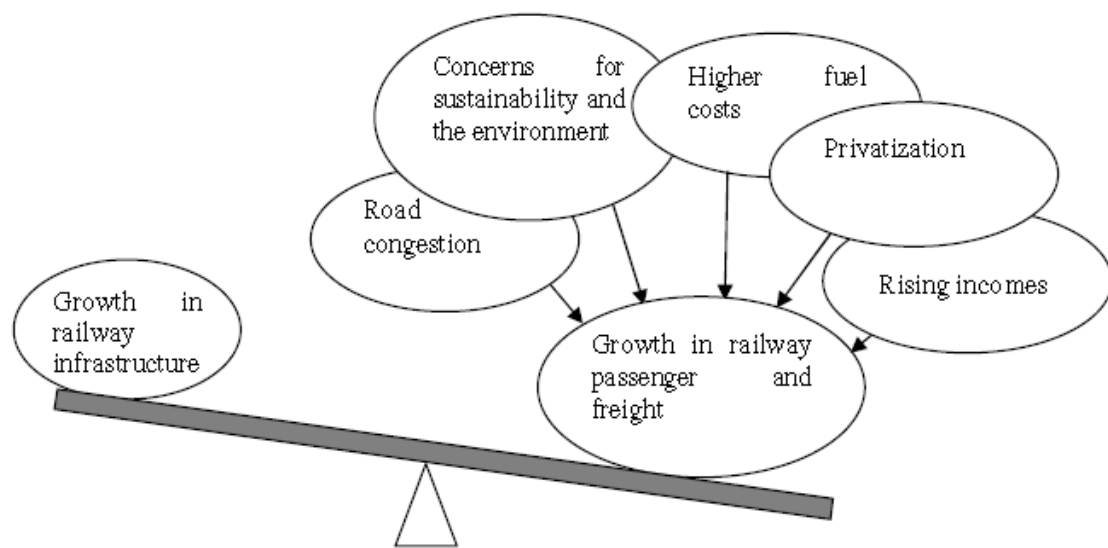


Figure 2.1: The scale of railway capacity challenge

2.6. Transportation in Ethiopia.

In Ethiopia, the dominant mode of transport is road transport, having a share of 90% in transporting passenger and cargo transports across the country. And, that has been the focal point of the government for the last two decades and continues to be so. The activities undertaken over the last 16 years in the sector enabled the country to raise the road coverage to 70%. The total length of road in the country has reached over 86,000kms due to the enormous investment and commitment of the EPRDF led government (Geological Map of Ethiopia(2nd edition)), (Ethiopian Herald., 10 March 2013.). In the past years Ethiopia invested more than 142 billion birr in the road sector. However, despite what the detractors routinely claim, the main source was not foreign donation. Of the entire total amount spent, 77 percent was by the government. One of the major works in that regard is the two roads linking the Addis Ababa-Adama Expressway with Addis Ababa City into two directions.

The 28.1-km roads Addis Ababa-Adama Expressway is being constructed at a cost of more than 4.2 billion birr allocated by the government of Ethiopia and loan obtained from Chinese EXIM bank. Another major example is the construction and renovation of 1,700-kms roads carried out in the Benshangul -Gumuz State with over 172 million birr in the last twelve

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months. Now, as result of the works, the once marginalized regions now have 3,000-kms roads.

Similarly, the capital city Addis Ababa, which has long been horrible in its roads network, has seen a major leap unprecedented in her recent history. Addis Ababa has constructed more than 1,219- kms road in the last five years with more than 10 billion birr budget. Now, Addis Ababa's road coverage has reached 15.64 per cent raising the network to 4,148-kms of which 2002- kms is asphalt, 727-kms cobblestone and the remaining 1,419- kms is gravel. In the processes, the city created jobs for more than 50,000 youths and women in cobblestone road construction. The same can be said with regard to other sectors of the transport industry.

To effectively solve such urban transportation problems especially that of the Downtown area, the government of Ethiopia started to build a Light Rail Transit in the city of Addis Ababa which is more energy-efficient and environment-friendly means of transport (Commission of the European Communities, 2007). (Ethiopian Railways Corporation (ERC) has the mandate to carry out the project; the project has planned two lines, the East-West line and the North-South line. About 2.8 km is the shared section, which has the greatest passenger flow.

During the feasibility study the Ethiopian Railways Corporation carried out the assessment and also performed the passengers flow forecast based on the number of existing transportation facilities in both routes as follows. Based on the passenger transport survey the passenger flow of Line North-South and East-West in Addis Ababa LRT is forecasted as 536,935 and 734,393 persons/day respectively. This is discussed in the following tables in detail.

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Table 2.2: The ERC Passenger Flow Survey about N-S Route (CHINA RAILWAY GROUP LIMITED, 2009)

Type of transportation	Number of vehicles	stations for short stations	Daily passenger (person/day)
Mini Bus	1160	26	299,92
Meduim Bus	72	8	69,264
Large Bus	–	30	62,503
Auxiliary meduim Bus	39	11	28,08
Auxiliary large Bus	91	26	77,168
Total	1,362	101	536,935

And similarly for the east to west route ERC has estimated as follows.

Table 2.3: The ERC Passenger Flow Survey about E-W Route

Type of transportation	Number of vehicles	stations for short stations	Daily passenger (person/day)
Mini Bus	1160	17	216,64
Meduim Bus	267	27	256,854
Large Bus	–	31	34,803
Auxiliary meduim Bus	188	32	135,36
Auxiliary large Bus	107	28	90,736
Total	1,722	135	734,393

2.7. Methods to evaluate railway capacity

Numerous approaches have been developed to evaluate railway capacity. The most relevant methods can be classified in three levels: Analytical Methods, Optimization Methods, and Simulation Methods.

2.7.1 Analytical methods

The **analytical methods** are the simplest methods for determining railway capacity. They usually obtain Theoretical Capacity through algebraic expressions, while Practical Capacity is obtained as a percentage of the Theoretical Capacity. Although the analytical methods are a good starting point to identify bottlenecks, the results are extremely dependent on the used method since different variables are taken into account (Abril et al, 2008).

Until 2004, the International Union of Railway, more generally known as the UIC leaflet 405 of 1983 (revised in 1996) (UIC Leaflet 405, 1996) method was recognized as the standard method to evaluate railway capacity, and it takes into account the number and order of trains. The main criticism is that it does not establish a link between capacity and railway performance quality (Abril et al, 2008).

More recently (Burdett, R.L., Kozan, E., 2006) developed other approaches to evaluate theoretical capacity (they call it “absolute capacity”), which incorporate several factors, such as the mix of trains, the signal locations and dwell times.

A review of analytical methods is presented by (Abril et al, 2008) and it can be seen that several authors have formulated analytical methodologies with the incorporation of different parameters. Those methodologies are very raw simplifications of reality, and therefore should only be used for preliminary solutions.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

2.7.2 Optimization methods

The **optimization methods** use mathematical programming techniques to obtain better solutions to the capacity problem than the analytical methods. A widely used method is saturation, which obtains capacity by scheduling the maximum number of train paths, starting either from an empty or an initial base timetable (Abril et al, 2008).

(Abril et al, 2008) considers the UIC 406 methodology as an optimization method. This is the most largely international accepted methodology which obtains railway capacity through timetable compaction and saturation. They present a review of optimization methods where several mathematical programming techniques are used. For instance, capacity problem can be modeled as a Job-Shop Scheduling Problem. Other authors like Carey and Lockwood, 1995 use heuristics, such as algorithms to assign trains to the timetable in order to find an optimal allocation to maximize capacity, whereas others Higgins et al. (1996) use local search, tabu search, genetic or hybrid heuristics, to find feasible solutions to the capacity problem. (Landex, A., 2008) describes a detailed application of the UIC method in the Danish railway network.

2.7.3. Simulation Method

Simulation Methods are reproductions of the real world operations that are used to test solutions (Abril et al, 2008). There are several available commercial simulation tools that simulate rail traffic with different inputs and outputs data. (Abril et al, 2008) presents the main features of the following simulation tools:

- DEMIURGE is the software used by SNCF, and it has capabilities to evaluate a network's capacity to absorb additional traffic, to locate bottlenecks, to calculate Unused Capacity of a timetable and to assist decision makers in future infrastructure investments.
- CMS from AEA Technology Rail is a system to plan railway Used Capacity through an automatic generation of timetables, which provides an easy scenario analysis.
- RAILCAP from Stratec gives an evaluation of the Used Capacity by a given timetable.

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- VIRIATO from SMA and Partners is a tool mainly used for the development of future service concepts and gives the saturation rate of a railway section by compressing a given timetable
- CAPRES developed by Lucchini and Curchod in 2001 is a model for the elaboration and saturation of timetables, and determines all the available train paths.
- FASTTRACK II is software developed by Multimodal Applied Systems and it is used to determine the feasibility of a timetable given a track configuration, measuring both the Theoretical Capacity and Practical Capacity.
- MULTIRAIL is another software developed by Multimodal Applied Systems which traces train path Conflicts in detailed graphical and tabular formats.
- OPENTRACK is software developed by OpenTrack Railway Technology used to answer questions about railway operations through the simulation of train movements under the constraints of the signaling system and timetable. It also handles simulation where random generators produce different initial delays and station delays.
- SIMONE is a simulation model developed by Incontrol Enterprise Dynamics designed to determine the robustness of a timetable, to identify bottlenecks and to analyze the causes and effects of delays.

(Kontaxi, E. & Ricci, S., 2010) present a comparative analysis concerning the functionality of 37 simulation tools. From this analysis the most fitted software to perform capacity analysis are CMS, DEMIURGE, IRCIM, MOM MALLAS, RAILCAP and RAILSYS, since they have the possibility to evaluate directly the Theoretical Capacity, Practical Capacity, Used Capacity and Available Capacity. CAPRES tool, which can determine Theoretical Capacity and Available Capacity, FAST TRACK II and RAILSIM tool, which can determine Theoretical Capacity and Practical Capacity are also presented as tools capable to perform capacity evaluations.

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Finally, (Kontaxi, E. & Ricci, S., 2010) present CASSANDRA, OPENTIMETABLE and SAMFOST tools as capable to determine Theoretical Capacity, RAILNET II and RAILSIM tools as able to determine Available Capacity, RASIM and SIMONE as able to determine Used Capacity. It is also to be noted that (Kontaxi, E. & Ricci, S., 2010) analysis was not able to determine the capacity evaluation ability in some simulation tools, such as OPENTRACK or MULTIRAIL.

In conclusion, although the application of analytical methods followed by optimization methods are good starting points for preliminary evaluations of railway capacity; a simulation method is needed to perform in depth capacity evaluations in railway networks.

2.8. Review of analytical methods

Among different approach to identify the railway capacity, Analytical methods has been chosen to realize this thesis because they model the railway infrastructure by means of mathematical expressions in a simple way that provides results of a first approximation. They also perform and use to support railway network capacity evaluation.

Analytical methods give a theoretical and practical operating trains result, which makes important for a preliminary railway capacity analysis.

It can be seen that several authors have formulated analytical methodologies with the incorporation of different parameters. Some of the methodologies will be listed below:

1. UIC leaflet 405

Twenty years ago the UIC proposed an analytical method (UIC 405, 1983), known as the UIC formula:

$$C = \frac{T}{t_{fm} + t_r + t_z} \dots\dots\dots (1)$$

Where,

C = capacity of the line (Number of trains operated in the time T)

T = period

T_{fm} = average of minimum train headways.

T_{zu} = addition time

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The UIC is the world-wide organisation for international cooperation among railways and its purpose is the standardisation and improvement of conditions for railway construction and operations. Its best-practice documents are recognized as world-wide standards and have been adopted by many countries. UIC 405 gives an explicit explanation of the relevant parameters based on a timetable. This method was officially dropped as a standard on capacity some years ago, but it lets an efficient estimation of the capacity of a line and it can be used as a reference measure and for identifying bottleneck.

This method can be appropriate to the AALRT because the UIC (1983) (Corrier F, 1982) determines the capacity by referring to the most critical section; through the introduction of an additional time, depending on the number of block sections and an increased margin ,the method considers the actual level of service. The critical section refers in this case of the common stations between the two routes (from Staduim to lidheta). A new UIC formulation (1996) allows relating capacity and quality of service.

2. Poole formula

Some simple theoretical formulae can estimate the maximum number of trains for a line without timetable. The most basic and earliest (practical) railway capacity formula was developed by (Poole, C, 1962) for the ideal capacity where traffic is totally homogeneous:

$$N = \frac{1440}{Hmin} \dots\dots\dots (2)$$

Which he later developed this formula further.

$$C = \frac{1440}{2t + \frac{t}{2} + m} \times 2 \dots\dots\dots (3)$$

Where;

C = Capacity in trains per day

1440 = Number of minutes per 24 hours

t = Minutes to travel between sidings

t/2 =Average dwell time waiting for opposing train to arrive

m = Delay for each meet due to braking, entering the siding, running the length of the siding, leaving the siding and accelerating to speed

2 = number of trains per pair

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- ➡ It should be noted that this measure has very limited practicality as not all the minutes of a day can be used for running trains. However, it can provide some clues about theoretically maximum possible trains.
- ➡ (Poole, C, 1962) Approximated the meet interaction at siding to create a proxy for headway. He developed a simple formula that accounted for the time required for pairs of trains in opposing directions to alternative their use of the single track section. And this equation Poole might be suitable for Addis Ababa LRT.

But this model becomes more inaccurate if traffic demand is non-uniform or there is a directional bias to the traffic that changes over times.

3. AREMA

The American Railway Engineering and Maintenance of way Association (AREMA, 1998) presents capacity equations in the manual for Railway Engineering. The AREMA equation of the theoretical capacity of a line segment is:

$$C = \frac{T \times N}{Hn} \dots\dots\dots (4)$$

T = Number of time units in the period for which capacity is being calculated.

N = Number of directions run on a single track

Hn = Maximum gross headway in N directions.

The idealized conditions assumed for the estimation of theoretical capacity is realistically not possible for any actual scenario. Practical capacity is a more sensible measurement of the number of trains that can actually move through a track with an acceptable amount of delay, level of service, and reliability. According to AREMA, practical rail-line capacity for freight operation can be expressed as:

$$C_p = C_t \times E \dots\dots\dots (5)$$

C_p = Practical line segment capacity

C_t = Theoretical line segment capacity

E = Dispatching efficiency for line segment

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The dispatching efficiency depends on a) type of signal, b) type of traffic, c) class of line, and d) terrain. A study by (Kraft, E.R., 1982) states that practical capacity is 60-75% of theoretical capacity.

Addis Ababa Light Rail Transit is a system for only passenger traffic and run with a double track along the routes. But this method is suitable for the track run on a single track and the service of the train run is freight operation. For that this method cannot be appropriate in AALRT.

2.9. Conclusion

From the reviewed made above, we have observed the several factors affecting railway capacity transportation and the methods developed to analyze railway capacity. From the various approaches, the UIC leaflet 405 and Poole methods will be analysed to determine which one is more suitable for Addis Ababa Light Rail Transit.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1: Introduction

The case study of this thesis is “Addis Ababa Light Rail Transit” and the study mainly concerned on the analysis and optimizing of Addis Ababa light Rail transit capacity; for the two main routes from Torhailoch to Ayat and Minilik II square to Kality. To make Analysis and to achieve the stated objectives, the proposed methodology above is used to evaluate theoretical capacity of railway but, thanks to its generalization, may be applied to whatever rail infrastructure.

3.2 Data Collection

To describe the situation, the attempt is made in identifying and collecting extensive data from various sources. These are the following.

a. Collecting necessary data from literatures:

The data collecting have been gathered from the review made in the literature review section such as:

- Population Distribution in Addis Ababa (Source statics Authority)
- The Addis Ababa City Population Distribution by Sub Cities
- Modal Split travel demand.

b. Data collection from Addis Ababa LRT Project:

The data for analysis were taken from Ethiopian Railway Corporation (ERC) for the case of Addis Ababa light Rail Transit project regarding the initial phase of the project. The Addis Ababa LRT's network consisting of two routes were identified with their design (CHINA RAILWAY GROUP LIMITED, 2009) and actual data which are:

❖ Design data

- The LRT of Addis Ababa city has a railway network which has two routes. These routes are the East– West line (the route from Ayat to Torhailoch) and the North – South line (the route from St. George church/Minelik II Square to Kality) as depicted in the figure with the red color for initial stage of infrastructure

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construction. Each route has double line. Within a section of 2.8 kilometers the two routes share the same track (from stadium to Lideta Light)...

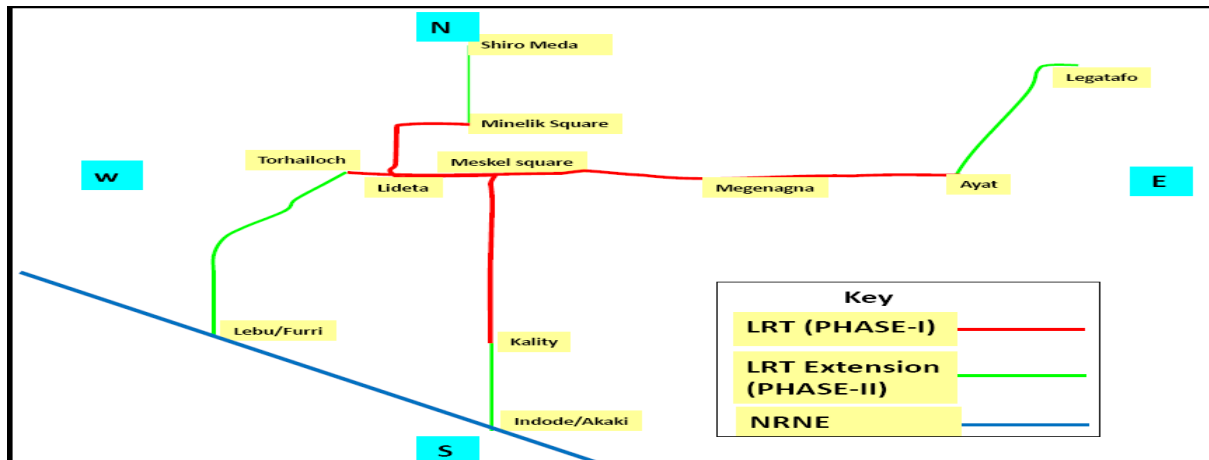


Figure 3.1: Addis Ababa City LRT alignment with extension

- The Addis Ababa LRT has 41 tram car units and out of these 21 is assigned for East-West corridor while the left 20 are assigned for North-South corridor. The tram car units will be assigned equally at the end four stations.
- With the average dwelling time of 30 seconds at each station.
- The maximum speed of the train is 80km/h and one of the tramcar is arranged to be operated with the capacity of 286 persons in one tramcar (with 64 seats and 6 standing person per m²).
- This operation will be continuing for 16 hours a day.
- The distribution of train for flat hour is 6 trains with 20minutes interval while for peak hour it consists 8 trains in 15minutes interval for the two lines.
- The vehicles for LRT are operated in two directions and have only one unit of coupled Tramcar marshalling. All are almost of the same performance/characteristics.
- Distance in EW line is 16.68 km and NS line is 17.4 km
- Average travelling speed is 18km/h

a. The East- West line has the following unique data

According to current social-economical situation, passenger flow, development tendency and integrated with population and employment current situation and development tendency along the line, as well as passenger flow documentations and other relevant study results, it is forecasted that the maximum unidirectional section passenger flow of Line E-W in peak hours

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will take place in the road section from Lideta Light to Leghar shared with Line N-S. The total unidirectional section passenger flows in initial stage is 38462 persons/day. The maximum passenger flow of initial stage is 5000 persons/hour.

➤ One-Day Unidirectional Passenger Flow: Persons/day is described in Table 3.1.

3.1: One –Day Unidirectional Passenger Flow in the East-West line.

Sections	Unidirectional Persons/day
Torhailoch~Lideta Light	15885
Lideta Light~Legehar	38462
Legehar~Adwa Square	19262
Adwa Square~CMC	7031
CMC~Ayat	5531

➤ Unidirectional Passenger Flow Forecast in Peak Hours Unit: Persons/h is shown in Table 3.2.

Table 3.2: Unidirectional Passenger Flow Forecast in Peak Hours in the E-W line

Sections	Unidirectional Persons/hr
Torhailoch~Lideta Light	2065
Lideta Light~Legehar	5000
Legehar~Adwa Square	2504
Adwa Square~CMC	914
CMC~Ayat	719

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Table 3.3: for all different indices of tramcar operation in E-W route.

Parameters		Values
Operation length (km)		17,4 km
Train marshalling		one unit
Rated number of person (person/tramcar)		286
Hourly traffic volume in peak hour pair/hour	sharing section for two directions	20
	Other section in this line	10
Minimum operating interval (minute)	sharing section for two directions	3
	Other section in this line	6
Transport capacity (1000 passengers/h)	sharing section for two directions	0.57
	Other section in this line	0.29
Train allocation	operating car	19
	spare tramcar and Maintenance tramcar	2
	Total	21

b. The North – South line has the following unique data

According to current social-economical situation, passenger flow, development tendency and integrated with population and employment current situation and development tendency along the line, as well as passenger flow documentations and other relevant study results, it is forecasted that the maximum passenger flow of Line N-S in peak hours will take place in the road section from Lideta Light to Leghar shared with Line E-W. The total unidirectional section passenger flow in initial stage, is 38462 persons/day. The maximum passenger flows of initial stage is 5000 persons/hour.

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- One-Day Unidirectional Passenger Flow: Persons/day has been presented in Table 3.4.

Table 3.4: One-Day Unidirectional Passenger Flow: Persons/day

Sections	Unidirectional Persons/day
Minelik II Square~Merkato	11623
Merkato~Lideta Light	13008
Lideta Light~Legehar	38462
Legehar~Goter	17708
Goter~Kality	16323

- Unidirectional Passenger Flow Forecast in Peak Hours Unit: Persons/h is given in Table 3.5.

Table 3.5: Unidirectional Passenger Flow Forecast in Peak Hours in the N-S line.

Sections	Unidirectional Persons/hr
Minelik II Square~Merkato	1511
Merkato~Lideta Light	1691
Lideta Light~Legehar	5000
Legehar~Goter	2302
Goter~Kality	2122

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- Operation Information of North - South Line is given in Table 3.6.

Table 3.6: Operation Information of North - South Line.

Parameters		Values
Operation length(km)		16.68 km
Train marshalling		one unit
Rated number of person (person/tramcar)		286
Hourly traffic volume in peak hour pair/hour	sharing section for two directions	20
	Other section in this line	10
Minimum operating interval (minute)	sharing section for two directions	3
	Other section in this line	6
Transport capacity (1000 passengers/h)	sharing section for two directions	5.7
	Other section in this line	2.9
Train allocation	operating car	18
	spare tramcar and Maintenance tramcar	2
	Total	20

❖ **Actual data**

Table 3.7: Technical data for Addis Ababa LRT

	Specification	Value
1	Service	passenger
2	trains allocation	41
4	Running time (min)	120
5	Operation hour per day (h)	16
6	Head way time (min)	15
7	Number of sections	21

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

3.3 Data Analysis procedure

The data gathered is organized and analyzed by ensuring the calculation of the Analytical method, for that the two necessary elements (t_{fm} and t_r) that have been analyzed will be stated in below and have been processed in a way that they can answer the problem of the research topic.

After collection of the necessary research data the analysis of the data and its interpretation will then follow.

3.3.1: Analytical method - UIC Leaflet 405

From the equation (1), in order to define the optimal capacity two main elements need to be calculating: the average minimum headway (t_{fm}) and the running time margin (t_r).

The exact calculation of t_{fm} takes into account the order of dispatch of trains belonging to different speed classes. The timetable is required to know the sequence cases where one train of type j follows one train of type i . The first version of the formula (UIC 405, 1983) required the exact number of sequence cases n_{ij} , while the revised version (UIC Leaflet 405, 1996) suggests a calculation of t_{fm} based only on the number of trains of each type, with a random approach for scheduling, using:

$$t_{fm} = \frac{\sum n_{ij} \times t_{fij}}{\sum n_{ij}} \dots\dots\dots(6)$$

Where

n_{ij} : Number of the cases of succession of trains;

t_{fij} : Durations of succession minimum of trains between two trains;

The UIC proposed two expressions for this extra time margin:

✓ $t_r = 0.67 \times t_{fm}$, when the desired utilization is 0.6

✓ $t_r = 0.33 \times t_{fm}$, when the desired utilization is 0.75

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

UIC specifies a guideline for standard values of infrastructure occupation time A in order to achieve a satisfying operating quality. These values are indicated as a function of the type of line and the infrastructure use.

Table 3.8: UIC's recommended values for infrastructure occupation.

Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	85%	70%
Dedicated high-speed line	75%	60%
Mixed traffic lines	75%	60%

Addis Ababa light rail transit is just dedicated suburban passenger traffic so the extra time margin will be in a daily period of 70% from the table.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

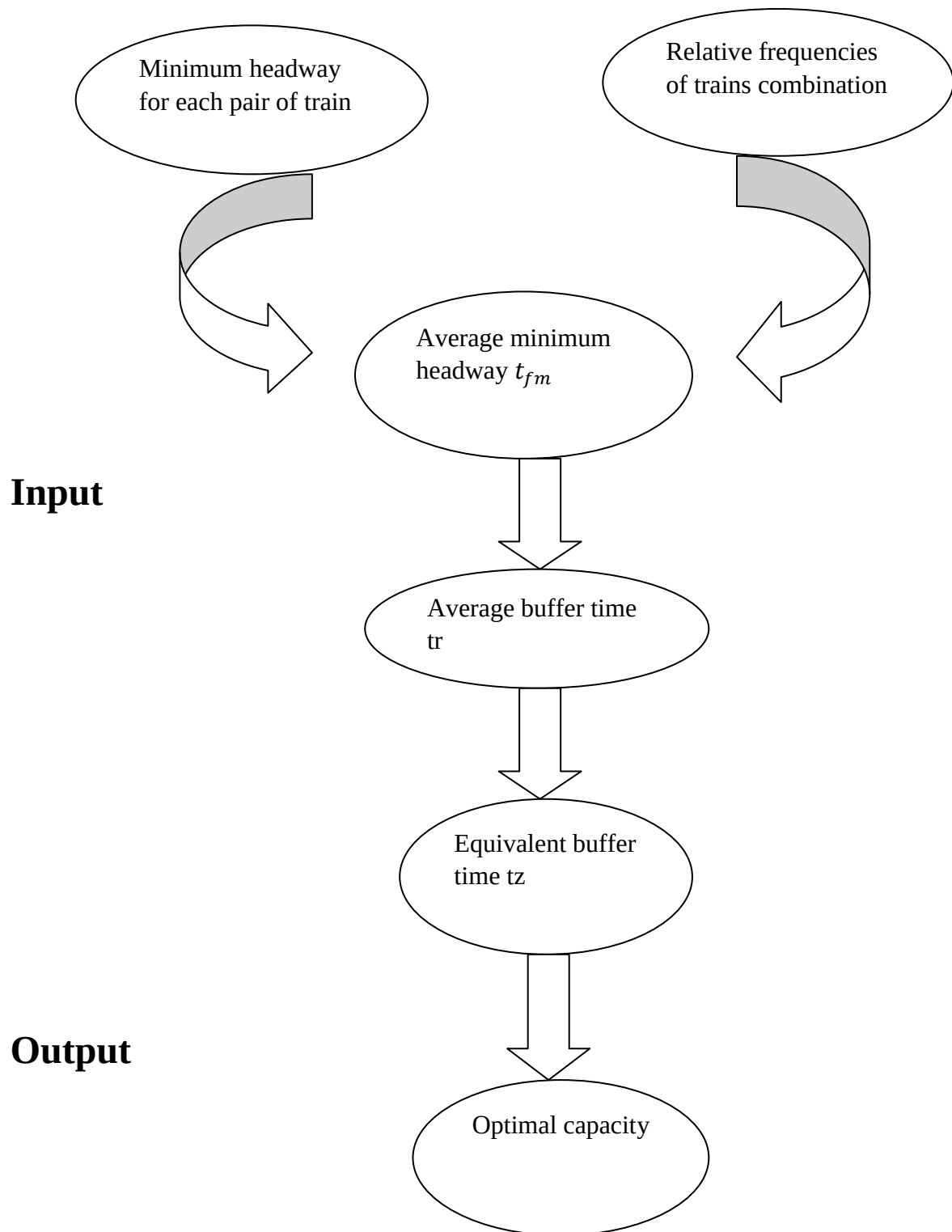


Figure 3.2: Calculation of optimal capacity

CHAPTER FOUR: DATA COLLECTION, PRESENTATION AND ANALYSIS

4.1: Transport demand in Addis Ababa

Urban transport in Addis Ababa is carried by a mixture of ownership structures, of which public and private operators are predominantly contenders for business. The modes of urban transport system in the Addis Ababa are categorized in to motorized and non- motorized traffic. As such the modes of transport include public bus; minibuses; car, train and the non-motorized transport, while walking and animal carts dominate the periphery. Currently, public transport including Anbessa buses, Higer mid-buses, Alliance buses, Minibus taxis, and Salon taxis. So the analyzing will be done by motorized traffic.

4.1.1: Population Distributions

The Addis Ababa City is divided into Ten Sub-cities and again the sub cities are further divided in to Ninety-Nine Kebeles. Based on the 2014 Population and Housing Census Report, There is a difference in sub-city population distribution which shows uneven distribution. The whole Populations are urban dwellers.

The majority of the city population lives in KolfeKeranyo (15.6%), Yeka (12.6%), Nefas-SilkLafto (11.5%), Bole (11.2%), Gullele (9.76%), Addis Ketema (9.3%), and Qirkos (8%) Lideta (7.4%), Arada (7.7%) and Akaki-Kality Sub City (6.7%) Arada and Akaki-Kality have the smallest share from the City's total population.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

Table 4.11: The Addis Ababa City Population projection Distribution by Sub Cities

Year	Addis Keteme	Akaki-Kaliti	Arada	Bole	Gullele	Kirkos	Kolfe-keranyo	Lideta	Nefas-Silk lafto	Yeka
2014	297793	211380	246680	360387	312096	258035	500163	235246	368883	404336
2015	305058	216538	252705	369189	319712	264337	512369	240989	377892	414212
2016	312414	221759	258808	378104	327426	270721	524729	246805	387017	424217
2017	320053	227182	265141	387355	335434	277346	537561	252842	396486	434599
2018	327364	232372	271205	396214	343099	283689	549844	258622	405553	444540
2019	334777	237634	277354	405195	350872	290121	562299	264482	414746	454619
2020	342191	242897	283502	414177	358645	296552	574755	270342	423940	464698
2021	349604	248160	289651	423159	366417	302984	587210	276203	433133	474778
2022	357018	253422	295799	432141	374190	309416	599666	282063	442327	484857
2023	364432	258685	301948	441123	381963	315847	612121	287924	451520	494936
2024	371845	263948	308097	450105	389736	322279	624576	293784	460713	505016
2025	379259	269210	314245	459087	397509	328711	637032	299644	469907	515095
2026	386672	274473	320394	468069	405281	335143	649487	305505	479100	525175
2027	394086	279736	326542	477051	413054	341574	661943	311365	488294	535254
2028	401499	284998	332691	486032	420827	348006	674398	317226	497487	545333
2029	408913	290261	338840	495014	428600	354438	686853	323086	506680	555413
2030	416327	295524	344988	503996	436373	360868	699309	328946	515874	565492

Source statics Authority

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

4.1.2 Addis Ababa population projection

Population size is one of the most important input data for travel demand modeling. Stratified population and socio-economic data of the study area is needed to utilize it in the model. Population Projection gives information on the size, structure and characteristics of the population in the future. The resulting projected population figures can be used for drawing development plans & policy making. This topic provides the projected population size of Addis Ababa for the years from 2014-2030.

Estimates of the future population size and growth rate of Addis Ababa with an assumption of fertility decline (medium variant) indicate a substantial increase in the coming decades. Though the growth rate declines gradually, the population is expected to increase from the current 3.43 million to 3.67 million in 2020, 4.07 million in 2025 and will reach 4.7 million by 2030 (Central Statistics Authority., 2007) . This is the consequence of both fertility and high net migration. Due to the expansion of the city area, now a day the ex-rural areas of Addis Ababa became urban area. Rapid population growth hampers socio-economic development efforts and undermines the environmental resource based upon which sustainable development alternatives depend.

Table 4.2: Source statics Authority

Year	Total	Year	Total
2014	3 194 999	2023	3 910 499
2015	3 273 001	2024	3 990 099
2016	3 352 000	2025	4 069 699
2017	3 433 999	2026	4 149 299
2018	3 512 502	2027	4 228 899
2019	3 592 099	2028	4 308 497
2020	3 671 699	2029	4 308 497
2021	3 751 299	2030	4 467 697
2022	3 830 899		

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

4.2 Passenger Demand

With the increase in travel demand and traffic management problems, travel demand forecasting models are being employed increasingly to make informed decisions about the operational improvements to the Existing transportation system and the design (Hannibal Bwire, 2008). On the first step of railway planning, the passenger demand has to be analyzed. As a result, the amount of travelers wishing to go from certain origins to certain destinations will be known. In order to establish a customer-oriented transportation service, the passenger demand or traffic volume must be estimated. To analyze the passenger demand and the number of train needed, a model to forecast the demand has been used; Modal Split.

4.2.1: Modal Split

In the four step demand modeling, the third step is modal split. The key aim of mode choice analysis is to distinguish the travel mode that travelers use in traveling between an origins location to a destination. In the travel demand model, the choice is for travel between a particular origin zone and a particular destination zone.

In modal split there are two types of logit model: Binary logit model and Multinomial logit model.

- **Binary logit model:** is the simplest form of mode choice, where the travel choice between two modes is made.
- **Multinomial logit model:** the travel choice among three or more modes is made as in my case (five modes).

Modal split models aim to determine the number of trips on different modes given the travel demand between different pairs of nodes (zones). These models try to mathematically describe the mode choice phase of the sequential demand analysis procedure. Generally, choice models are used for modal split analysis. That is, it is assumed that the probability of choosing a particular mode is the probability that the perceived utility from that mode is greater than the perceived utility from each of the other available modes. (Mathew and K V Krishna Rao; Tom V.)

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

For North-South route, different modes of travel between the zones exist – Taxi (lada), Bus, Train, Mini-Bus and private car. It is given that all trip-makers have access to private transport and that the perceived utility of a mode m , i.e. $v(m)$ is given by:

$$v_m = -0.004t_m - 0.005c_m - 0.003u_m + 0.15d_m \dots\dots\dots(7)$$

Where,

t_m is the in-vehicle travel time in minute for mode

c_m is the out-of-pocket cost in birr for mode m

u_m is the waiting time in minutes for mode m , and

d_m is a dummy variable which is 1 when the mode is private transport, 0 otherwise.

Assuming that the variable values are as shown in Table 4.2 are made from the origin zone to the destination zone determine the number of trips made by the different modes. Use Logit model.

Table 4.3: Variable values used on modal split models				
	Variable values			
	t_m (min)	c_m (birr)	u_m (min)	d_m
Taxi (lada)	25	200	0	1
Bus	50	3	20	0
Train	60	6	15	0
Mini-Bus	35	10	5	0
Car	25	350	0	1

First, calculate the perceived utility for each mode:

- v (taxi): $(-0.004 \times 25) - (0.005 \times 200) - (0.003 \times 0) + 0.15$

$$v \text{ (taxi)} = -0.95$$

- v (Bus) : $(-0.004 \times 50) - (0.005 \times 3) - (0.003 \times 20) + 0.15 \times 0$

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

$$v(\text{Bus}) = -0.275$$

- $v(\text{Train}) = (-0.004 \times 60) - (0.005 \times 6) - (0.003 \times 15) + 0.15 \times 0$

$$v(\text{Train}) = -0.315$$

- $v(\text{mini-bus}) = (-0.004 \times 35) - (0.005 \times 10) - (0.003 \times 5) + 0.15 \times 0$

$$v(\text{mini-bus}) = -0.205$$

- $v(\text{car}) = (-0.004 \times 25) - (0.005 \times 380) - (0.003 \times 0) + 0.15 \times 1$

$$v(\text{car}) = -1.85$$

Where the binary model can easily be extended to multiple modes. The equation for such a model can be written as:

$$P_{IJ}^t = \frac{e^{-\beta c_{ij}^t}}{\sum e^{-\beta c_{ij}^n}} \dots \dots \dots (8)$$

So, we use Logit model to determine the probability pm that a particular mode m , will be chosen.

- $P(\text{taxi}) = \frac{e(-0.95)}{e(-0.95) + e(-0.275) + e(-0.315) + e(-0.205) + e(-1.85)}$

$$P(\text{taxi}) = 0.136$$

- $P(\text{Bus}) = \frac{e(-0.275)}{e(-0.95) + e(-0.275) + e(-0.315) + e(-0.205) + e(-1.85)}$

$$P(\text{Bus}) = 0.267$$

- $P(\text{Train}) = \frac{e(-0.315)}{e(-0.95) + e(-0.275) + e(-0.315) + e(-0.205) + e(-1.85)}$

$$P(\text{train}) = 0.256$$

- $P(\text{Mini-Bus}) = \frac{e(-0.205)}{e(-0.95) + e(-0.275) + e(-0.315) + e(-0.205) + e(-1.85)}$

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

$$P(\text{Mini-Bus}) = 0.286$$

- $$P(\text{car}) = \frac{e(-0.205)}{e(-0.95) + e(-0.275) + e(-0.315) + e(-0.205) + e(-1.85)}$$

$$P(\text{car}) = 0.050$$

4.2.3 The LRT Transport Network System

The North –South Route

The Line North-South goes along the important North South transportation corridors in Addis Ababa which covers 16.9 km. This line goes through city center, and is one of the most important contacting lines between city center and city Southern and Northern parts as well as suburbs. The central part of this line goes through highly populated areas and the busiest commercial areas with large traffic flow; the Southern part of the line goes through industrial zone of the city and Kalit Town. This line passes through six sub cities going through Menelik II Square ~ Merkato ~ Lideta ~ Lagare ~ Gotera ~ Kallti ~ Akaki and also shares with the East West line in the road section from Lideta to Lagare.

The East-West Route

The Line East-West goes along the important East -West transportation corridor in Addis Ababa which covers 17.4 km. The two lines (North-South and East-West lines) use common track of about 2.8 km. This line goes through city center, and is one of the most important contacting lines between city center and city Western parts. The Eastern and central parts of this line go through highly populated areas, the busiest commercial areas and Ayat residential area with large traffic flow; the Western part of the line goes through western city and line includes Torhailoch ~ Lideta ~ Lagare ~ Adwa Square ~ CMC ~ Ayat. and the details for both routes are shown in figure 1 below.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

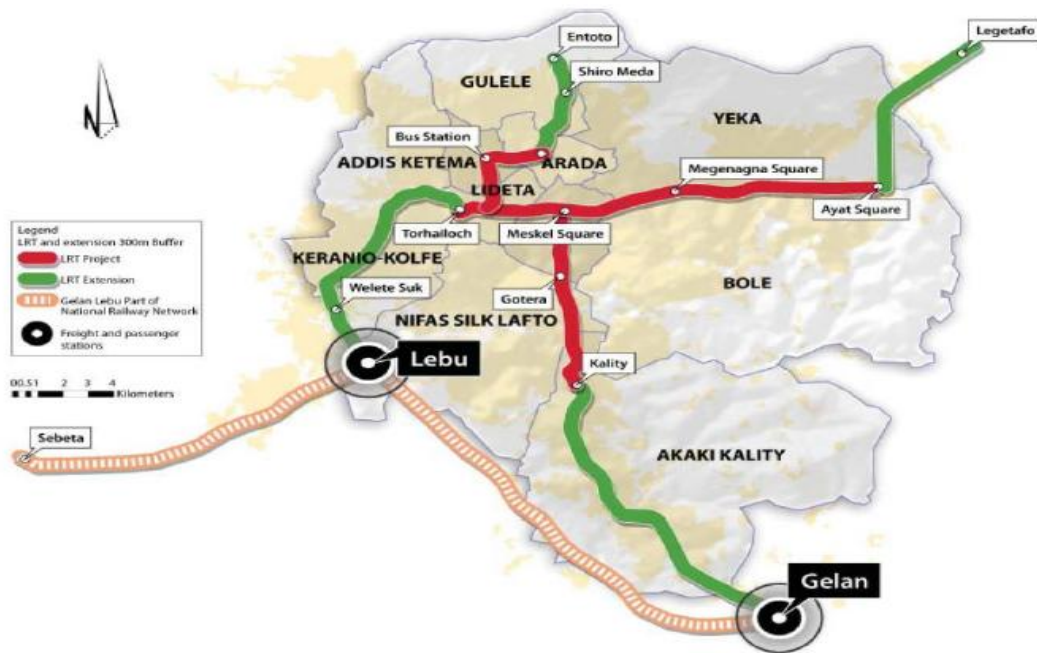


Figure 4.1: The Addis-Ababa LRT Transport Routes Profile

The study area for the calculation of demand passenger is working on the sub-city closest to light rail Transit routes. Sub city on both at left and right of the LRT routes.

By using the Addis Ababa LRT transport routes profile as it has shown in Figure 4.1, the closest subcity of the two routes has been demarked.

- **For North-South routes:** Arada, Addis Ketema, Lideta, Qirkos, Nefas Silk lafto
- **For East-West route:** Lideta, Qirkos, Bole, Yeka

2017:

North-South

Table 4.4: The sub city population in NS line closest to LRT

Sub city	Population
Arada	265141
Addis Ketema	320053
Lideta	252842
Qirkos	277346
Nefas Silk lafto	396486
Total	1511866

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

East- West

Table 4.5: The sub city population in EW line closest to LRT

Sub city	Population
Lideta	252842
Qirkos	277346
Bole	387355
Yeka	434599
Total	1352142

Number of trains regarding the demand of passenger = Number of population $\times$ per cent of mode train / $2 \times$ the capacity of one unit tram. To determine that number of trains, it has determined that 5 per cent (Ethiopian Railway Corporation) of the total population of the two lines need train service, based by the LRT passenger flow.

North-South: $1511866 \times 0.05 \times 0.256 / 2 \times 286 = 33.83 \approx 34$ train/ day

East-West: $1352142 \times 0.05 \times 0.256 / 2 \times 286 = 30.25 \approx 30$ train/day

The results show that the number of trains satisfying the request of passenger might be 34 trains in North-South line while 30 train/ day in EW line.

Several years were studied and regrouped in the table below.

Table 4.6: The demand passenger in both lines (train/day)

Year	NS line population	NS line (train/ day)	EW line population	EW line (train/ day)
2019	1581480	36	1414417	32
2021	1651575	37	1477124	33
2023	1721671	39	1539830	35
2025	1791766	40	1602537	36
2027	1861861	42	1665244	37
2030	1967003	44	1759302	40

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

4.3: Calculation of line capacity analytically method.

4.3.1 Poole formula

To analyze the maximum number of trains by using Poole equation we use the equation (3) because it was developed later and is more precise than the previous one.

$$C = \frac{960}{2t + \frac{t}{2} + m} \times 2$$

Where, 960 min is for 16 hours of operation in AALRT.

$$C = \frac{960}{2 \times 56 + 30 + 6} \times 2 = 13 \text{ trains/day}$$

4.3.2: UIC leaflet 405

Given the above parameters, the capacity values can be obtained and helps to allocate resources on the routes of both corridors so as to provide the number of trains. The values that should be obtained are mostly calculated using the actual timetable of trains, and also for number of sections of both routes. The timetable was made by reading the graph in the appendix and considers the arrival and departure time of the trains for EW and NS line table 3.9(appendix).

❖ Theoretical capacity

In Analytical method, theoretical and practical capacity should be determined. First theoretical capacity defines the maximum number of trains that can be operating in these two lines using UIC Leaflet 405 and then practical which is 60-75% of theoretical capacity will be determined.

But to find the number of trains that should be allocated on route at a time, first the number of average minimum headway tfm and then the margin time tr should be calculated using the following formula represented in the table 4.16 and 4.17:

- The calculation has been realized by using the timetable above in chap 3.
- Time period is the total operating time per day i.e. 16-hours = 960min
- The number in first column indicates the succession of trains.

The maximum number of trains that can be operating in EW line has been calculated and represented in the table.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

Table 4.7: The capacity calculation in EW line.

Ayat-Meri	n_i	n_j	t_{ij}	$n_i \times n_j$	$t_{fm} = \sum (n_i \times n_j \times t_{ij}) / \sum (n_i \times n_j)$	$t_r = 0,44 \times t_{fm}$	$t_{zu} = 0,25 \times a$	$C = 960 / t_{fm} + t_r + t_{zu}$
1	1	1	12	1				
2	1	1	12	1				
3	1	1	12	1				
4	1	1	12	1				
5	1	1	12	1				
6	1	1	12	1				
7	1	1	12	1				
Total			84	7	12	5,28	5,25	42,61

Station	t _{fm}	t _r	C
Meri- CMC	12	8,04	37,96
CMC- St Michael	11	7,37	40,64
St Michael- college service	11	7,37	40,64
College service- Management Institut	11	7,37	40,64
Mnagement Institut- Gurd shola 1	9	6,03	47,74
Gurd shola 1- Gurd shola 2	10	6,7	43,73
Gurd Shola2- Megagnagna	10	6,7	43,73
Megagnagna- Lem Hotel	10	6,7	43,73
Lem Hotel- Hayahulet 1	10	6,7	43,73
Hyahulet- Hayahulet 2	10	6,7	43,73
Hayahulet2- St Urael	10	6,7	43,73
Bambis-St estifanos	10	6,7	43,73
Coca Cola-Torhailoch	8	5,36	48,95

The maximun number of trains that can be operating in NS line has been calculated and represented in the table:

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

Table 4.8: The capacity calculation at stations in NS line.

Kality-Abo junction	n_i	n_j	t_{fij}	$n_i \times n_j$	$t_{fm} = \sum (n_i \times n_j \times t_{fij}) / \sum (n_i \times n_j)$	$t_r = 0,44 \times t_{fm}$	$t_{zu} = 0,25 \times a$	$C = 960 / t_{fm} + t_r + t_{zu}$
1	1	1	12	1				
2	1	1	12	1				
3	1	1	12	1				
4	1	1	12	1				
5	1	1	12	1				
6	1	1	12	1				
7	1	1	12	1				
Total			84	7	12,000	5,280	5,25	42,61

Stations	t _{fm}	t _r	C
Saris-Adey Ababa	12	5.28	42,61
Adey Ababa-Nefas Silk 1	12	5.28	42,61
Nefas Silk1-Nefas Silk2	12	5.28	42,61
Nefas Silk2- Lancha	12	5.28	42,61
Lancha--Temenja Yazh	11	4.84	45
Temenja Yazh-Riche	10	4.4	47
Riche-Meshwalekya	9	3.96	52
Meshwalekya-Staduim	9	3.96	52
Darmar-Abenet	8	3.52	57
Abenet-Sebetegna	8	3.52	57
Sebetagna-Autobus Tera	9	3.96	52
Autobus Tera-Gojam Berenda	9	3.96	52
Gojam Berenda-Atikilt Tera	9	3.96	52
Atikilt Tera- Menelik II square	9	3.96	52

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

Table 4.9: common stations between the two routes.

Stations	t/m	tr	C
Stadium	6	2.64	69
Leghar	5	2.2	77
Mexico	6	2.64	69
Tegbared	5	2.2	77
Lideta	6	2.64	69

The capacity of each station was studied to show the maximum operational number each of the two routes. The study above shows there is a slight difference between the results of the capacity. The minimum result value determines in this case, the capacity of the route.

This result shows almost the same to the number of trains along all routes at peak hours. So, it is feasible as expected to be allocated/assigned along all routes. In the shared route it allocates more trains as it is a bottleneck sections.

So ideally, on both above, calculations show that around 42 trains can be handled in the routes and will be allocated at peak hours. For 2.83 km of common station, we have seen there are more trains can be operated in those sections which are around 69 trains.

But, it is not possible to actually run the number of trains that can be worked out mathematically. So practical capacity represents to determine a more realistic measure.

❖ Practical Capacity.

Practical capacity is calculated under more realistic assumptions, which are related to the level of expected operating quality and system reliability. It is the capacity that can

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

permanently be provided under normal operating conditions. It is usually around 80 % of the theoretical capacity.

- **For EW and NS line**

Practical capacity:

$42.61 \times 0.8 = 34$ trains can be actually run in both routes.

- **For common station**

Practical capacity:

$69 \times 0.8 = 55$ trains can be actually run in this common line.

Practically calculating, the exact number of train that can in both North-South and East-West routes is around 34 trains per day which this output can satisfy the passenger demand because it considers the passenger demand so as to save running time and operating.

Running time

The time of travel for the given distance and running at the given speed is 16.68km/(18km/hr) which is equal to 0.926 hour (0.966 in EW line) or about 1 hour for a single trip for a train. Accordingly, the running time between two consecutive stations (considering average distance) is 60 minute divided by 22station a separation which gives 2.73 minutes on both line.

The headway time

The headway time is the time difference between successive trains along the same route. But the headway time calculation depends on the type of signalling system (moving or fixed block). The AALRT use fixed block signalling system (ERC) so it will be calculated as a fixed block formula.

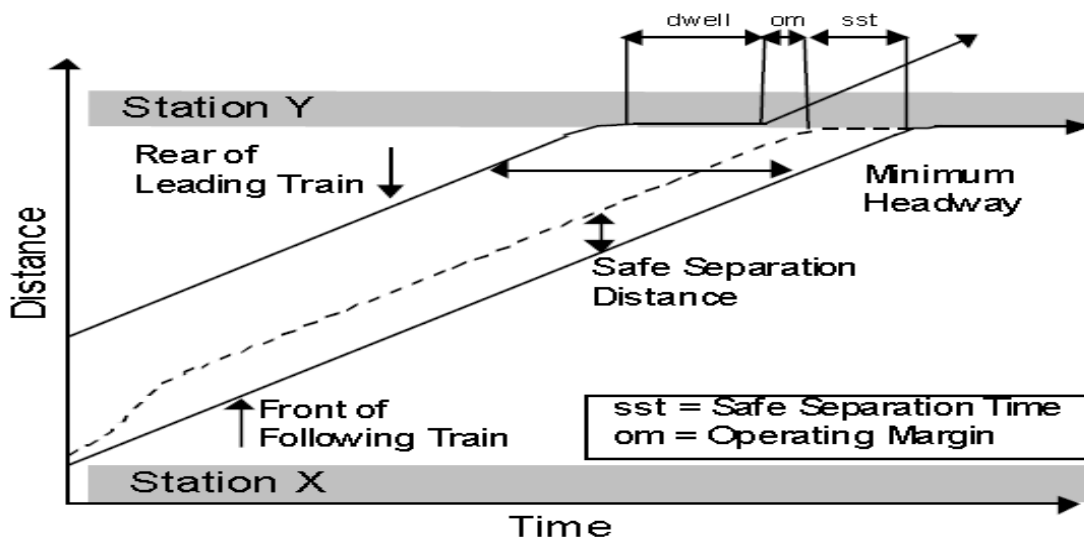
Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

FIXED-BLOCK SYSTEMS AND THROUGHPUT

Station close-in time or Headway Stations

The time between a train pulling out of a station and the next train entering—referred to as *close-in time* is the main constraining factor on rail transit lines. This time, also known as the *safe separation time*, is primarily a function of the train control system, train length, approach speed, and vehicle performance. Close-in time, when added to the dwell time and an operating margin, determines the minimum possible headway achievable without regular schedule adherence impacts—referred to as the *non-interference headway*. The diagram below shows a distance-time station stop diagram.

Figure 4.2: Distance-Time Plot of Two Consecutive Trains (acceleration and braking curves omitted for clarity)



The headway calculation depends on several parameters such as braking distance, dwell time, stopping distance, acceleration and line speed etc. So that it is better to use conventional headway calculation approach which is:

$$H(s) = \sqrt{\frac{2(L+D)}{as}} + \frac{L}{va} + \left(\frac{100}{K} + B\right)\left(\frac{va}{2ds}\right) + \frac{as \, tos^2}{2va} \left(1 - \frac{va}{vmax}\right) + tos + tjl + tbr + td + tom...(8)$$

Where: [typical values shown in square brackets]

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

H(s) = station headway (s)

L = length of the longest train; 56 m

D = distance from front of stopped train to start of station exit block; [30m]

va = station approach speed (m/s)

vmax = maximum line speed (m/s)

K = braking safety factor—worst case service braking is K% of specified normal rate—typically 75%; [75]

B = separation safety factor—equivalent to number of braking distances plus a margin, (surrogate for blocks) that separate trains.

tos = time for overspeed governor to operate; [3 s]

tjl = time lost to braking jerk limitation; [0.5 s]

tbr = operator and brake system reaction time; [1.5 s]

td = dwell time; 45 s

tom = operating margin; 20 s

as = initial service acceleration rate; [1.3 m/s² or 4.3 ft/s²] and

ds = service deceleration rate. [1.3 m/s² or 4.3 ft/s²]

N.A:

$$H(s) = \sqrt{\frac{2(56+30)}{1.3}} + \frac{56}{0.3} + \left(\frac{100}{0.75} + 0.5\right) \left(\frac{0.3}{2 \times 1.3}\right) + \frac{1.3 \times 3^2}{2 \times 0.3} \left(1 - \frac{0.3}{19.5}\right) + 3 + 0.5 + 1.5 + 20 + 45$$

$$H(s) = 302.811 \text{ s} \approx 5.046 \text{ min}$$

The number of trip depends on the section with higher volume of passenger flow. In this way, the higher load is located between Lideta light ~ Meskel Square which is 38462 passengers per day. But the capacity of one train is 286 persons and there are 22 trains along the lines. Therefore, the total trip per day for the whole trains will be 38462/ (286*22) which is equal to 6.11 times which means 6 times for each train in both lines.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

❖ Discussion

The analysis of both methods made above shows that the UIC 405 is more appropriate in case of Addis Ababa LRT. By using this method it can be seen that it responds sufficiently the passenger demand. The results on both North-South and East-West routes are made by calculated the theoretical and practical capacity.

In the North-South LRT route, the maximum number of trains for the current year is 34 trains/day which is approximately equal with the passenger demand analysis.

In the East-West LRT route, the analysis of the maximum number trains shows 34 trains/day which is slightly higher than the passenger demand analysis (around 30 trains).

In both line 34 trains are supposed to be practically allocated at peak hour along all routes of the AALRT system within a headway time of 5 min which is higher than the available capacity designed by the ERC. So that the ERC must improve the infrastructure of the routes.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

To assess the capacity utilization at AALRT routes, the UIC405 leaflet analytical methods are used to analyse the current capacity of the two lines. These methods consider basic factors that affect the line capacity such as the timetable, the headway time and the extra margin time. The passenger demand for number of train needed is an important issue to determine before. Based on these models and the procedures involved the number of train are calculated both North-South and East-West LRT routes for current and the next years.

The North-South route analysis shows that 34 trains can be practically operated just like the East-West route analysis shows with 34 trains. But the demand analysis for the current year shows that passengers need 34 trains. By comparing the capacity and the demand analysis it can be seen that actually it is enough train for passengers for both line if we consider the number of trains analyzed but require more for next years.

Assessment of improvement areas for optimizing the capacity of Addis Ababa LRT

5. 2 Recommendation

As the socio- economic condition of the city increase, there will be a continuous increase in Transportation and LRT Transportation demand in particular.

Modernization of the LRT Transport is measured by its efficiency and this is achieved by incorporating the improvement of railway capacity. Using analytical method to analyze the assessment the line capacity is a good start for railway capacity analysis and gives a preliminary result whether it is theoretically or practically.

The line capacity calculation indicates that after the current year it is strong probable that this will not be able to satisfy the request of passenger according to demand analysis made. So I recommended the Ethiopian Railway Corporation (ERC) to improve operational parameters by increasing the number of trains which require reducing the headway time.

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Table 3.9: The actual timetable for the two routes**a) East-West line**

Stations name	10104	10204	10304	10802	10404	10504	10604	10704
Ayat	07:10:00	07:24:00	07:42:00	07:55:00	08:10:00	08:22:00	08:40:40	08:55:20
Meri	07:12:00	07:26:30	07:44:00	07:58:00	08:12:30	08:23:05	08:43:00	08:57:00
CMC	07:15:00	07:30:00	07:47:00	08:03:00	08:14:20	08:26:05	08:46:00	09:00:10
St Michael	07:17:05	07:34:00	07:50:05	08:05:30	08:17:00	08:29:00	08:48:40	09:03:20
Service College	07:20:05	07:37:00	07:53:05	08:08:05	08:19:00	08:32:00	08:51:00	09:05:50
Management Institut	07:23:00	07:40:00	07:56:40	08:10:30	08:21:00	08:34:00	08:53:00	09:08:00
Gurd Shola 1	07:26:05	07:43:40	08:00:00	08:13:50	08:23:15	08:37:00	08:56:00	09:11:00
Gurd Shola 2	07:31:00	07:48:00	08:05:00	08:17:05	08:27:00	08:40:00	09:02:30	09:15:00
Megagnagna	07:34:10	07:52:00	08:09:00	08:20:00	08:30:00	08:42:20	09:04:05	09:17:00
Lem Hotel	07:39:00	07:57:00	08:12:00	08:23:00	08:33:00	08:45:00	09:07:00	09:20:00
Hayahulet 1	07:42:10	08:00:00	08:14:30	08:25:00	08:35:00	08:47:10	09:09:05	09:22:00
Hayahulet 2	07:44:00	08:02:50	08:17:00	08:27:00	08:37:20	08:49:10	09:11:40	09:25:00
St Urael	07:47:20	08:05:05	08:19:00	08:29:00	08:39:50	08:52:00	09:14:00	09:27:20
Bambis	07:49:50	08:08:00	08:21:05	08:31:05	08:41:00	08:54:30	09:16:00	09:30:00
St estifanos	07:52:00	08:10:00	08:23:05	08:33:05	08:43:00	08:56:30	09:18:00	09:32:10
Staduim	07:54:30	08:12:00	08:25:02	08:39:00	08:45:05	08:59:00	09:20:30	09:34:50
Leghar	07:56:05	08:14:00	08:27:02	08:42:00	08:47:05	09:01:00	09:22:00	09:37:00
Mexico	07:58:05	08:16:00	08:28:30	08:43:00	08:50:00	09:04:00	09:24:00	09:39:00
Tegbared	08:00:20	08:18:00	08:32:00	08:45:15	08:52:50	09:06:00	09:26:00	09:42:00
St Lideta	08:01:30	08:20:00	08:33:40	08:47:30	08:55:00	09:08:30	09:28:00	09:44:00
Coca Cola	08:04:05	08:22:00	08:35:20	08:49:00	09:57:00	09:14:00	09:30:00	09:46:20
Torhailoch	08:06:00	08:24:00	08:37:40	08:51:00	08:59:30	09:16:30	09:32:10	09:49:00

b) North-South line

Stations name	20104	20204	20304	20404	20504	20604	20704	20804
kality	07:14:00	07:28:00	07:40:00	07:57:00	08:12:00	08:27:40	08:42:00	08:57:20
Abo junction	07:17:00	07:30:00	07:42:00	08:00:00	08:14:30	08:30:00	08:44:00	09:00:00
Saris	07:20:00	07:32:30	07:45:00	08:04:00	08:17:20	08:33:00	08:47:00	09:03:00
Adey Ababa	07:22:05	07:35:00	07:47:00	08:07:00	08:19:50	08:35:00	08:49:05	09:05:00
Nefas Silk 1	07:25:00	07:37:00	07:50:00	08:11:30	08:23:05	08:38:00	08:51:50	09:07:30
Nefas Silk 2	07:27:00	07:39:05	07:52:00	08:14:50	08:26:00	08:40:00	08:53:40	09:09:40
Lancha	07:32:00	07:43:00	07:56:00	08:20:00	08:30:30	08:44:10	08:57:20	09:13:50
Temenja Yazh	07:34:00	07:45:00	07:58:00	08:23:00	08:33:00	08:46:20	08:59:50	09:15:40
Riche	07:36:05	07:47:00	08:00:00	08:26:00	08:35:40	08:48:20	09:01:40	09:17:10
Meshwalekya	07:38:05	07:48:00	08:02:00	08:28:00	08:37:20	08:50:05	09:03:00	09:19:10
Staduim	07:42:10	07:52:00	08:06:00	08:32:00	08:41:20	08:54:00	09:06:20	09:23:00
Leghar	07:45:00	07:53:30	08:07:30	08:35:00	08:43:30	08:56:00	09:08:00	09:25:00
Mexico	07:47:00	07:55:05	08:09:30	08:37:10	08:46:00	08:58:00	09:10:00	09:27:00
Tegbared	07:49:00	07:57:30	08:12:00	08:39:50	08:48:20	09:00:00	09:12:00	09:29:00
Lideta	07:51:00	07:59:20	08:14:00	08:42:00	08:50:20	09:02:00	09:14:20	09:31:00
Darmar	07:53:00	08:01:05	08:16:00	08:44:00	08:52:10	09:04:00	09:16:30	09:33:10
Abenet	07:55:10	08:03:50	08:18:00	08:47:00	08:55:00	09:06:20	09:19:00	09:36:00
Sebetegna	07:57:20	08:06:00	08:20:00	08:49:00	08:57:00	09:08:10	09:21:00	09:38:00
Autobus tera	08:00:00	08:09:00	08:23:30	09:53:00	09:00:00	09:11:10	09:23:00	09:41:05
Gojam Berenda	08:02:20	08:11:00	08:25:30	08:55:30	09:02:00	09:13:10	09:26:00	09:43:10
Atikilt Tera	08:04:00	08:13:00	08:28:00	08:58:00	09:04:00	09:15:30	09:28:00	09:45:00
Minilik II Square	08:07:00	08:16:00	08:31:00	09:00:00	09:07:00	09:13:00	09:30:00	09:48:00