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MASTER'S DEGREE THESIS

ON

TRAIN OPERATION SYSTEM DEVELOPMENT FOR ADDIS ABABA LIGHT RAIL TRANSIT

By

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Advisor

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Submitted to Addis Ababa University, Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering, in partial fulfillment for the award of the Degree of Master of Science In Mechanical Engineering (Railway Engineering Stream).

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "**TRAIN OPERATION SYSTEM DEVELOPMENT FOR ADDIS ABABA LIGHT RAIL TRANSIT**" is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

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(Advisor)

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Abstract

This research paper mainly deals with the train operation system development for railway transport of Addis Ababa LRT. The prime justification for the introduction of a Light Rail System in Addis Ababa is the provision of major improvements to public transport in the city, particularly with reference to greatly increased carrying capacity, reduced pollution and improved the service of operation. To achieve this, system analysis approach is presented for the investigation of train operations in railway stations and routes based on demand, network, timetable (train schedule), and rolling stock and crew analysis data. Network and train schedule analysis are the main focus of this paper which are solved using a simulation model programmer language Arena5. The simulation model is formulated in the way that it represents the appropriate actual working system of the Addis Ababa LRT. For the constructed simulation model, the "*Program*" is well made and *run*. The simulation model combines the two routes together and the number of waiting time result shows the stations operations are busy from Lideta to Meskel Square including the route between both stations where the two routes separate to east and south lines. Therefore, these route and stations are the ***bottle neck*** of the Addis Ababa LRT corridors. Testing the real operation by simulation, Delay minimization and resource utilization, waiting time for each station and the route bottle neck identification are the major output of the research. This research is done depending on the actual data for the Addis Ababa light rail transit and its application is more for the future operation coming soon. Finally, the operation data are verified and the simulation model output is valid.

Keywords: *Train schedule, operations, station, route, speed, dwell time*

Table of Contents

Tables

Figures

Notation

ERC - Ethiopian Rail Way Corporation

ILPTP – Integrated Line Planning and Timetabling Problem

LRT - Light Rail Transit

LRV - Light Rail vehicles

Mc - Motor car

MIP - mixed integer programming

MoTaC – Ministry of Transport and Communications

O-D – Origin Destination matrices

PESP – Periodic Event Scheduling Problem

PIS - Passenger Information System

PID - Passenger Information Display

SAMFOST – Simplified Analytical Model for Single tracks

SIMAN – Simulation Model Analysis

TNV – Trein -NummerVolgsystemen (The Dutch train detection data tools)

Tp - Trailer without driver's cab and with pantograph

TVEM – Timetable Variant Evaluation Model

CHAPTER ONE

Introduction

Ethiopia has launched the construction of a 5,000 km railway network which aims to link the capital, Addis Ababa, to various regions of the country which is part of the country's five-year transformation plan (Corporation, 2011). The new railroad network is planned to have at least 8 main routes that extends to all compass points. The Addis Ababa LRT is also the part of the plan which is now under construction. Therefore studying about and preparing for the operation is indispensable to make the city transportation system modern and efficient.

1.1. Concepts of Train and Its Operations

A train is defined as one or more railway vehicles capable of being moved. It may consist of a locomotive (sometimes more than one) to provide power with various unpowered vehicles attached to it. It may also consist of a multiple unit, i.e. several vehicles formed into a fixed formation or set, which carry their own power and do not require a locomotive. A train may be only a locomotive running light (deadheading) to a point elsewhere on the railway. It can be classified as passenger carrying, freight or, rarely nowadays, mixed. The Addis Ababa train is low-floor articulated 6-axle modern trams, consisting of three modules, bi-directional driving vehicles. Two tramcars shall be able to operate with double heading. The Addis Ababa train formation is Mc+Tp+Mc, where Mc module is motor car with driver's cab and Tp module is trailer without driver's cab and with pantograph (Limited C. R., Technical Specification of Vehicles, 2013)

The system development of train operation analysis approach is presented for investigation of train operations in railway stations based on infrastructure (network) analysis, schedule (timetable) analysis, and rolling stock analysis and crew analysis data. The estimated blocking times, buffer times and track occupancies are compared with real operations data recorded automatically by track circuits. Statistical analysis of train operations clearly reveals that the trains operate at lower than design speed. Furthermore, the dwell times at platform tracks are systematically extended due to hinder by other trains and behavior of railway personnel (Hansen, 2005)

The scheduled headway between arrival and departure of some pairs of trains at critical route nodes running times at junctions are generally exceeded and often leads to route conflicts. The quality of timetable design and train operations throughout the route would be improved significantly if the feasibility of the scheduled arrival and departure times at major transfer stations was proven by a detailed estimation of the blocking and buffer times based on observed running times and delays during operations. The buffer time at junctions and level crossings should reflect the distribution of real train speeds and blocking times. Therefore, it is important to study and research about train operation system development for the new coming of Addis Ababa light rail transit.

1.2 Statement of the Problem

Even though there is no actual train operation currently in Ethiopia, it is important doing on the railway operation system development for the railway personnel and society before the real operation started. In train operation root conflict, train delay and human behavior are the most common problems in railway industry. Therefore the problem areas that were studied in this paper are: train delay, unimpressive utilization of resources, train traffic control, Crew unpunctuality and testing train operation by simulating for Addis Ababa LRT. Therefore, the purpose of this study is to identify train operation factors, minimize train delay, identify the route bottle neck and give effective transport service and to answer the following basic research questions in the case Addis Ababa LRT.

- What are the factors that cause train schedule delay?
- How to use the schedule or time table effectively?
- How train operation punctuality increase?
- Can the Addis Ababa LRT operate with the design operation data (simulation checkup)

- ❖ The need of understanding *modeling* and *simulation* from concept to expected result
- ❖ Well communication with simulation package-*Arena Software*

1.3 Objective

General objectives

The general objective of this research is to analysis and develops the train operation systems for Addis Ababa Light Rail Transit.

Specific objectives

The specific objectives of this study are:

1. To model and simulate the two Addis Ababa LRT corridors (Piazza to Kaliti and Torhyloch to Ayat) using the programmer language software Arena5.
2. To identify the factors that cause train delay throughout the Addis Ababa LRT operation systems.
3. Entail the appropriate train traffic control system and man power for the system operations, and to raise awareness regarding operation safety issue.

1.4 Scope of the study

The Addis Ababa LRT covers the East-West and North-South transport corridors. The initial phase of the project is 34km length and expected to extend up to 74km in the long term plan. The East-West corridor passes through the city center from the eastern peripheries of the city to the west. The initial phase of this route is 17.1km length and expected to extend up to 37.7km in the long term plan. The North-South corridor is a heavily-used route; it is utilized to access Africa's largest open market at Merkato. The initial phase of this route is 16.97km length and expected to extend up to 36km in the long term plan. The study covers all systems of the east-west line from Ayat to Torhyloch and the north-south line from Piazza to Kaliti. Therefore the paper of this study focuses on the initial routes of the Addis Ababa LRT.

1.5 Significance of the Study

Railway will produce economically feasible construction, environmental friendly, safe, comfortable and competent mode of transportation system in the world. The objective of good train operation is to use the route, the rolling stock and crews in the most effective way since train is an expensive piece of things and the infrastructure of a railway is its most expensive one. The operation system development in this work is analyzed by using the Arena5 simulation model, station stopping time and route travel time ,maximum and minimum train speed, identifying the route bottle neck, inter station distance and time between consecutive train travelling and resource allocation were mostly accessed to make the Addis Ababa LRT train operation full. Therefore this paper is aimed to show the Addis Ababa LRT operation by simulating and identifies the factors those can affect the train operation and cause delay. The city Light Rail Transit design operation data are also checked by simulation check up.

1.6 Structure of the Thesis

This research is composed of five chapters. The first chapter is the introduction part that contains: introduction and justification of the study, the problem statement, research questions, the objective, scope, the significance of the study, and structure of the research. In the second chapter, the literature reviews of related train operation, network analysis, timetable scheduling analysis and the software Arena5 tools are briefly discussed. In the third chapter, the methodology that is used for doing the research is introduced. In this chapter, the research process, research approaches and data synthesis and analysis method are discussed. In the fourth chapter, the operation factors, system development analysis and the results of the study are briefly presented with its corresponding discussions. Finally in chapter five, the conclusion and recommendation for train operation system development, future work, and contribution of the thesis are briefly deliberated.

CHAPTER TWO

Literature review

Railways are complex technical systems. They are often considered to be static, stiff and inflexible. As long as only constant, non-dynamic parts, such as the infrastructure, are considered, the system is quite easy to understand. But the reality for train operation system is different. The variance in different parameters makes the system difficult. Some examples:

- ❖ The infrastructure is adjusted and complemented all the time. Most of the adjustments are minor, but these changes nonetheless imply that important factors for operation vary over time.
- ❖ The timetable creates a well defined structure. However, the capacity is utilized differently every day since the actual timetable varies from one day to another due to delays, extra trains and cancelled trains. Therefore the planned timetable is modified from time to time. The principles for this capacity allocation also change over time.
- ❖ The available capacity, which is an important condition for the timetable, varies over time. Failures, construction works, accidents and delays all make the available capacity vary over time.
- ❖ The railway system is used and operated by humans. Human behavior varies naturally from one time to another. Train crews, dispatchers and passengers all contribute to this variance.

All these variances make the railway system complex and interesting to analyze. Modeling the railway system means modeling all these variables. To find general relations in this noise of superposed variances is not easy. That means systematic method needs to understand the train operation system development. Moreover, strong interactions between factors can be expected, that make the task of analysis even more difficult. (Stockholm, 2010)

Train delays are one of the most important performance indicators of railway operations, which result from many related factors, such as the layout of the infrastructure, the occupancy of the infrastructure, the variation of running times, arrivals and departures, and the traffic control. First, the infrastructure must provide enough capacity and smooth routes. The timetable is the basic plan for train operation. On the one hand, the timetable should ensure the efficient and balanced use of the infrastructure. On the other hand, it should be flexible enough to cope with stochastic disturbances during operations. Suitable recovery times in a timetable are very important to reduce train delays, whereas buffer times can decrease delay propagation. Stochastic disturbance of operations cannot be eliminated and will always occur, but its statistical distribution can be grasped by analyzing historic and actual train operation data. To some extent, this will help to forecast and prevent train delays. Traffic control is the final means to supervise and improve the train punctuality. The effectiveness of traffic control in case of perturbations, however, depends on the quality of the actual schedule, the time and precision of conflict detection and the available means for disposition.

The interdependencies among the related factors are strengthened with the increase of traffic density and train speed, not only, which requires a further enhancement of the precision of time calibration a more comprehensive and accurate analysis of train operations. Therefore Railway operation planning, train operation and the safety issues are the most indispensable one which have to integrate in the train operation system analysis. Most modern research into railway operation concerns single track and double-track systems or entire networks of double-track lines and stations that connect them. The others are focus on timetable scheduling and train detection data. That means the train operation in railway stations is investigated systematically based on network, timetable and train detection data. Train detection data and train delays at stations can be analyzed with a high precision of about a second by means of the recently developed tools TNV-Prepare and TNV-Filter (Goverde R.M.P, 2001a)Earlier publications (Goverde, 2001b) deal with the distribution of train delays in some stations of the Dutch Railways.

2.1 Railway stations

Railway station is the selected place on a railway line, where trains halt for one or more of the following purposes: (ARORA, 2008A)

- For exchange of passengers.
- For exchange of goods.
- For control of train movements.
- To enable the trains on a single line track to cross from opposite directions.
- To enable the following express trains to overtake.
- For taking diesel or coal and water for locomotives.
- For detaching engines and running staff.
- For detaching or attaching of compartments and wagons.
- For sorting of bogies to form new trains, housing of locomotive in loco-sheds etc.
- It emergencies in ease of dislocation of track due to rains or accidents etc.

Railway stations and routes play a vital role for passengers, non-travelling users, the staff and the communities in which they are located. They serve the growing needs of an increasingly mobile population and are used by a wide range of users. With many journeys made by rail each day, Network Rail recognizes the importance of its customers and the need to put passengers first. To ensure that the expectations of its customers are met in full, the Guide places passengers at the forefront of the design process, acknowledging that all elements of station design should be considered to help meet their needs. In order to understand fully the perceptions of these users it is important to engage with them from the outset of the design process to ensure that their requirements are understood and integrated. Stations are primarily a means of access to the national rail network, in turn acting as a gateway to or from other destinations. They have become increasingly important as destinations in their own right as places to shop, work, or simply to meet family and friends. Most stations also function as interchange hubs, providing connections between different transport modes. (Goggin, 2011)

2.2 Operational Areas of railway station

There are four main functional areas typically housed in most stations as a general. They are; core, transition, peripheral, and administrative areas. The main users of these four functional areas are generally passengers, staff, guest and visitors.

- Core areas: focus on processing passengers. It includes ticketing, information, baggage handling, reclaiming, and waiting.
- Transit areas: connect transit facilities in the core areas to the transportation modes. It includes restrooms, telephones, and commercial spaces.
- Peripheral areas: support circulation outside the main buildings. They often include platforms, tracks, and vehicle service spaces.
- Administrative area: control both traffic and station management. These areas can be isolated from other facilities or inserted among them.

These operational areas of railway station are mostly used in interregional big stations where it is also impartial applicable for light rails transits.

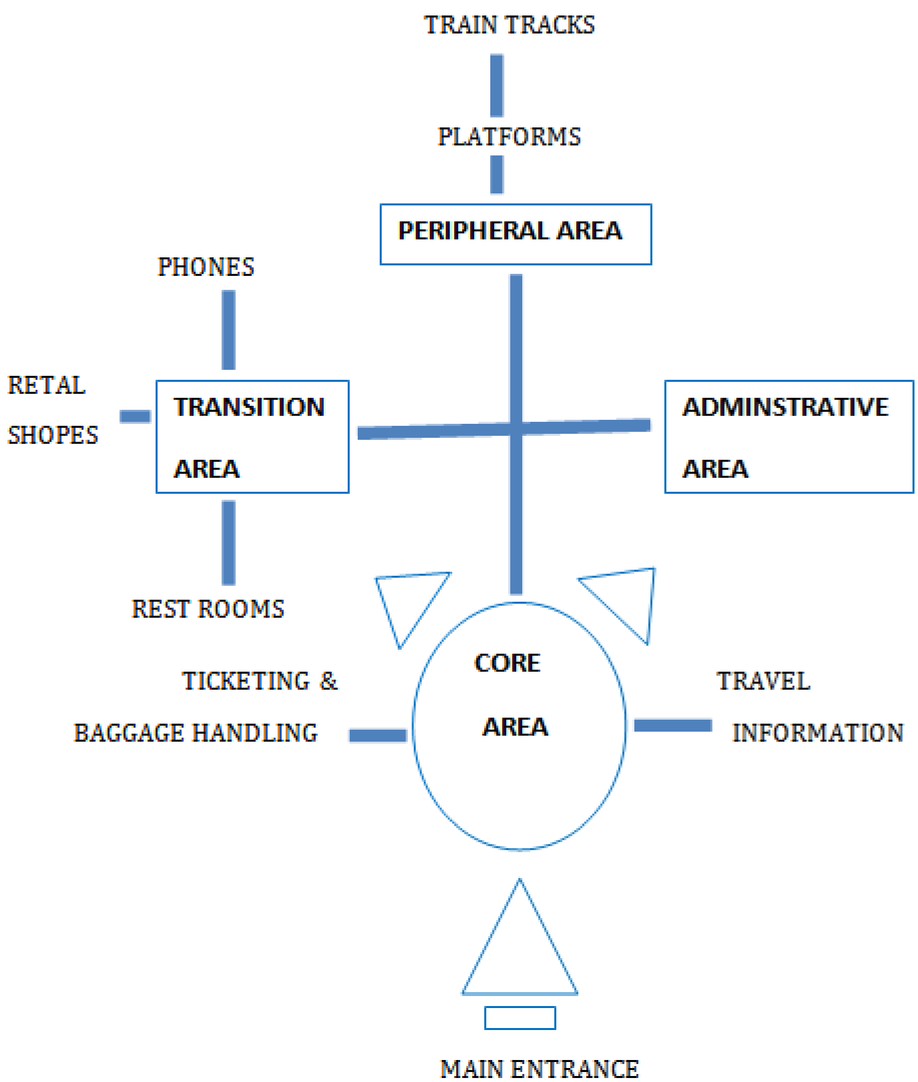


Figure 1, Operational areas of railway station

2.2.1 Station platform

Train stations comprise of the building(s), site access, parking, tracks, platforms, and all appurtenances necessary to conduct transportation. Station platform is a raised structure or area within a station providing access to or from a train. Station platforms shall be located on straight track unless the particular geographical characteristics of the site and the characteristics of the railway at the proposed location of the platform do not provide a reasonable opportunity for achieving. The Addis Ababa LRT platforms (stations) will be located at-grade, below ground and on structures. The East-West route has 22 platforms, among which 5 are elevated platforms, 1 underground platform and 16 ground platforms. On the other hand the North-South route has 22 platforms, among which 9 are elevated platforms （5 common platforms at the common line, 2 underground platforms and 11 ground platforms. (Limited C. R., Preliminary Design for Ethiopia Addis Ababa LRT phase I, 2009)

2.2.2 Depots

The Depots are located near the extremities of the East-West line, and at the southern end of the North-South Line of Addis Ababa LRT. The Depots will provide facilities for the servicing, repair, maintenance and stabling for the light rail vehicles (LRVs). The main workshop will be equipped with specialized machinery to maintain vehicle components such as wheels, bogies, brakes and electronic controls. The Depot areas should allow additional space for an increase in the stabling sidings as the number of LRVs increases. (Limited C. R., Technical Specification of Vehicles, 2013)

2.2.3 Track Switch, Turnout and Crossing

Switch: It is a pair of moveable rails with their fastenings and operating rods, providing a connection over which to divert the movement of rolling stock and other on-track equipment. Switches may be operated by power operated switch and lock movements; electrically locked hand-operated machines; or hand-operated trail able switch stands, depending on the location and purpose of the switch.

Turnout: It is a particular grouping of two tracks joined together with a frog and switch so arranged to allow for the transfer of rolling stock and on-track equipment to cross from one track to another. For a turnout on main track, its rail type shall be identical with main track. (Gebeyehu, 2012) This switch and turnout are located at the start points (Piazza, Torhyloch, Ayat and Kaliti) and Lideta and Meskel Square where the two line merges and separate for the common route use.

2.2.4 Passenger Information

Information systems on stations are variously referred to as a Passenger Information System (sometimes referred to as PIS) or Passenger Information Display (PID). Passenger information systems are essential for any railway. One of the most common complaints by passengers on railways is the lack of up to date and accurate information. There are two types of information constant and instant. Constant information can be described as that which describes the services and fares available and which changes only a few times a year or less. For instant systems, it can be assumed that passengers require knowing: (ARORA, 2008A)

- The time now
- The destination and expected time of arrival of the next train
- The stations served by this train
- Where the train will stop - for variable length trains
- Other destinations served from this station and from which platform

2.3 Public Rail Transport Planning and operations

Public rail transport planning and operations are a highly complex task according to Thomas Lindner, [2000]. Too many objects interact with each other to be manageable simultaneously. Various sub problems of different nature like network design, scheduling or routing occur, and the solutions of most of those sub problems depend on the solutions of the other sub problems. Analytical models get more and more important in supporting managerial decision-making. The fundamental mathematical model he used here is the Periodic Event Scheduling Problem (PESP).

Thomas also divides the operation planning in to several steps due to the tremendous size of the public rail traffic system. In a first step, the passenger demand has to be analyzed. As a result, the amount of travelers wishing to go from certain origins to certain destinations is known. This is important, to determined lines or routes. The second step is train schedule planning. All arrival and departure times of the lines are fixed, now engines and coaches have to be assembled to trains, which are assigned to lines. The third step is the crew management, which means the distribution of personnel in order to guarantee that each train is equipped with the necessary staff.

2.3.1 Line planning Problem

The line planning problem is defined as follows: for a given railway infrastructure (given as a set of interconnected blocks and stations), traveling times on each block and passenger demand determine the set of lines and frequencies so as to satisfy some operational constraints, such as demand satisfaction, and optimize some operational goal, such as costs and service levels.

(Bussieck. M.R, 1996) Present a MIP model for choosing a set of lines and their frequencies so as to maximize the number of direct travelers. The authors assume that passengers between any two stations use a shortest path with respect to travel time or travel distance. The lines are chosen so that on each segment a predetermined frequency of trains is ensured. The model does not take into account the operational costs of the lines. These costs are somewhat bounded by the frequency constraints, namely, the total number of trains that can be run is bounded. The direct-travelers variables represent the number of direct travelers between each pair of stations on each line, this leads to a huge model which is unsolvable for real-world instances. The model size is reduced significantly by changing these variables to represent only the number of direct travelers between each pair of stations, without taking into account what line is used (assuming that the distribution of travelers to lines is carried out later). The reduced model is solvable in a reasonable time after introducing some cutting planes. The solution of the reduced model is a lower bound on the optimal solution of the original problem. In addition, a feasible solution for the original problem can be derived from this optimal solution.

2.3.2 Train Timetabling Problem

The train timetabling problem is defined as follows: for a given set of lines, frequencies and possibly departure times of each train, determine the arrival and departure time at each block and station such that safety constraints are satisfied and possibly other goals are achieved. Train timetabling is divided in to two. The first one is cyclic timetabling which is mainly used in passengers' trains scheduling where passengers' demands can be estimated far in advance, journey times vary between a few minutes to a few hours and the frequencies of lines are relatively high. In a cyclic timetable, each trip is operated repeatedly once or a few times during each cycle. From the passengers' point of view, such timetables are more convenient because all they need to remember are the times in a cycle when trains arrive at their station. The second one is non-cyclic timetabling which is mainly used in freight trains scheduling where the demand for trains is irregular and may be unknown in advance and the travel time of each train may vary from a few hours to a few days.

(W.Ukovich, 1989) Propose a general mathematical model for scheduling activities of periodic type. The Periodic Event Scheduling Problem (PESP) is to set the times (in a period) of a given set of periodic events so as to satisfy a set of periodic constraints. Each periodic constraint represents the relationship between an ordered pair of periodic events. The events are scheduled for one period (cycle time) so that later this period can be repeated over the planning horizon. In addition to the general model, the authors present more specific cases on which the model can be applied such as: periodic job-shop, transportation scheduling and traffic light scheduling. The authors conclude with a suggestion to adapt the general model to specific problems in order to improve computational efficiency.

2.4 Single track and Double track operations

Infrastructure configuration, timetable design and delays play important roles in the competitiveness of railway transport operation. This is especially true on single-track lines where the run times and other timetable related parameters are severely restricted by crossings (train meetings). The crossings also make the lines' operation more sensitive to disturbances. Double-tracks with mixed traffic also show these features.

(E.R, 1974) Presents a simple model that can be used to describe the scheduled delay as a function of the traffic intensity. The main timetable assumption, that makes the study general, is that trains' departure times are independent random variables that are uniformly distributed over the defined time period. Given this randomized timetable, the time costs (delays) for crossings and over takings are calculated. One conflict at a time is identified and resolved and so the trains are treated pair-wise. (A.J, 1987) Presents a method to find the best locations of crossing stations for a given timetable and line alignment. The method focuses on frequent small delays that can be managed by longer crossing stations (i.e. partial double-tracks) and time supplements. Longer delays are handled by secondary crossing stations. The study concludes that single-tracks work quite well, as long as infrastructure and timetable are coherent and delays limited. (Higgins, 1995) Address the overall timetable reliability in terms of schedule adherence. They present a model that can be used to prioritize investments designed to improve timetable reliability. Using their model it is possible to compare effects of track, station and rolling stock projects.

Double-track lines operated with mixed traffic show properties similar to those of single-tracks. In this case overtaking implies scheduled delays as well as risk of delay propagation. (Wendler E., 2008) Provides a general introduction to capacity analysis based on queuing theory. He considers both scheduled delays and knock-on delays and emphasizes the usefulness of queuing theory for long and medium term studies, where the requested train paths are not known in detail. (R.J, 2001) Provide a model to forecast knock-on delays due to differences in speed of trains on double-track line sections. These speed differences may be caused by different train services, or by primary delays. Train arrivals are modeled as a stochastic process, requiring train frequencies of each service only. Running time distributions for each train service is then obtained solving a system of linear differential equations. The model seems to be useful for analysis of isolated track sections between overtaking stations and the approach is well suited for long term planning where no detailed timetable data is available. All together, these contributions help to enhance future railway operation and thus increase the competitiveness of the railway even more.

Stockholm, 2010 shows the advantages of simple models for analysis of railway operation. He presents two tools for infrastructure and timetable planning. He shows how the infrastructure can be analyzed through fictive line designs, how the timetable can be treated as a variable and how delays can be used as performance measures by using a simple analytical model SAMFOST and a combinatorial, mathematical model TVEM. A simplified analytical model SAMFOST (Simplified Analytical Model for Single-tracks), has been developed to calculate the crossing time as a function of infrastructure configuration, vehicle properties, timetable and delays for two crossing trains. TVEM, Timetable Variant Evaluation Model, is a generic model that systematically generates and evaluates timetable variants on double-track lines. This method is especially useful for mixed traffic operation where the impact of the timetable is considerable.

(Kaspi, 2010) presented the train planning problem by integrating the line planning problem and timetabling using ILPTP (integrated line planning and timetabling problem) and O-D (origin–destination matrices). He divided the operation planning problems into several sub-problems like Line Planning, Timetabling, Plat forming, Rolling Stock Circulation and Crew Planning. In his study, he focuses on quality of service aspects derived by decisions made during the line planning and timetabling phases. The quality of service is measured in terms of total time spent by the passengers in the railway system, including waiting time at the stations of origin, connections and travel time. He formulate an integrated Line planning and Train Timetabling model, devise methods to encode a feasible solution and to quickly evaluate it. He then applies the Cross Entropy meta-heuristic in order to solve the problem by taking the Israeli railway system as a test bed.

(Hansen, 2005) Presented the investigation of train operations in railway stations based on network, timetable and train detection data. The tools TNV-Prepare and TNV-Filter were applied for the analysis of train detection data at the stations. The estimated blocking times, buffer times and track occupancies are compared with real operations data recorded automatically by track circuits according to their research. Their paper presents the objectives and approach applied for a detailed analysis of the variations of train operations at railway stations. It describes the way of estimating the scheduled and real use of track capacity by means of blocking time graphs in order to determine the critical track sections and the resulting time margins. Then, a detailed analysis of arrival and departure delays and speed is performed on the basis of automatically recorded train detection data in order to estimate the corresponding distributions in the case of a major Dutch station.

2.5 Arena Overview

Arena is a flexible, powerful modeling and simulation software tool that allows the user to construct a simulation model and run experiments on the model. The software generates several reports as a result of a simulation run.

2.5.1 The Arena window

After Arena starts, the computer screen shows the Arena window. Figure 2 below shows what the Arena window typically looks like. There are three main regions that can be identified in the main Arena window:

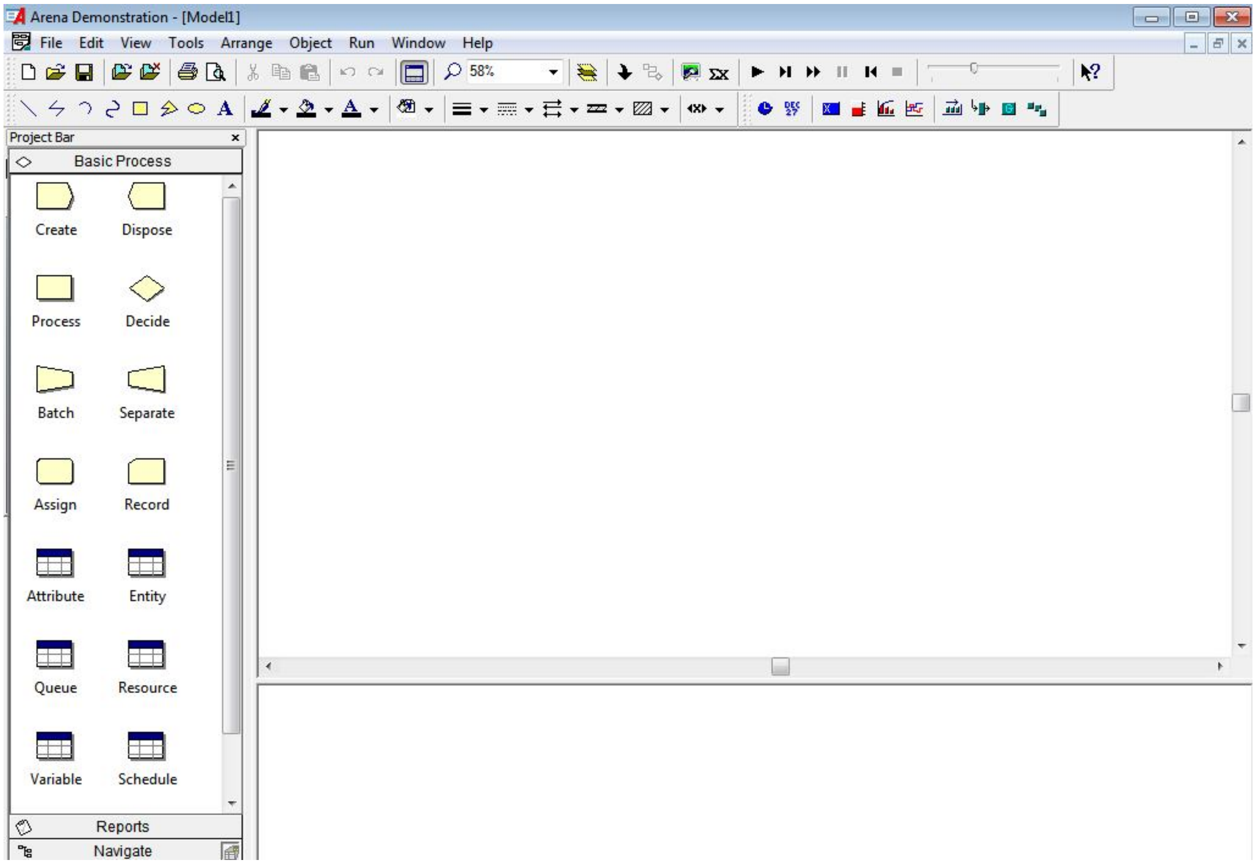


Figure 2, the Arena window

- The Project Bar, located on the left side of the Arena window and below the tool bars. The project bar contains three panels: the Basic Process panel, the Report panel, and the Navigate panel. Every panel contains several modules that are used in constructing simulation models.
- The Model window flowchart view, located on the right side of the Arena window and below the tool bars. This view is actually the workspace for the simulation model. It will contain all the model graphics: the flowchart, animation, and other drawings of the model.
- The Model window spreadsheet view, located on the right-hand side and below the flowchart view. The spreadsheet view shows the model data.

2.5.2 Arena Modules

The construction of simulation models with Arena, involves using modeling shapes, called modules, from the Basic Process panel. These modules are used as the building blocks in constructing a simulation model. There are two types of modules on a panel:

- Flowchart modules. The user places flowchart modules in the model window and connects them to form a flowchart, which describes the logic of model. The most common flowchart modules are: Create, Process, Decide, Dispose, Batch, Separate, Assign, and Record.
- Data modules. The user can edit these modules in the spreadsheet interface. These modules are not placed in the model window. The most common data modules are: Resource, Queue, Variable, Schedule, and Set.

A model is constructed in the model window flowchart view, which is the workspace of the model. From the Project bar, the user drags the flowchart modules needed into the model flowchart and connects the modules together. To edit a flowchart module, the user either double-clicks on the module shape and fills in the form, or edits its data in the spreadsheet. The definition of a data module is carried out by clicking on the shape of then module in the Project bar to activate its spreadsheet. Then the user can edit the data of the module. Flowchart modules exist both in the model workspace and as a row in the spreadsheet. Data modules exist only in spreadsheet view. Data modules can be added or deleted via the spreadsheet, while flowchart modules can only be added or deleted by placing the object or removing the object from the model workspace.

2.5.3 Using Arena

To build a simulation model and to carry out simulation runs with Arena, a user performs the following steps:

1 Construction of a basic model. Arena provides the model window flowchart view, which is a flowchart-style environment for building a model. The user selects and drags the flowchart module shapes into the model window and connects them to define process flow of the model.

2 Adding data to the model parameters. The user adds actual data (e.g., processing times, resource demands, others) to the model. This is done by double-clicking on module icons and adding data.

3 Performing a simulation run of the model. The user runs the simulation and examines the results.

4 Analysis of the simulation results provided by the automatic reports of Arena. The user can expand the statistics.

5 Modifying and enhancing the model according to the user needs.

2.5.4 Arena Hierarchy and Analyzers

In Arena modules are defined utilizing other modules. The base modules in Arena hierarchy represent SIMAN language. A specific set of modules forms a panel. A number of panels are a template (e.g. SIMAN, Arena, Basic process, etc.)

Arena Input Analyzer

The Input Analyzer is a standard component of the Arena environment. It is used to determine the quality of fit of probability distribution functions to input data. It generates sets of random data. The data files processed by the Input Analyzer typically represent the time intervals associated with a random process

Arena Process Analyzer

The Process Analyzer assists in the evaluation of alternatives presented by the execution of different simulation model situations. This is useful to simulation model developers, as well as decision makers. The Process Analyzer is focused at post-model comparison of models. The role of the Process Analyzer then is to allow for comparison of the outputs from validated models based on different model inputs.

Interpreting Results/Reports in Arena

There are ten reports provided by Arena. They are: category overview, category by replication, activity areas, entities, processes, queues, resources, transfers, user specified and frequencies. In general, Arena is a very versatile integrated simulation development tool. Constructing a simulation model involves identifying one or more flow objects known as entities that flow through the system and then building a flowchart of the model using Arena's flowchart modules. The model is then enhanced by editing some of the data modules. Arena provides a simple method to setup the simulation parameters and the model input parameters. A variety of reports with the corresponding simulation results is produced. (Garrido, 2009)

2.6 Railway Safety System

The railroad is still undeniably one of the safest modes of transport in levels of safety compared with the other mode of transport. However, as complex systems, despite the high technical and organizational effort to prevent accidents, sometimes such accidents happen with catastrophic consequences. It is recognized that such accidents rarely have simple causes and behind the obvious or direct causes, such as human errors or indirect concealed causes. The main objective of the safety work is therefore to avoid these causes, if possible, or to control them. Improving network and effective operations are the main technological improvements to railroad safety.

2.6.1 Railway Accident

Accident is an occurrence in the course of working of railway which does or may affect the safety of the railway, its engine, rolling stock, permanent way and works, fixed installations, passengers or servant or which affect the safety of others or which does or may cause delay to train or loss to the railway. The types of railway accident that may occur are:

- ❖ Derailment- may be at plain track, curves or junctions.
- ❖ Collision- may be head-on, rear-end, and grade (level) crossing
- ❖ Fire and violent eruption (including sabotage or terrorism) and
- ❖ Others (falls from train, collision with people on tracks)

The main causes of such accident can be divided into three groups

a. Inadequate technical activities.

b. Ineffective communication and organization (management).

c. Weaknesses in safety culture.

Example of such causes include

- ✓ Mechanical problems (signal failures, equipment failures and train control)
- ✓ Human factors (train operation)
- ✓ Infrastructure defect (track, roadbed and structure)
- ✓ Environment or external factors (weather-related, obstruction)

Therefore railway operation safety is the most indispensable one that everybody (the staff, society, management and technical persons) have to give attention and fulfill their responsible as much as required. This is important for the railway operation of Ethiopia as it is on construction.

Ethiopia is constructing a new national wide rail networks which contains both single and double tracks even if most of the lines are single tracks according to the government plan. But the Addis Ababa LRT is totally double tracks. Now Ethiopia has launched the construction of a 5,000 km railway network in two phases which aims to link the capital, Addis Ababa, to various regions of the country and 34km Addis Ababa LRT which is part of the country's five-year transformation plan and the newly established Ethiopian Railway Corporation is responsible for the supervision of the construction. The new railroad network is planned to have at least 8 main routes that extends to all compass points. The rail line will expected to link not less than 49 urban centers, where railway stations are to be established. The proposed rail line crosses the borders of all regions, except Gambella. The network connects, among others, the Chartered Cities Addis Ababa & Dire Dawa, 7 of the 9 State capitals, and towns bordering Sudan, Kenya and Djibouti. The construction of the railroads required high finance, while creating ‘job opportunity for several hundred thousands of people. Though the construction of the new railroad system is to be conducted in two phases, it is basically one program which is pivotal to the renaissance of the nation. The Addis Ababa LRT also conducted in two phases. The initial stage covers 34km while the long-term will cover 74km in two main lines namely East-west and North-South. (Corporation, 2011)

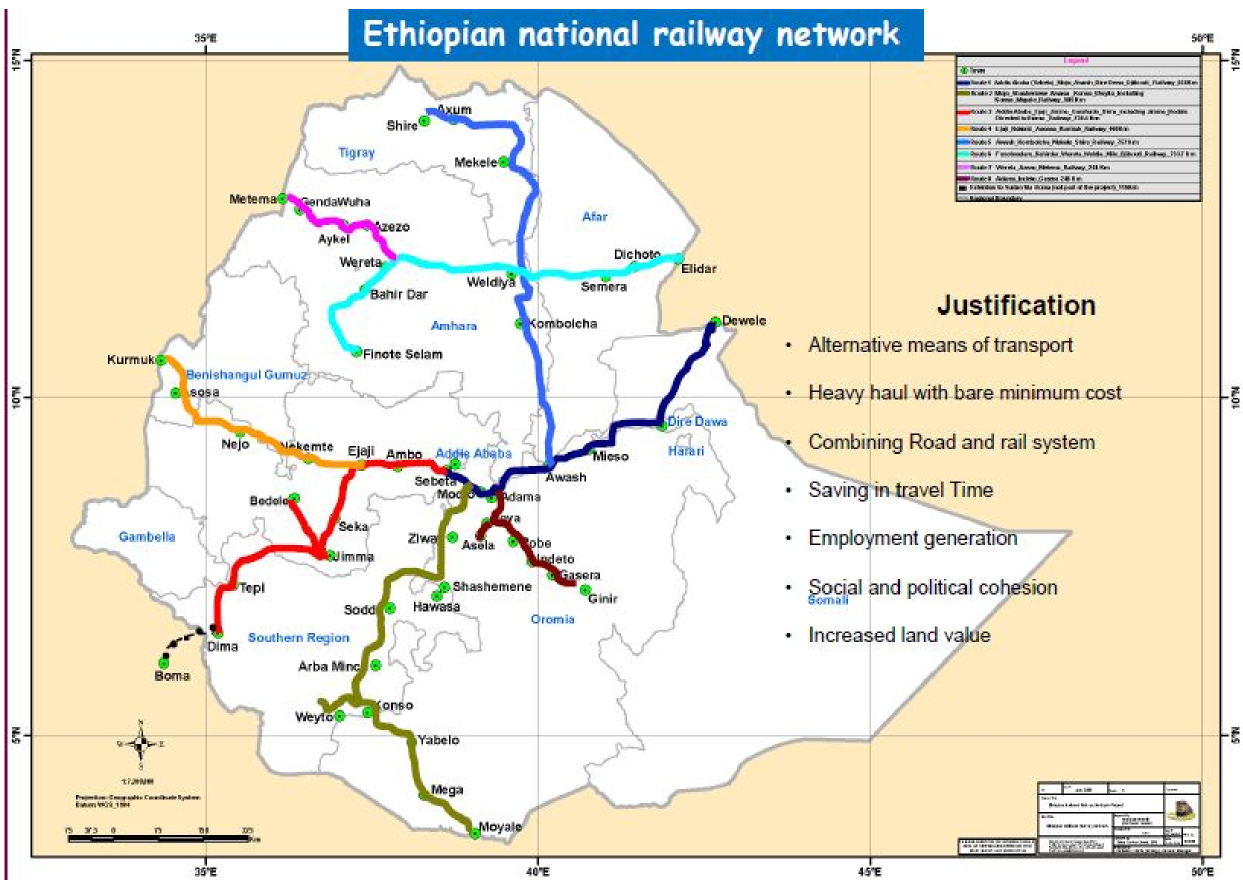


Figure 3, Ethiopian new rail network plans

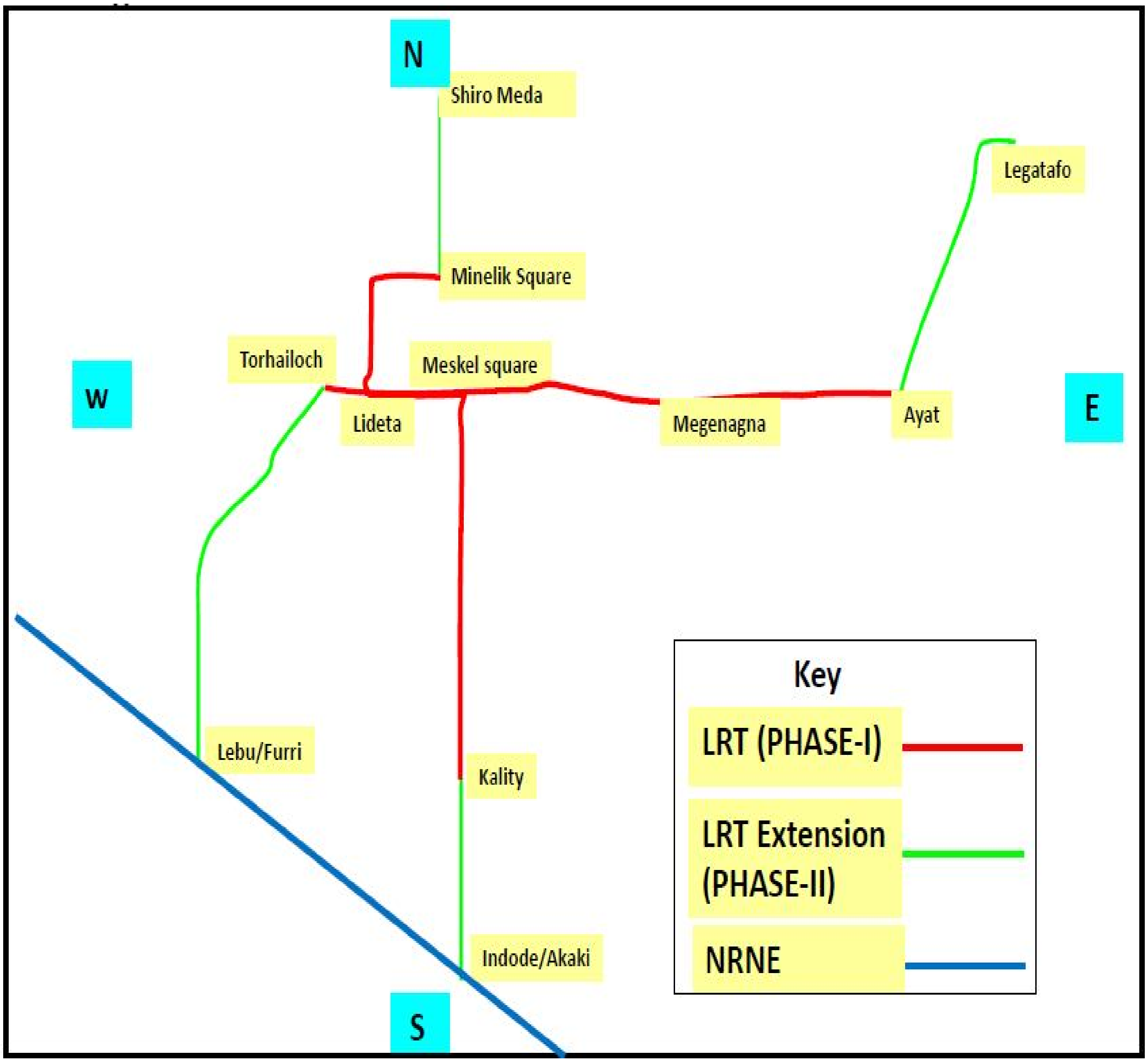


Figure 4, Addis Ababa LRT

2.7 Summary of the literature review

From the comprehensive literature review it becomes clear that there exist only very few number of publications, which take into consideration train operation system development at railway stations and routes. Different researches have been done on railway planning, operation and safety management for different countries in the railway transport history which is the main important in the railway operation at different times as discussed above. (R.M.P, 2000b) analyzed train detection data and train delays at stations using the recently developed tools TNV-Prepare and TNV-Filter. (Lindner, 2000) deals about Public rail transport planning and operations by dividing in to three steps as discussed above by using fundamental mathematical model the Periodic Event Scheduling Problem (PESP). (Bussieck. M.R, 1996) present a MIP model for choosing a set of lines and their frequencies so as to maximize the number of direct travelers. (Stockholm, 2010) shows the advantages of simple models for analysis of railway operation using the analytical model SAMFOST and TVEM. (Hansen, 2005) presented the investigation of train operations in railway stations based on network, timetable and train detection data using the tools TNV-Prepare and TNV-Filter. (Kaspi, 2010) presented the train planning problem by integrating the line planning problem and timetabling using ILPTP (integrated line planning and timetabling problem) and O-D (origin–destination matrices).

These researches were done to solve their particular research problems and recommend the future work also to fulfill the gaps in the railway operation. None of the above researchers use the tool Arena5 simulation model in the analysis of train operation. Railway operation includes network, timetable, rolling stock and man power integration. Different countries have their own operation planning depending on their transport demand and capacity. This paper deals with the train operation system development for railway transport of Ethiopia, Addis Ababa LRT. Addis Ababa is a multi nation with dense population where there is a huge passenger transport needs and economic development which requires modern transportation system. To do this a system analysis approach is presented for investigation of train operations in railway stations and routes based on network, timetable and train allocation data. The network and train schedule analysis are evaluated using the simulation model software Arena5 for the investigation of Addis Ababa LRT.

The main objective of this research is to analysis and develops the train operation system for Addis Ababa Light Rail Transit based on infrastructure; timetable and identifying delay factors that may face the rail transport of Ethiopia. The train operation system analysis for the railway transport of Ethiopia is important because operational designed schedule failure causes train delay. Train delays and route conflicts are one of the most important performance indicators of railway operations, which result from many related factors, such as the layout of the infrastructure, the occupancy of the infrastructure, the variation of running times, arrivals and departures, resource limitation and the traffic control which is the research gap of this paper. Therefore the knowledge of train operation and factors that cause timetable delay is very important to avoid the schedule conflicts. This can be done by showing how the infrastructure can be analyzed through fictive line designs, how the train schedule can be treated as a variable and how delays can be used as performance measures using the Arena5 simulation model. All together, these contributions help to enhance future railway operation and thus increase the competitiveness of the railway transport of Ethiopia even more. The paper concludes providing the most important standard train operation for the Addis Ababa LRT and recommends for the future works especially when the train actual operation will start.

CHAPTER THREE

RESEARCH METHODOLOGY

Research Methodology is a procedure that describes clear and systematic steps to guide researcher in the process of completing the research. Its purpose is to achieve the objective of the study.

3.1 Research Process

This paper is done through the scientific research process and focus on the Addis Ababa Light Rail Transit (LRT) train operation system development case study. To do this, first different literatures, reference books, internet web-sites, articles and international journals those focus on train operations were accessed and the standardized railway operation is understood. Then the research problem and objective of the research were discussed. On the other hand scope of the research, significance of the study and the thesis structure were argued. The passenger transport operation factors are identified and discussed. The route corridors conceptual model is made. Then the input data were identified and made ready to the software usage. The probably assumption for the passenger flow of the Addis Ababa routes are fitted using the Poisson distribution summary from the input analyzer. The simulation software is opened and the input functions were filled at necessary place for the modules Create, Assign, Station, Process and Route. The model window flowchart is made and the simulation run setup is done. Then the simulation model is run and examines the results. The result is well discussed and the simulation model is verified and validated. Finally the paper work is concluded and the necessary recommendation and future work is mentioned.

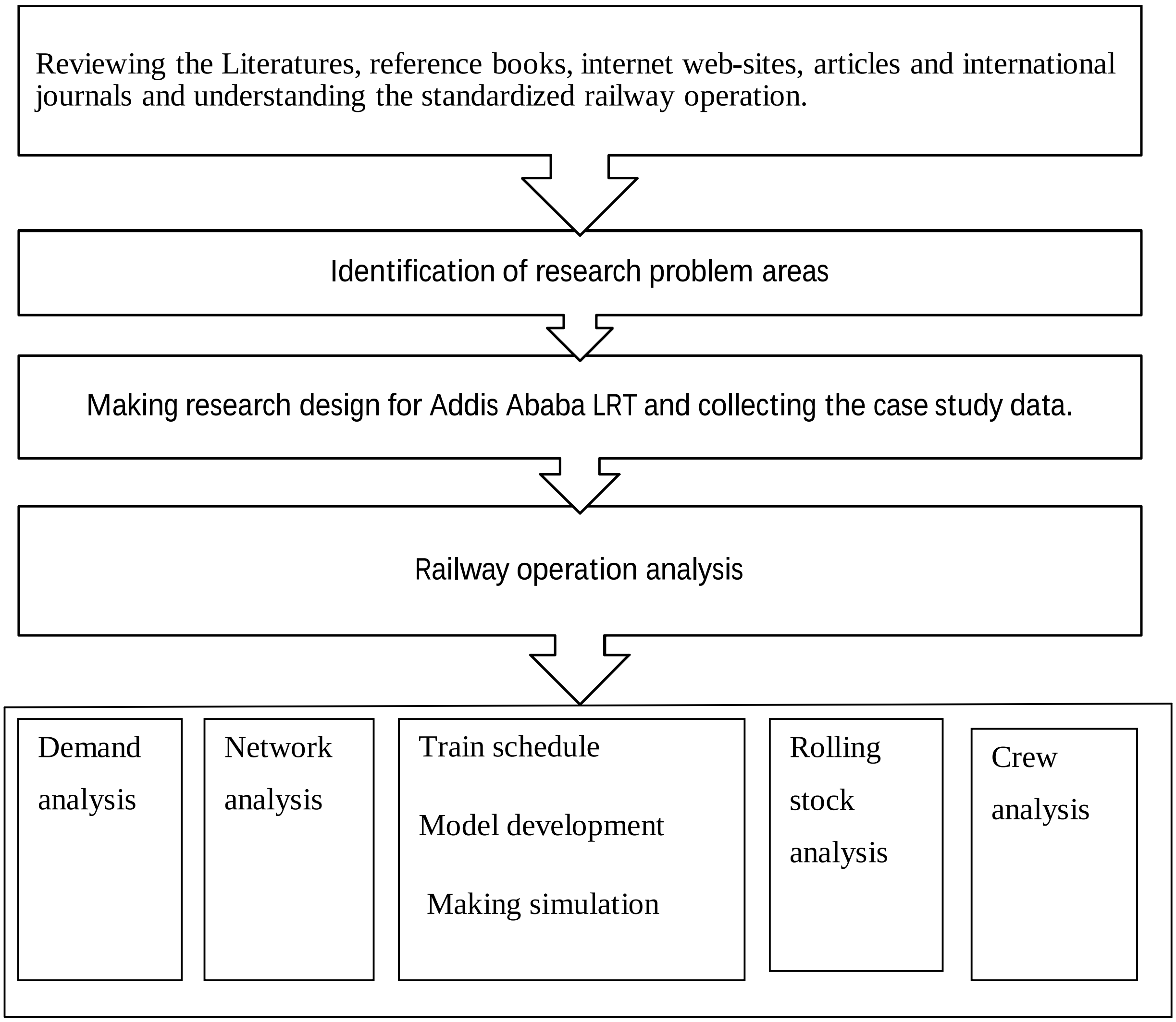


Figure 5, Research process frame works

3.2 Research Approaches

The case study of this research is" Addis Ababa Light Rail Transit "and the study mainly concerned on train operation system development for the two main routes: from piazza to kaliti and torhyiloch to Ayat through the common route "Lideta to Meskel square". To make train operation system development, and to achieve the stated objective, both quantitative and qualitative methods were used for data collection and data analysis during the researching. The rolling stock analysis and crew analysis are discussed qualitatively while the network analysis and train schedule analysis are analyzed using Arena5 simulation model software and the report results are discussed.

3.3 Data Collection Approaches

The data for analysis were taken from the Ministry of Transport and Communications (MoTaC) and Ethiopian Railways Corporation (ERC) for the case of Addis Ababa Light Rail Transit. These data are: hourly demand distribution on and off peak-hour, train average speed, train loading capacity per trip, number of tramcar assigned for the route, route length, operation hour per day, maximum waiting time, number of stations and platforms, average length between platforms. These data are the Addis Ababa LRT design feasibility studies and it is the operation planning data. Thus train operation planning problems i.e. Line Planning, Timetabling, Plat forming, Rolling Stock Circulation and Crew Planning are the most common important train operation factors. In this study, we focus on the network and train scheduling phases because it will be vast if we focus on the all operation factors so this paper is limited to study on the network analysis and train scheduling for Addis Ababa Light Rail Transit (LRT) in detail using the Arena simulation model software even if the others are also discussed. These improve the quality of services since the quality of service is measured in terms of total time spent by the passengers in the railway system, including waiting time at the stations of origin, connections and travel time.

3.4 Software used

The software used for the network and train schedule analysis in this paper is Arena5. Arena is the most effective when analyzing complex, medium to large-scale projects related to supply chain, manufacturing, processes, logistics, transportation, distribution, warehousing, and service systems. It is a software package used for graphically describing Simulation Analysis (SIMAN) models. It is the preeminent solution for better business decisions with simulation. It is an easy-to-use, powerful tool that allows you to create and run experiments on animated models of our systems. Arena modeling constructs, called modules, are grouped into templates for arrangement into hierarchical model diagrams. Arena's modules represent types of data and commands within the software. These modules effectively represent a vendor-specific simulation language.

3.5 Data Analysis Method

In this phase the demand analysis for on and off-peak hour, network analysis, train scheduling, rolling stock analysis and crew management analysis were done.

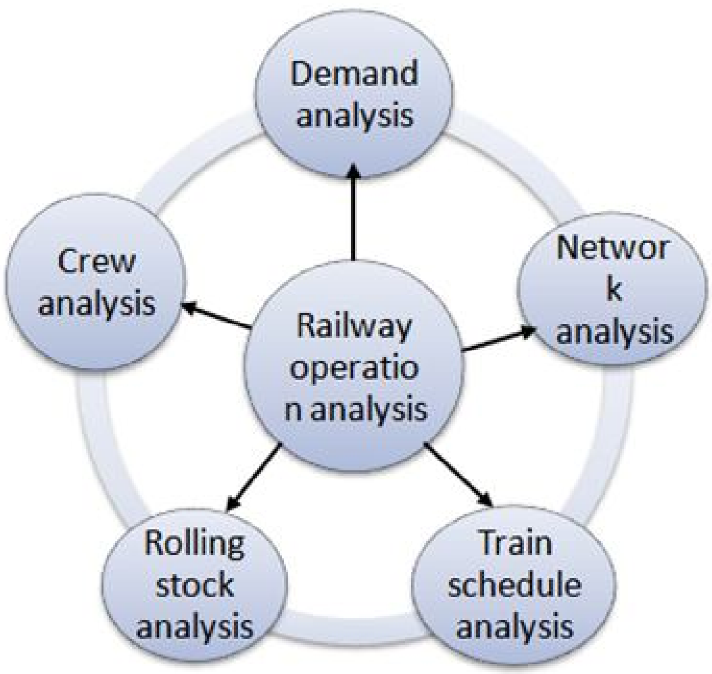


Figure 6, Railway operation factors

For the train scheduling data analysis and the network analysis the conceptual and simulation model were developed. The simulation model was done by the software package arena5. The input data were added to the software by function in the Arena modules. The passenger distribution probably assumption is fitted using Poisson distribution summary and assigned in the function. Then the software program is well done and run after the run setup is fixed. The software output report is discussed and the input parameters which affect the train operation were identified. The verification and validation of the process proposed were made. Finally, the paper is concluded and the appropriate train operation without delay is recommended.

CHAPTER FOUR

Analysis and Discussion

4.1 Addis Ababa East-West and North-South Corridor

The Addis Ababa LRT covers the East-West and North-South transport corridors. The initial phase of the project is 34km length and expected to extend up to 74km in the long term plan.

The East-West corridor passes through the city center from the eastern peripheries of the city to the west. In its final phase, the East-West Major residential and real estate development locations at Ayat, CMC, Gurdshola and the area west of Torhailoch are accessed through this route. Meskel Square is the major public gathering location in Addis Ababa and Meganagna Square is an important transit hub and commercial centre. The East-West corridor crosses the ring road twice at Megenagna and Torhailoch. In its final phase, it is proposed that the LRT route will connect to the future national railway hubs at Legetafo and Sebeta. The initial phase of this route is 17.1km length and expected to extend up to 37.7km in the long term plan.

The North-South corridor is a heavily-used route; it is utilized to access Africa's largest open market at Merkato. The initial phase of the project starts from Giorgis (Piazza) in the north and heads a little distance to the west to access Merkato and Autobus Tera (the Intercity Bus Terminal). Afterwards, the route heads south until it joins the East-West route at Lideta. From Lideta to Meskel Square both services have a common route until the North-South route bifurcates to the south heading to the new Gotera interchange, Saris and Kaliti. In its final phase the route will cross the ring road at Kaliti interchange and extend to a new railway hub at Akaki. The northern end of the route will be extended from Giorgis to Shiromeda. The initial phase of this route is 16.97km length and expected to extend up to 36km in the long term plan.

The LRT route will connect eight major transit interfaces to provide an integrated transit network. With transfers at these locations, passengers will be able to move quickly from suburban areas to the city centre and vice versa. The major transfer points are:

- Megenagna taxi/bus station
- Stadium-Lagar taxi/bus station
- Mexico Square
- Giorgis taxi/bus station
- Autobus Tera (Intercity Bus Terminal station)
- Lideta station
- Meskel Square
- Gotera Interchange

In addition to these major connection points, there are other stations where heavy traffic flows are anticipated such as Torhailoch, Urael, Hayahulet, Ayat, Saris and Kaliti. Moreover, stations will be located at reasonably tolerable walking distances which will facilitate foot access.

The Addis Ababa LRT stations will be located at-grade, below ground and on structures. Despite the variety of the locations, standard details and a common theme should be introduced to link all the station structures to the LRT system. The exciting possibilities for station sites when developed as commercial enterprises, with resulting financial advantages for the LRT system, particularly at "Transit Hubs", is considered during the stations design. The heavily used at-grade stations and all stations on viaducts will be reached by overhead footbridges. Underground stations will have subway accesses. The at-grade stations will also have pedestrian crossing access for use by the handicapped, the infirm and others. All 'major' LRT stations will be provided with either footbridge or subway access. It should be well designed, pleasing to the eye, comfortable and convenient for the passenger as well as efficient in layout and operation. Therefore it must be properly managed and maintained and must be operated safely. Eventually it is expected that all stations will be equipped with dedicated access for safety reasons.

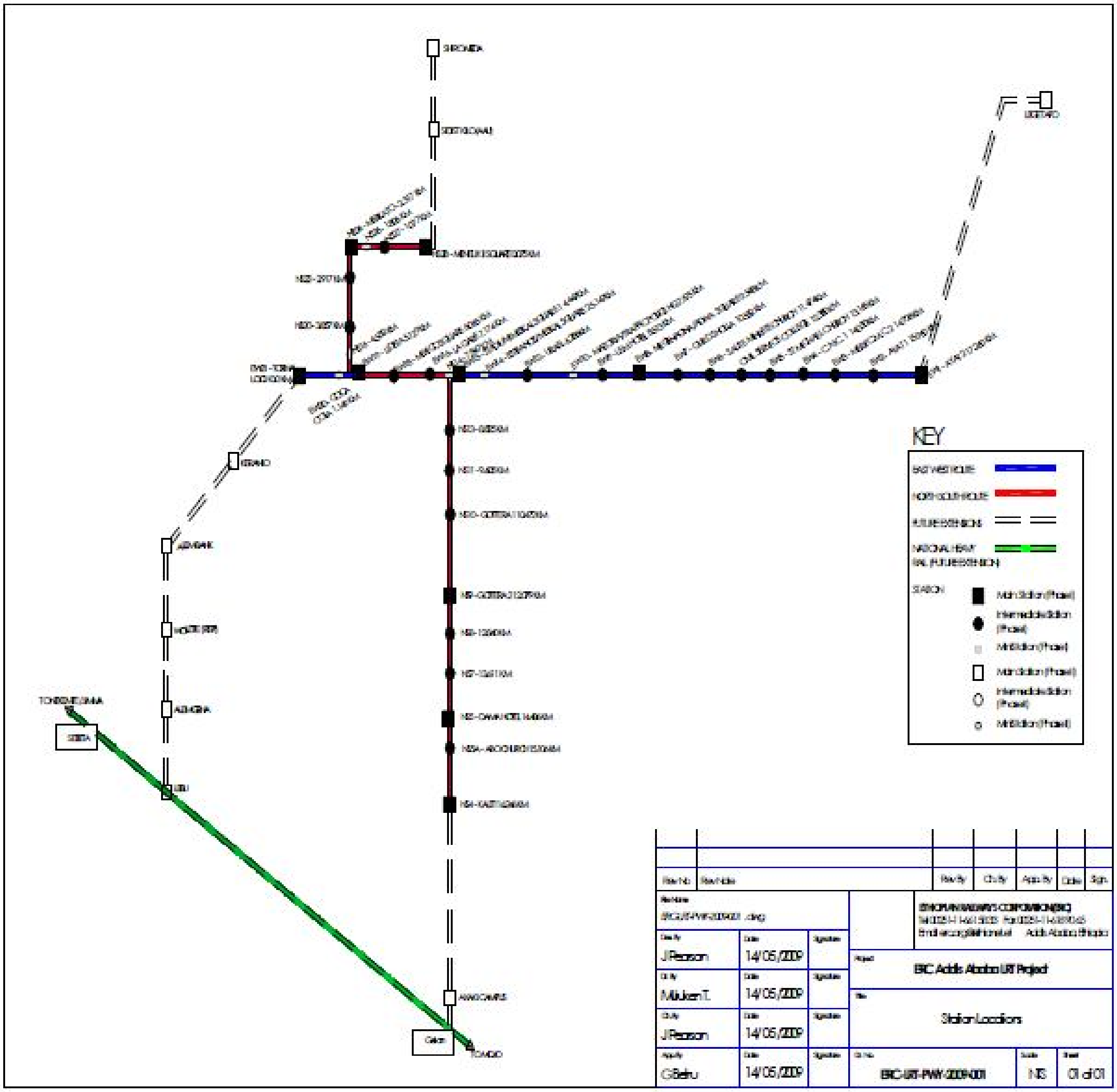


Figure 7, Overall Schematic Diagram of Addis Ababa LRT

4.2 Passenger Transport Operations Analysis

Nowadays, public rail transport operations are a highly complex task. Too many objects interact with each other to be manageable simultaneously. Various sub problems of different nature like network design, scheduling or routing occur, and the solutions of most of those sub problems depend on the solutions of the other sub problems. Due to severe competition from other transportation modes, the rail industry is eager to improve its operational efficiency and rationalize its operations and decisions. Analytical models get more and more important in supporting managerial decision-making.

Due to the tremendous size of the public rail traffic system, the Operation planning process is divided into several Steps. In a first step, the passenger demand has to be analyzed. In order to establish a customer-oriented transportation service, the passenger demand or traffic volume also must be given or estimated. As a result, the amount of travelers wishing to go from certain origins to certain destinations is known. As a subsequent task, lines where trains run are determined. Also, the frequencies for the lines are determined. Afterwards, in the train schedule planning step, all arrival and departure times of the lines are fixed. This has to be done subject to the periodicity of the system. Now the trains and coaches have to be assigned to lines. This is called planning of rolling stock. A similar task is the crew management, which means the distribution of personnel in order to guarantee that each train is equipped with the necessary staff.

A problem of the decomposition is that the optimal solution for one part serves as fixed input for the subsequent problem. One cannot expect an overall optimal solution in the end. It is even possible that at some point, former decisions have to be changed, and a part or the complete process has to be repeated. Nevertheless, this art graphic provides the inter dependency of traffic operation planning problem into manageable tasks.

4.2.1 Demand Analysis

The major part of the proposed LRT alignment route is located along existing streets which are currently serviced by buses, and taxis. According to Ministry of Transport and Communications (MoTaC), and Ethiopian Railways Corporation (ERC) (2009) the recorded average demand hourly distribution of Addis Ababa LRT in the corridor is shown in the following table.

From(hour)	To(hour)	Approximate percent of Trips in the corridor
0:00	4:00	0:00%
4:00	6:00	2:00%
6:00	9:00	30:00%
9:00	12:00	10:00%
12:00	13:30	10:00%
13:30	15:30	10:00%
15:30	21:00	32:00%
21:00	22:00	4:00%
22:00	24:00	2:00%
Total per 24 hours		100:00%

Table 1, Hourly Distribution of the Demand Based on the LRT Corridor Data

4.2.2 Rolling Stock Analysis

The trips established by the train schedule must be performed by some vehicles (motor unit, coaches) and crews (like engine drivers, conductors etc.). Operation analysis methods for vehicle scheduling in public transportation are very important. Since the dispatch of rolling stock and personnel has the main influence on the overall transport service costs, optimization methods are essential at this step, and other parts of the operation analysis may have to be revised. In the rolling stock circulation problem, one has to determine an appropriate allocation of rolling stock units to the trips to be operated. Relevant objectives to be pursued are service to the passengers, efficiency, and robustness. Service to the passengers' means that on each trip the provided capacity should be sufficient to transport the expected numbers of passengers according to given norms.

The Addis Ababa LRT will have 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. Since each corridor has two start and end points, the tram car units will be assigned equally at the end four stations. They will operate at an average speed of 30 to 40 km/hr with the average dwelling time of 30 seconds at each station. The maximum speed of the tramcar is 80km/hr and one unit of the tramcar is arranged to be operated with the capacity of 286 persons in one tramcar (with 64 seats and 6 standing persons per m2). This operation will be continuing for 16 hours a day. The vehicles shall be able to operate under the ground, on the ground or on elevated lines. It is ensured that the vehicles be able to safely operate at lower speeds with Grade 8 wind (20.7m/s) when operating on the ground and elevated lines and that the empty vehicles be able to safely park on the lines with Grade 9 wind (24.4m/s).The vehicles shall be maintained and checked inside the on-ground depot and parked outside the depot.

4.2.3 Crews Analysis

A set of tasks, which can either be passenger train movements, empty train movements, or shunting activities, must be assigned to train drivers such that each task is covered and each train driver has a feasible duty. In this case, a duty is a sequence of tasks after each other that can be carried out by a single employee on a single day. A duty is feasible if a large set of constraints are fulfilled, e.g. the length of the duty does not exceed the maximum spread time, and there is a meal break in a duty with a certain minimum length, and so on.

Crew management not only consists of dispatching train crews, but also local staff like cleaning staff or ticket office staff. Often, there are complex constraint systems for such duties due to union contracts for break regulations or working times. The management of the railroad operation should ensure that the railroad is operated smoothly and safely. Regular rules and training sessions should be provided to ensure that the qualification of operating crews is maintained and to expand the operating personnel pool. Operational management should consistently allow the operation of trains and associated activities to proceed safely, smoothly, and efficiently by ensuring that the equipment and tools needed are serviceable and available, that there are sufficient numbers of qualified operating personnel, and that all personnel involved are properly coordinated. There should seek uniformity across all train operations, so that training is simplified, operating personnel are entirely interchangeable within various tasks, and misunderstandings about procedure are minimized. Railways must ensure that any type of resource remains in a consistent cycle and balance of locomotives and crews in a corridor have to check up.

4.2.4 Network analysis

The Addis Ababa LRT is divided in to two main route category namely as East-West corridor and North-South corridor. Each corridor has 22 stations with minimum inter stations distance of 525m and 1210m maximum distance. The average interval distance is 815m according to the ERC design data shows. Line is given by a route and a corresponding frequency. The route is given by a path in the railroad track network. The frequency determines how often this line is served in accordance to the schedule period. This is what means by Line planning mean to select lines from a set of feasible lines subject to certain constraints and pursuing certain objectives. Some possible constraints are that there must be enough lines (or trains respectively) to carry all passengers, the capacity of tracks must not be exceeded or that the required trains must be available. Common objectives are minimization of costs or maximizing the number of travelers with a direct connection. The periodicity of the schedule has to be kept in mind when designing line plans.

The line plan serves as direct input for the train scheduling problem, where arrival and departure times for the lines have to be found. Furthermore, the line plan determines which travelers have to change a train during their trip and thus need acceptable connection times. The line or route conceptual model for the Addis Ababa LRT is as shown below.

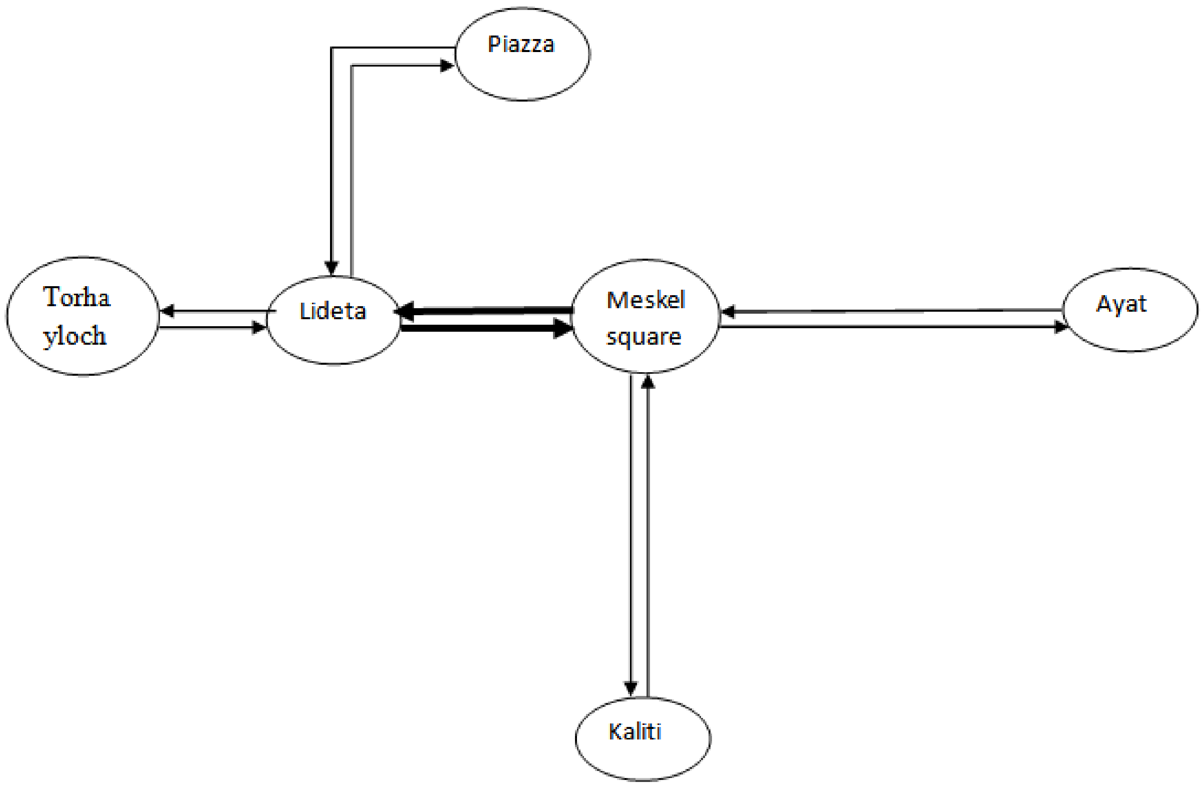


Figure 8, Route corridors conceptual model for Addis Ababa LRT

4.2.5 Train Schedule Analysis

The train schedule is the backbone of public rail transport planning and operation, i.e. the generation of train schedules is the core subject for train operation. A train schedule consists of the arrival and departure times of the lines at certain points of the network. Depending on the required resolution, these points are stations (low resolution) or even switches and important signal points (high resolution). In general, schedules for public transport are periodical, i.e. the schedule is repeated after a basic time period or, for short period. The schedule fixes arrival and departure times for lines and thus train delay time has to be more or less minimized or avoided for all trains of the line. An individual train corresponds to a trip of the line. The following table shows the Addis Ababa LRT routes with its specific justifications.

4.3 Making Simulation model

Modeling methodologies include network representations, process concept, and the entity-attribute-set approach. The model representation is formulated in the way that it represents the appropriate actual working system of the Addis Ababa LRT. The model is encoded by using a simulation programming language using Arena5. Arena icons are connected in a flowchart to represent entity flow. The conceptual model is translated into modeling software. For the constructed simulation model, the "Program" is well made and run.

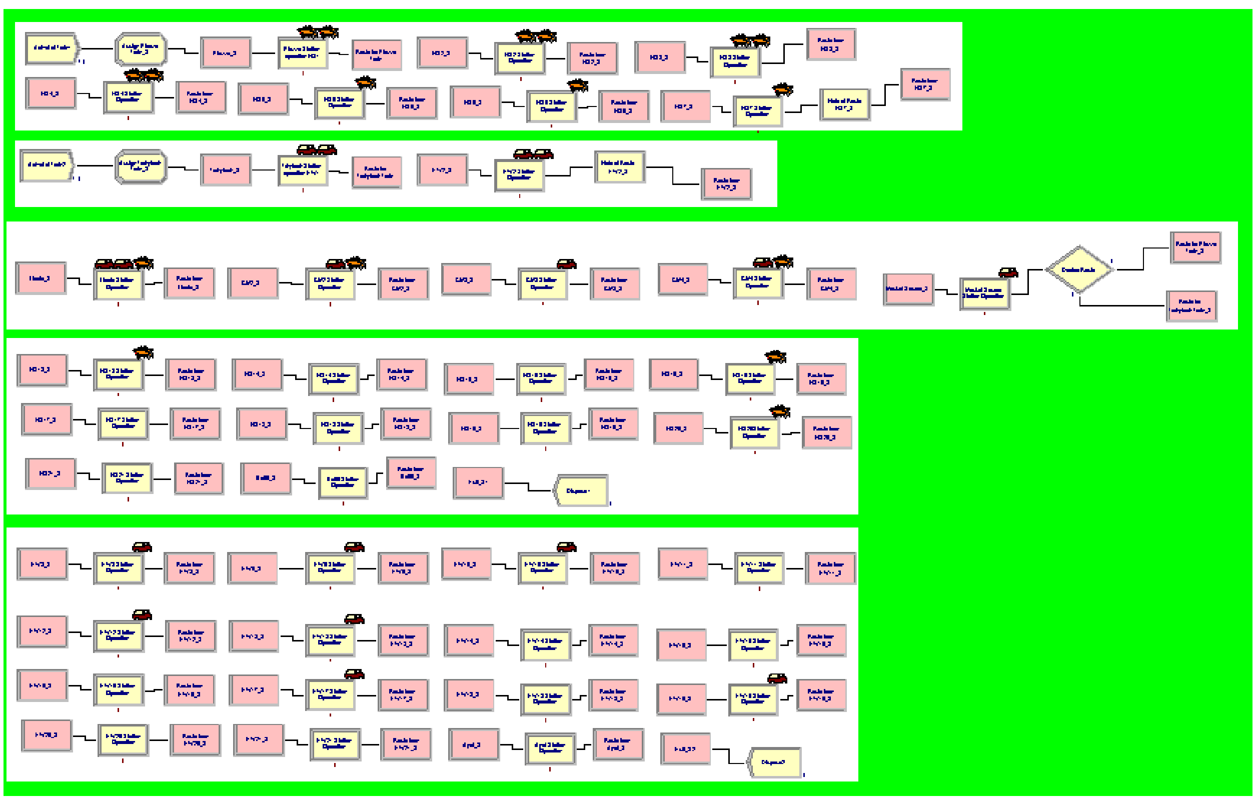


Figure 9, Simulation model over view

Technical Data input for Addis Ababa LRT corridors.

The following table shows the input technical data from which the simulation function input are calculated. The minimum and maximum operation speed is given as 20 and 70 km/hr, and the distance between each station is also given therefore the route time is calculated and added to the software as a uniform function.

S/N	specification	value
1	Test speed	80 km/hr
2	Maximum operation speed	70 km/hr
3	Minimum operation speed	20 km/hr
4	Average dwell time	30 second
5	Train travel interval	6 minute
6	Rated Passengers （Persons/tramcar）	286
7	Train allocation	41
8	Number of stations / platforms	39
9	Number of common stations / platforms	5
10	Operation hours per day	16 hours

Table 2, Technical data for Addis Ababa LRT

S/N	station	Value in meter
1	NS1- NS2	653
2	NS2- NS3	741
3	NS3- NS4	945
4	NS4- NS5	609
5	NS5- NS6	612
6	NS6- NS7	861
7	NS7- NS8	744

8	NS8- NS9	725
9	NS9- NS10	733
10	NS10- NS11	691
11	NS11- NS12	569
12	NS12- NS13	435
13	NS13- NS14	908
14	NS14- NS15	481
15	NS15- NS16	610
16	NS16- NS17	555
17	NS17- NS18	1971
18	NS18- NS19	908
19	NS19- NS20	481
20	NS20- NS21	540
21	NS21- NS22	840
22	NS22- Exit	223

Table 3, Distance between stations for N-S line

S/N	station	Value in meter
1	EW1- EW2	390
2	EW 2- EW3	776
3	EW 3- EW4	725
4	EW4- EW5	733
5	EW5- EW6	691
6	EW6- EW7	569
7	EW7- EW8	435
8	EW8- EW9	650
9	EW9- EW10	583
10	EW10- EW11	675
11	EW11- EW12	952

12	EW12- EW13	770
13	EW13- EW14	746
14	EW14- EW 15	802
15	EW15- EW16	804
16	EW16- EW17	1083
17	EW17- EW18	970
18	EW18- EW19	724
19	EW19- EW20	860
20	EW20- EW21	863
21	EW21- EW22	1092
22	EW22- Exit	182

Table 4**,** Distance between stations for E-W line

The number of passenger at a time is calculated by dividing the station passenger distribution at peak hour for thirty because peak hour is three hours duration at morning (6:00-9:00 am) and the train goes ten times an hour. This is shown in the table below.

S/N	station	Unit: person			
		No. of passengers getting on trains at peak hours	No. of passenger on at a time	No. of passengers getting off trains	No. of passenger off at a time
1	NS1	0	0	1675	55.83
2	NS2	10	0.33	1485	49.5
3	NS3	43	1.43	1386	46.2
4	NS4	121	4	1345	44.83
5	NS5	120	4	735	24.5
6	NS6	213	7.1	708	23.6
7	NS7	325	10.833	706	23.5

8	NS8	866	28.87	574	19.13
9	NS9	965	32.17	788	26.27
10	NS10	994	33.13	1038	34.6
11	NS11	1174	39.13	1223	40.77
12	NS12	1073	35.77	1083	36.1
13	NS13	654	21.8	730	24.33
14	NS14	646	21.53	622	20.73
15	NS15	682	22.73	427	14.23
16	NS16	917	30.27	372	12.4
17	NS17	1152	38.4	273	9.1
18	NS18	1475	49.17	196	6.53
19	NS19	1411	47	81	2.7
20	NS20	918	30.6	18	0.6
21	NS21	977	32.57	4	0.133
22	NS22	1480	49.33	0	0

Table 5, Passenger flow of Addis Ababa Light Rail N-S in morning peak hours.

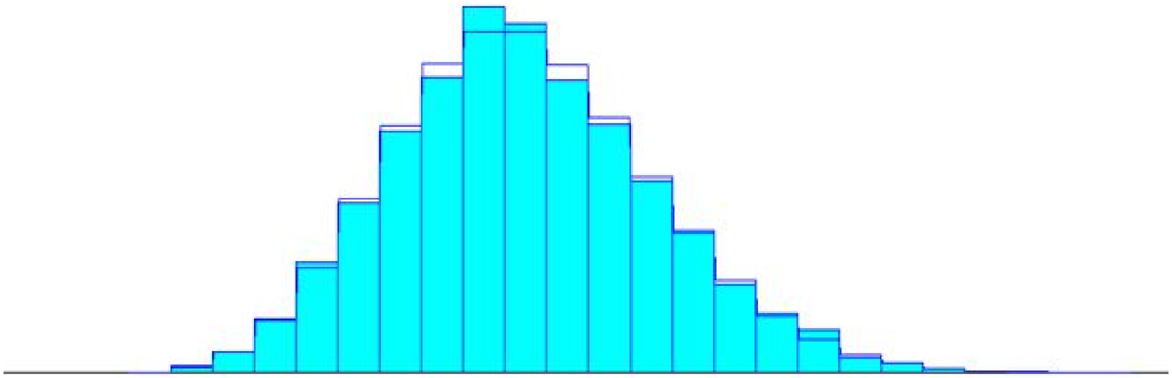
S/N	station	Unit: person			
		No. of passengers getting on trains at peak hours	No. of passenger on at a time	No. of passengers getting off trains	No. of passenger off at a time
1	EW1	0	0	2284	76.13
2	EW2	16	0.53	1742	58.07
3	EW3	38	1.27	1122	37.4
4	EW4	76	2.53	1072	35.73
5	EW5	146	4.87	963	32.1
6	EW6	376	12.53	1105	36.83
7	EW7	580	19.33	904	30.13

8	EW8	675	22.5	680	22.67
9	EW9	716	23.87	547	18.23
10	EW10	958	31.93	564	18.8
11	EW11	845	28.17	679	22.63
12	EW12	1513	50.43	1617	53.9
13	EW13	1409	46.97	1909	63.63
14	EW14	756	25.2	612	20.4
15	EW15	380	12.67	149	4.97
16	EW16	435	14.5	117	3.9
17	EW17	686	22.87	142	4.73
18	EW18	936	31.2	115	3.83
19	EW19	1193	39.77	68	2.27
20	EW20	1210	40.33	23	0.77
21	EW21	1511	50.37	6	0.2
22	EW22	1635	54.5	0	0

Table 6, Passenger flow of Addis Ababa Light Rail E-W in morning peak hours.

*(**Source:** Preliminary Design for Ethiopia Addis Ababa E-W & S-N（Phase Ⅰ）Light Rail Transit Project)*

The probably assumption for the passenger flow of the Addis Ababa LRT is fitted using the Poisson distribution summary as shown in figure below by analyzing the morning peak hour passenger flow as the input analyzer data file and assigned in the simulation model.



```
        Distribution Summary

Distribution:   Poisson
Expression:     POIS(9.96)
Square Error:   0.000179

Chi Square Test
  Number of intervals   = 19
  Degrees of freedom    = 17
  Test Statistic        = 14.3
  Corresponding p-value = 0.643

        Data Summary

Number of Data Points   = 5000
```

Figure 10, Passenger distribution

4.3.1 Simulation Model Results and Discussions for North to South and West to East line

In this section the results of the simulation run for the queuing analysis, utilization of resources, bottleneck analysis, delays, and maximum number of trains in service and throughout analysis at each station and route would be discussed below.

- ❖ For this route the starting point is Piazza and Torhyloch station and the train operation also starts here for the North-South and West-East corridor.
- ❖ The two routes meet each other at Lideta station and use common line until they separate at Meskel Square station to Kaliti and Ayat stations.
- ❖ The service priority uses “First come first served” queuing principle at all stations.
- ❖ The Holding principle is applied on the routes before Lideta station by scanning for condition of route busy.
- ❖ The trains assigned for their route decided to move on their proper direction at Meskel Square.
- ❖ The trains are assigned as the resource for the simulation analysis.
- ❖ Each platform stopping time and the route travel time is considered during the simulation.
- ❖ The number of Replications of the Run set up is 41 and its Replication length is 200 minutes while the run base time unit is hour.
- ❖ The animation speed factor (time units per frame) is 48.6 and the animation frame delay is 0.01seconds.
- ❖ The guided transporter matrix size is 30.

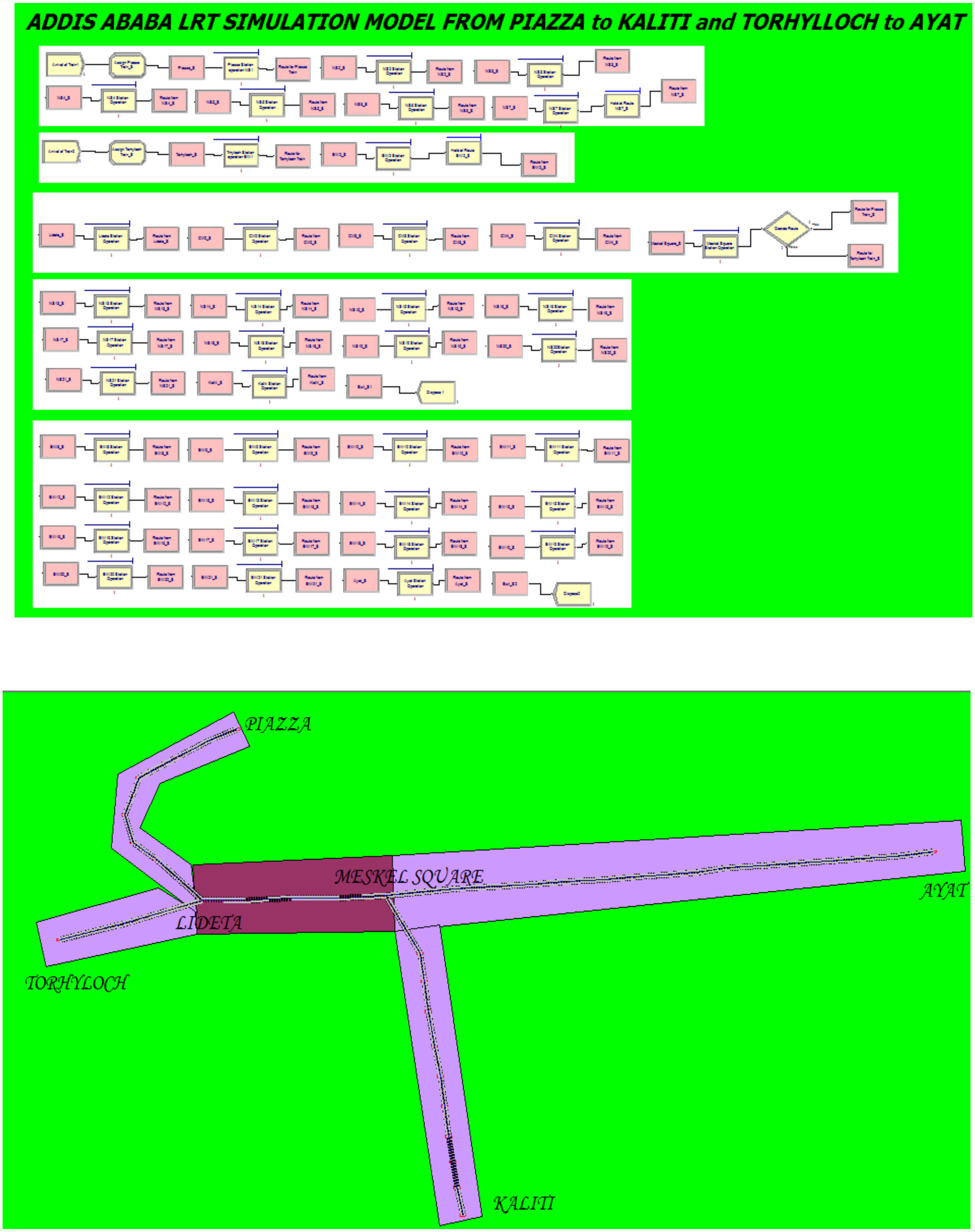


Figure 11, Simulation Model from Piazza to Kalit and Torhyloch to Ayat

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Busy	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Scheduled	Average	Half Width	Minimum	Maximum
Train	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Train	0.9767

	Number In	Number Out
Ayat Station	1.00	1.00
CM2 Station	31.00	26.00
CM3 Station	26.00	23.00
CM4 Station	23.00	20.00
EW10 Station	9.00	7.00
EW11 Station	7.00	6.00
EW12 Station	6.00	5.00
EW13 Station	5.00	5.00
EW14 Station	5.00	4.00
EW15 Station	4.00	4.00
EW16 Station	4.00	3.00
EW17 Station	3.00	3.00
EW18 Station	3.00	2.00
EW19 Station	2.00	2.00
EW2 Station	29.00	25.00
EW20 Station	2.00	1.00
EW21 Station	1.00	1.00
EW8 Station	12.00	10.00
EW9 Station	10.00	9.00
Kaliti Station	1.00	0.00
Lideta Station	36.00	32.00
Meskel Square	20.00	17.00
NS13 Station	5.00	5.00
NS14 Station	5.00	4.00
NS15 Station	4.00	3.00
NS16 Station	3.00	3.00
NS17 Station	3.00	2.00
NS18 Station	2.00	2.00
NS19 Station	2.00	2.00
NS2 Station	29.00	25.00
NS20Station	2.00	1.00
NS21 Station	1.00	1.00
NS3 Station	25.00	22.00
NS4 Station	21.00	19.00

Table 7, some simulation results for the N-S and W-E direction

Discussion of the North-South and West-East Simulation results

From the simulation model the stopping time (dwell time) is taken by the triangular function making thirty second the average stopping time. The route speed is changed into the time using the distance between stations for minimum (20km/hr) and maximum (70km/hr) operation speed and feed to the software as uniform distribution and the software simulated. Simulation is a technique for imitating the behavior of a situation or system using an analogous model, situation, or apparatus, to gain information more conveniently or to train personnel. It is the process of numerically evaluating a system model and estimating variables of interest. It is also the make fun of the operation of a real-world process or system over time. That means the above simulation executes the Addis Ababa light Rail Transit model from Piazza to Kaliti and from Torhyloch to Ayat as the real operation. This is used to understand the pre-operation design testing.

After all the simulation run completed, the reports performance measurements listed in Appendix-A shows the valuable results for the train operation performance indicators which is shown in the tables form and briefly discussed below. This performance report is used to define the logical and physical components of a system. Standard features in simulation model include the description of resource utilization; queues detail summary, process logic, and system data. From the result table above, the category by replication shows the time per entity for the minimum, average and maximum waiting time per entity, total time per entity, number of train waiting at each station. The process detail summary shows the value added time and the waiting time at each station, the number of train in and out at each station for the simulation model run set up. On the other hand the queue detail summary reports the waiting time for each station operation queue. This simulation model combines the two routes together and the number of waiting time result shows the stations operations are busy from Lideta to Meskel Square including the route between both stations where the two routes separate to east and south lines. Therefore, these route and stations are the bottle neck of the Addis Ababa LRT corridors.

4.3.2 Simulation Model Results and Discussions for South to North and East to West line

In this section the results of the simulation run for the queuing analysis, utilization of resources, bottleneck analysis, delays, and maximum number of trains in service and throughout analysis at each station and route would be discussed below.

- For this route the starting point is Kaliti and Ayat stations and the train operation also starts here for the South-North and East-West corridor.
- The two routes meet each other at Meskel Square station and uses common line until they separate at Lideta station to Piazza and Torhyloch stations.
- The service priority uses “First come first served” queuing principle at all stations.
- The Holding principle is applied on the routes before Meskel Square station by scanning for condition of route busy.
- The trains assigned for their route decided to move on their proper direction at Lideta station.
- The trains are assigned as the resource for the simulation analysis.
- Each platform stopping time and the route travel time is considered during the simulation.
- The number of Replications of the Run set up is 41 and its Replication length is 200 minutes while the run base time unit is hour.
- The animation speed factor (time units per frame) is 48.6 and the animation frame delay is 0.01seconds.
- The guided transporter matrix size is 300.

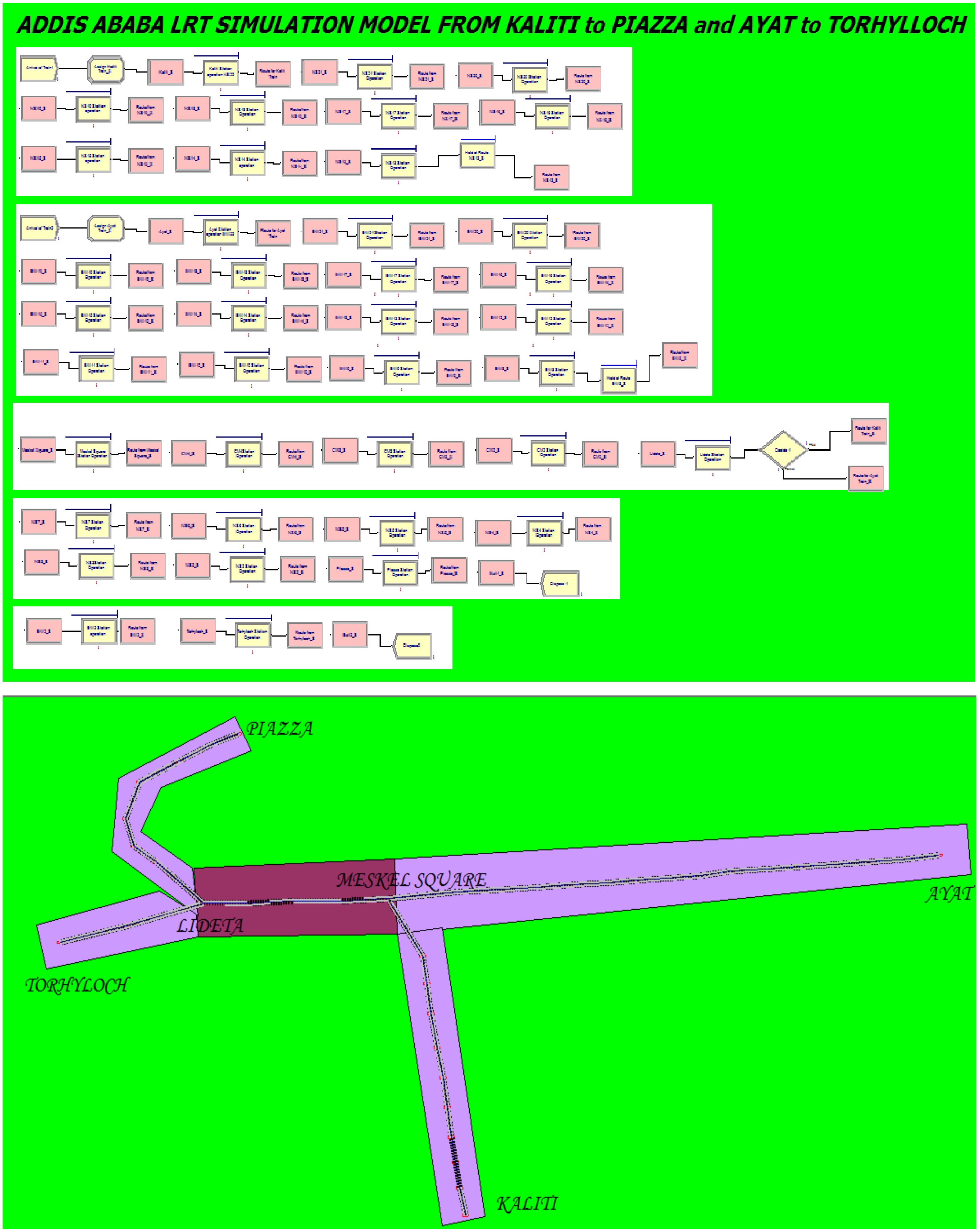


Figure 12, Simulation Model from Kalit to Piazza and Ayat to Torhyloch

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Busy	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Scheduled	Average	Half Width	Minimum	Maximum
Train	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Train	0.9767

	Number In	Number Out
Ayat Station	34.00	29.00
CM2 Station	7.00	5.00
CM3 Station	8.00	7.00
CM4Station	10.00	8.00
EW10 Station	5.00	4.00
EW11 Station	6.00	5.00
EW12 Station	7.00	6.00
EW13 Station	8.00	7.00
EW14 Station	10.00	8.00
EW15 Station	12.00	10.00
EW16 Station	13.00	12.00
EW17 Station	15.00	13.00
EW18 Station	18.00	16.00
EW19 Station	21.00	18.00
EW2 Station	1.00	0.00
EW20 Station	25.00	21.00
EW21 Station	29.00	25.00
EW8 Station	4.00	4.00
EW9 Station	4.00	4.00
Kaliti Station	34.00	29.00
Lideta Station	5.00	5.00
Meskel Square	11.00	10.00
NS13 Station	9.00	7.00
NS14 Station	10.00	9.00
NS15 Station	12.00	10.00
NS16 Station	13.00	12.00
NS17 Station	16.00	14.00
NS18 Station	18.00	16.00
NS19 Stattion	21.00	19.00
NS2 Station	1.00	1.00
NS20 Station	25.00	21.00
NS21 Station	29.00	25.00
NS3Station	1.00	1.00
NS4 Station	2.00	1.00

Table 8, some simulation results for the reverse direction

Discussion of the South-North and East-West Simulation results

From the simulation model the stopping time (dwell time) is taken by the triangular function making thirty second the average stopping time. The route speed is changed into the time using the distance between stations for minimum (20km/hr) and maximum (70km/hr) operation speed and feed to the software as uniform distribution and the software simulated. Simulation is a technique for imitating the behavior of a situation or system using an analogous model, situation, or apparatus, to gain information more conveniently or to train personnel. It is the process of numerically evaluating a system model and estimating variables of interest. It is also the make fun of the operation of a real-world process or system over time. That means the above simulation executes the Addis Ababa light Rail Transit model from Kaliti to Piazza and from Ayat to Torhyloch as the real operation. This is used to understand the pre-operation design testing.

After all the simulation run completed, the reports performance measurements in Appendix-B shows the valuable results for the train operation performance indicators which is shown in the tables form and briefly discussed here. This performance report is used to define the logical and physical components of a system. Standard features in simulation model include the description of resource utilization; queues detail summary, process logic, and system data. From the result table above, the category by replication shows the time per entity for the minimum, average and maximum waiting time per entity, total time per entity and number of train waiting at each station. The process detail summary shows the value added time and the waiting time at each station, and the number of train in and out at each station for the simulation model run set up. On the other hand the queue detail summary reports the waiting time for each station operation queue. This simulation model combines the two routes together and the number of waiting time result above shows the stations operations are busy from Meskel Square to Lideta including the route between both stations where the two routes separate to west and north lines. Therefore, these route and stations are the bottle neck of the Addis Ababa LRT corridors.

4.3.3 Verification

- It is well seen in debugging the program
- Since the program runs almost as it is intended in the simulation model ,it is Verified
- The result mach with the real system of the station condition
- It runs and verified for the check of validity

4.3.4 Validation of the model

- Since the result shows an acceptable level of confidence in the performance at each station, the processing proposed model is valid.
- The proposed model is indeed an accurate representation of the real system.
- The other important element is that the model is well credible and the results bear us decision-making process.
- Since the model and simulation out-come is validated, a model can be used to investigate a wide variety of "***what if***" questions about the real train operation.

CHAPTER FIVE

Conclusions and Recommendation

5.1 Conclusions

The railway operation problem consists of several interrelated sub-problems. These are problems related to demand, infrastructure, time table schedule, rolling stock assign and skilled man power. This paper dealt with all of them but two of the main sub-problems are more discussed and software analyzed; the network problem and the train scheduling problem. Each of these problems has received great attention in the literature. Since both problems are hard to solve, they are typically solved using the simulation model software. Modeling methodologies include network representations, process concept, and the entity-attribute-set approach. The model is encoded by using a simulation programming language using Arena5. Arena icons are connected in a flowchart to represent entity flow. The conceptual model is translated into modeling software. The model representation is formulated in the way that it represents the appropriate actual working system of the Addis Ababa LRT. From the simulation model the stopping time (dwell time) is taken by the triangular function making thirty second the average stopping time. The route speed is changed into the time using the distance between stations for minimum (20km/hr) and maximum (70km/hr) operation speed and feed to the software as uniform distribution. For the constructed simulation model, the “Program” is well made and run. The operation design data are verified and the Addis Ababa Light Rail Transit operation test is checked up for both corridors and the common routes by the simulation software. After all simulation, the reports performance measurements are shown as results for the train operation performance indicators in the table form and briefly discussed. The simulation model combines the two routes together and the number of waiting time, train stations in and out etc results in the table shows the stations operations are busy from Lideta to Meskel Square including the route between both stations. Therefore, these route and stations are the **bottle neck** of the Addis Ababa LRT corridors where route conflict is very high if the train scheduled is missed. Finally the operation data are verified and the simulation model output is valid.

5.2 Recommendation

In the global and local transport modes competition, to own the potential pull of more market share and business profit margins from the transport service within the due date, the Ethiopian Railway Corporation should have to prepare himself for the skilled manpower and improve the operation of Addis Ababa LRT service for the future from time to time. Train operations and traffic control have to keep in the modern way by the introduction of a comprehensive management information system concerning the distribution and reasons of primary and consecutive train operation problems. Such a data base could be incorporated into an advanced decision support tool for dispatchers and provide realistic models of the propagation of actual trains operation in stations and routes. Through properly train operation schedule and control, it is possible to avoid delay or route conflict. The data collected for this research are preliminary design data since there is no train operation yet. But if the data was on operational stage, a more realistic result could be obtained. Therefore the Ethiopian Railway Corporation is recommended to perform schedule analysis during operation stage. Finally the ERC is recommended to use the Arena tool to control the train operation.

5.3 Future work

A system analysis approach is presented for investigation of train operations in railway routes and stations based on network, timetable and train detection data. The analysis of train operations clearly reveals that the trains operate at lower than design speed. Furthermore, the dwell times at platform tracks are systematically extended due to hinder by train’s operation factors. This paper is done for the Addis Ababa train operation analysis system development depending on the preliminary design data. Therefore it is possible to analysis the train operation depending on the actual data recorded after the real operation will start and can do further research on train scheduling problem for the Addis Ababa Light Rail Transit if any.

5.4 Contribution of the Thesis

This paper is focused on the train operation system development for the Addis Ababa Light Rail Transit. To do this the researcher referred so many research papers, internet web sites, international journals and article which are related to train operation and the like. This is used to understand how to coordinate and write scientific research on this work and contributes good experience. Meanwhile the thesis enables to understand the major factors that influence the train operation, how delay is the train operation performance indicator and how it can be minimized. In other case the paper also academically contributes to study and apply the Simulation Model (SIMAN) software programmer language Arena5 for the Addis Ababa LRT as it is actual operating using the design input data. This simulation is well done and run to test the city train operation, identify the bottleneck of the route and provides necessary train information like number of train transfer, waiting time, resource utilization, number in and number out at each station etc for the number of replication animation setup. Finally the paper will very useful for the Ethiopian Railway Corporation as it focus on train operation because after infrastructure completion the knowledge of operation and maintenance is the very important one to continuous the successful transport service. Therefore this paper contribute to the body of knowledge on the Addis Ababa Light Rail Transit operation process and verify the designed operation data by checking with the Arena5 simulation software.

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Appendix

Appendix A. North-South and West-East Line Simulation Results

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum	Maximum
Ayat Station Operation	0.3728	(Insufficient)	0.3728	0.3728
CM2 Station Operation	0.2086	(Insufficient)	0	0.4297
CM3 Station Operation	0.2160	(Insufficient)	0.01190513	0.4306
CM4 Station Operation	0.2201	(Insufficient)	0.00443422	0.4337
EW10 Station Operation	0.2061	(Insufficient)	0.03103097	0.4122
EW11 Station Operation	0.2071	(Insufficient)	0.02836629	0.4080
EW12 Station Operation	0.1999	(Insufficient)	0.04367733	0.3833
EW13 Station Operation	0.2334	(Insufficient)	0.06158685	0.4229
EW14 Station Operation	0.2241	(Insufficient)	0.07496467	0.3764
EW15 Station Operation	0.2649	(Insufficient)	0.1032	0.4339
EW16 Station Operation	0.2501	(Insufficient)	0.1268	0.3854
EW17 Station Operation	0.2975	(Insufficient)	0.1544	0.4375
EW18 Station Operation	0.2718	(Insufficient)	0.1898	0.3539
EW19 Station Operation	0.3229	(Insufficient)	0.2172	0.4286
EW2 Station Operation	0.2151	(Insufficient)	0.00508749	0.4345
EW20 Station Operation	0.2636	(Insufficient)	0.2636	0.2636
EW21 Station Operation	0.3085	(Insufficient)	0.3085	0.3085
EW8 Station Operation	0.2194	(Insufficient)	0.02621362	0.4424
EW9 Station Operation	0.2281	(Insufficient)	0.01188737	0.4303
Kaliti Station Operation	0	(Unknown)	0	0
Lideta Station Operation	0.2200	(Insufficient)	0	0.4441
Meskel Square Station Operation	0.2193	(Insufficient)	0.00946732	0.4360
NS13 Station Operation	0.2521	(Insufficient)	0.08931585	0.4222
NS14 Station Operation	0.2490	(Insufficient)	0.1033	0.4202
NS15 Station Operation	0.2331	(Insufficient)	0.1291	0.3463
NS16 Station Operation	0.2775	(Insufficient)	0.1557	0.4075
NS17 Station Operation	0.2481	(Insufficient)	0.1896	0.3066
NS18 Station Operation	0.3110	(Insufficient)	0.2417	0.3804
NS19 Station Operation	0.3536	(Insufficient)	0.2726	0.4347
NS2 Station Operation	0.2158	(Insufficient)	0	0.4380
NS20Station Operation	0.3249	(Insufficient)	0.3249	0.3249
NS21 Station Operation	0.3988	(Insufficient)	0.3988	0.3988
NS3 Station Operation	0.2233	(Insufficient)	0	0.4392
NS4 Station Operation	0.2266	(Insufficient)	0.01714099	0.4313
NS5 Station Operation	0.2222	(Insufficient)	0.00063238	0.4396
NS6 Station Operation	0.2087	(Insufficient)	0.00742452	0.4204
NS7 Station Operation	0.2069	(Insufficient)	0.02271156	0.4297
Piazza Station operation NS1	0.2191	(Insufficient)	0	0.4478
Trhyloch Station operation EW1	0.2115	(Insufficient)	0.00250848	0.4398

Table 9, Result summary of waiting time.

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum	Maximum
Ayat Station Operation	0.3811	(Insufficient)	0.3811	0.3811
CM2 Station Operation	0.2169	(Insufficient)	0.00828802	0.4372
CM3 Station Operation	0.2245	(Insufficient)	0.02063390	0.4382
CM4 Station Operation	0.2285	(Insufficient)	0.01312279	0.4417
EW10 Station Operation	0.2145	(Insufficient)	0.03949862	0.4208
EW11 Station Operation	0.2160	(Insufficient)	0.03685567	0.4166
EW12 Station Operation	0.2080	(Insufficient)	0.05185561	0.3919
EW13 Station Operation	0.2416	(Insufficient)	0.06955061	0.4309
EW14 Station Operation	0.2325	(Insufficient)	0.08433762	0.3846
EW15 Station Operation	0.2732	(Insufficient)	0.1112	0.4421
EW16 Station Operation	0.2585	(Insufficient)	0.1346	0.3945
EW17 Station Operation	0.3055	(Insufficient)	0.1621	0.4463
EW18 Station Operation	0.2795	(Insufficient)	0.1972	0.3619
EW19 Station Operation	0.3307	(Insufficient)	0.2256	0.4358
EW2 Station Operation	0.2234	(Insufficient)	0.01405747	0.4430
EW20 Station Operation	0.2716	(Insufficient)	0.2716	0.2716
EW21 Station Operation	0.3165	(Insufficient)	0.3165	0.3165
EW8 Station Operation	0.2277	(Insufficient)	0.03489209	0.4503
EW9 Station Operation	0.2364	(Insufficient)	0.01906661	0.4386
Kaliti Station Operation	0	(Unknown)	0	0
Lideta Station Operation	0.2283	(Insufficient)	0.00930589	0.4518
Meskel Square Station Operation	0.2276	(Insufficient)	0.01805930	0.4441
NS13 Station Operation	0.2606	(Insufficient)	0.0969	0.4298
NS14 Station Operation	0.2572	(Insufficient)	0.1115	0.4292
NS15 Station Operation	0.2417	(Insufficient)	0.1379	0.3539
NS16 Station Operation	0.2860	(Insufficient)	0.1635	0.4169
NS17 Station Operation	0.2562	(Insufficient)	0.1972	0.3152
NS18 Station Operation	0.3201	(Insufficient)	0.2510	0.3891
NS19 Station Operation	0.3620	(Insufficient)	0.2805	0.4435
NS2 Station Operation	0.2242	(Insufficient)	0.00720743	0.4472
NS20Station Operation	0.3333	(Insufficient)	0.3333	0.3333
NS21 Station Operation	0.4067	(Insufficient)	0.4067	0.4067
NS3 Station Operation	0.2317	(Insufficient)	0.00765698	0.4474
NS4 Station Operation	0.2350	(Insufficient)	0.02554481	0.4390
NS5 Station Operation	0.2309	(Insufficient)	0.00942136	0.4474
NS6 Station Operation	0.2172	(Insufficient)	0.01683545	0.4299
NS7 Station Operation	0.2152	(Insufficient)	0.03106468	0.4380
Piazza Station operation NS1	0.2274	(Insufficient)	0.00812184	0.4564
Trhyloch Station operation EW1	0.2196	(Insufficient)	0.01028850	0.4478

Table 10, Result summary of total waiting time.

Number Waiting	Average	Half Width	Minimum	Maximum
Ayat Station Operation.Queue	0.1118	(Insufficient)	0	1.0000
CM2 Station Operation.Queue	2.0543	(Insufficient)	0	5.0000
CM3 Station Operation.Queue	1.7320	(Insufficient)	0	5.0000
CM4 Station Operation.Queue	1.4919	(Insufficient)	0	4.0000
EW10 Station Operation.Queue	0.5915	(Insufficient)	0	2.0000
EW11 Station Operation.Queue	0.4852	(Insufficient)	0	1.0000
EW12 Station Operation.Queue	0.4094	(Insufficient)	0	1.0000
EW13 Station Operation.Queue	0.3500	(Insufficient)	0	1.0000
EW14 Station Operation.Queue	0.3023	(Insufficient)	0	1.0000
EW15 Station Operation.Queue	0.3178	(Insufficient)	0	1.0000
EW16 Station Operation.Queue	0.2361	(Insufficient)	0	1.0000
EW17 Station Operation.Queue	0.2678	(Insufficient)	0	1.0000
EW18 Station Operation.Queue	0.1658	(Insufficient)	0	1.0000
EW19 Station Operation.Queue	0.1937	(Insufficient)	0	1.0000
EW2 Station Operation.Queue	1.9016	(Insufficient)	0	4.0000
EW20 Station Operation.Queue	0.1470	(Insufficient)	0	1.0000
EW21 Station Operation.Queue	0.0926	(Insufficient)	0	1.0000
EW8 Station Operation.Queue	0.7712	(Insufficient)	0	2.0000
EW9 Station Operation.Queue	0.6583	(Insufficient)	0	2.0000
Hold at Route EW2_S.Queue	0	(Insufficient)	0	0
Hold at Route NS7_S.Queue	0	(Insufficient)	0	0
Kaliti Station Operation.Queue	0.1309	(Insufficient)	0	1.0000
Lideta Station Operation.Queue	2.3554	(Insufficient)	0	6.0000
Meskel Square Station Operation.Queue	1.3122	(Insufficient)	0	3.0000
NS13 Station Operation.Queue	0.3781	(Insufficient)	0	1.0000
NS14 Station Operation.Queue	0.3607	(Insufficient)	0	1.0000
NS15 Station Operation.Queue	0.2845	(Insufficient)	0	1.0000
NS16 Station Operation.Queue	0.2498	(Insufficient)	0	1.0000
NS17 Station Operation.Queue	0.2300	(Insufficient)	0	1.0000
NS18 Station	0.1866	(Insufficient)	0	1.0000

Table 11, Result summary of number of train waiting.

NS19 Station Operation.Queue	0.2122	(Insufficient)	0	1.0000
NS2 Station Operation.Queue	1.8856	(Insufficient)	0	4.0000
NS20Station Operation.Queue	0.1252	(Insufficient)	0	1.0000
NS21 Station Operation.Queue	0.1196	(Insufficient)	0	1.0000
NS3 Station Operation.Queue	1.6352	(Insufficient)	0	4.0000
NS4 Station Operation.Queue	1.3946	(Insufficient)	0	3.0000
NS5 Station Operation.Queue	1.2057	(Insufficient)	0	3.0000
NS6 Station Operation.Queue	0.9965	(Insufficient)	0	3.0000
NS7 Station Operation.Queue	0.8508	(Insufficient)	0	2.0000
Piazza Station operation NS1.Queue	2.2562	(Insufficient)	0	5.0000
Trhyloch Station operation EW1.Queue	2.1899	(Insufficient)	0	5.0000

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum	Maximum
Train	0.9859	(Insufficient)	0	1.0000

Number Busy	Average	Half Width	Minimum	Maximum
Train	0.9859	(Insufficient)	0	1.0000

Number Scheduled	Average	Half Width	Minimum	Maximum
Train	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Train	0.9859

Table 12, Result summary of resource utilization.

Process Detail Summary

Time per Entity

	Total Time	VA Time	Wait Time
Ayat Station	0.38	0.01	0.37
CM2 Station	0.22	0.01	0.21
CM3 Station	0.22	0.01	0.22
CM4 Station	0.23	0.01	0.22
EW10 Station	0.21	0.01	0.21
EW11 Station	0.22	0.01	0.21
EW12 Station	0.21	0.01	0.20
EW13 Station	0.24	0.01	0.23
EW14 Station	0.23	0.01	0.22
EW15 Station	0.27	0.01	0.26
EW16 Station	0.26	0.01	0.25
EW17 Station	0.31	0.01	0.30
EW18 Station	0.28	0.01	0.27
EW19 Station	0.33	0.01	0.32
EW2 Station	0.22	0.01	0.22
EW20 Station	0.27	0.01	0.26
EW21 Station	0.32	0.01	0.31
EW8 Station	0.23	0.01	0.22
EW9 Station	0.24	0.01	0.23
Kaliti Station	0.00	0.00	0.00
Lideta Station	0.23	0.01	0.22
Meskel Square	0.23	0.01	0.22
NS13 Station	0.26	0.01	0.25
NS14 Station	0.26	0.01	0.25
NS15 Station	0.24	0.01	0.23
NS16 Station	0.29	0.01	0.28
NS17 Station	0.26	0.01	0.25
NS18 Station	0.32	0.01	0.31
NS19 Station	0.36	0.01	0.35
NS2 Station	0.22	0.01	0.22
NS20Station	0.33	0.01	0.32
NS21 Station	0.41	0.01	0.40
NS3 Station	0.23	0.01	0.22
NS4 Station	0.24	0.01	0.23
NS5 Station	0.23	0.01	0.22
NS6 Station	0.22	0.01	0.21
NS7 Station	0.22	0.01	0.21
Piazza Station	0.23	0.01	0.22
Trhyloch	0.22	0.01	0.21

Table 13, Result summary of time per Entity.

	Number In	Number Out
Ayat Station	1.00	1.00
CM2 Station	31.00	26.00
CM3 Station	26.00	23.00
CM4 Station	23.00	20.00
EW10 Station	9.00	7.00
EW11 Station	7.00	6.00
EW12 Station	6.00	5.00
EW13 Station	5.00	5.00
EW14 Station	5.00	4.00
EW15 Station	4.00	4.00
EW16 Station	4.00	3.00
EW17 Station	3.00	3.00
EW18 Station	3.00	2.00
EW19 Station	2.00	2.00
EW2 Station	29.00	25.00
EW20 Station	2.00	1.00
EW21 Station	1.00	1.00
EW8 Station	12.00	10.00
EW9 Station	10.00	9.00
Kaliti Station	1.00	0.00
Lideta Station	36.00	32.00
Meskel Square	20.00	17.00
NS13 Station	5.00	5.00
NS14 Station	5.00	4.00
NS15 Station	4.00	3.00
NS16 Station	3.00	3.00
NS17 Station	3.00	2.00
NS18 Station	2.00	2.00
NS19 Station	2.00	2.00
NS2 Station	29.00	25.00
NS20Station	2.00	1.00
NS21 Station	1.00	1.00
NS3 Station	25.00	22.00
NS4 Station	21.00	19.00
NS5 Station	18.00	16.00
NS6 Station	16.00	13.00
NS7 Station	13.00	11.00
Piazza Station	34.00	29.00
Trhyloch	34.00	29.00

Table 14, Result summary of train in and out.

Queue Detail Summary

	Waiting Time
Ayat Station Operation.Queue	0.37
CM2 Station Operation.Queue	0.22
CM3 Station Operation.Queue	0.22
CM4 Station Operation.Queue	0.22
EW10 Station Operation.Queue	0.21
EW11 Station Operation.Queue	0.21
EW12 Station Operation.Queue	0.20
EW13 Station Operation.Queue	0.23
EW14 Station Operation.Queue	0.22
EW15 Station Operation.Queue	0.26
EW16 Station Operation.Queue	0.25
EW17 Station Operation.Queue	0.30
EW18 Station Operation.Queue	0.27
EW19 Station Operation.Queue	0.32
EW2 Station Operation.Queue	0.22
EW20 Station Operation.Queue	0.26
EW21 Station Operation.Queue	0.31
EW8 Station Operation.Queue	0.22
EW9 Station Operation.Queue	0.23
Hold at Route EW2_S.Queue	0.00
Hold at Route NS7_S.Queue	0.00
Kaliti Station Operation.Queue	0.00
Lideta Station Operation.Queue	0.22
Meskel Square Station Operation.Queue	0.22
NS13 Station Operation.Queue	0.25
NS14 Station Operation.Queue	0.25
NS15 Station Operation.Queue	0.23
NS16 Station Operation.Queue	0.28
NS17 Station Operation.Queue	0.25
NS18 Station Operation.Queue	0.31
NS19 Station Operation.Queue	0.35
NS2 Station Operation.Queue	0.22
NS20Station Operation.Queue	0.32
NS21 Station Operation.Queue	0.40
NS3 Station Operation.Queue	0.22
NS4 Station Operation.Queue	0.23
NS5 Station Operation.Queue	0.22
NS6 Station Operation.Queue	0.21
NS7 Station Operation.Queue	0.21
Piazza Station operation NS1.Queue	0.22
Trhyloch Station operation EW1.Queue	0.21

Table 15, Result summary of Queue waiting time.

Appendix B. South-North and East-West Line Simulation Results

Time per Entity

Wait Time Per Entity	Average	Half Width	Minimum	Maximum
Ayat Station operation EW22	0.2038	(Insufficient)	0.00452286	0.4274
CM2 Station Operation	0.2581	(Insufficient)	0.07753000	0.3741
CM3 Station Operation	0.2789	(Insufficient)	0.07562702	0.4380
CM4Station Operation	0.2569	(Insufficient)	0.03533933	0.4289
EW10 Station Operation	0.2194	(Insufficient)	0.1187	0.2994
EW11 Station Operation	0.2244	(Insufficient)	0.0972	0.4124
EW12 Station Operation	0.2244	(Insufficient)	0.06625162	0.4223
EW13 Station Operation	0.2222	(Insufficient)	0.07223026	0.4101
EW14 Station Operation	0.2072	(Insufficient)	0.04358767	0.4032
EW15 Station Operation	0.2162	(Insufficient)	0.02936793	0.4240
EW16 Station Operation	0.2204	(Insufficient)	0.01773808	0.4405
EW17 Station Operation	0.2045	(Insufficient)	0.01049160	0.4004
EW18 Station Operation	0.2162	(Insufficient)	0.01526323	0.4377
EW19 Station Operation	0.2066	(Insufficient)	0.00828295	0.4145
EW2 Station operation	0	(Unknown)	0	0
EW20 Station Operation	0.2055	(Insufficient)	0.00376763	0.4152
EW21 Station Operation	0.2049	(Insufficient)	0	0.4388
EW8 Station Operation	0.3098	(Insufficient)	0.1754	0.4224
EW9 Station Operation	0.2638	(Insufficient)	0.1517	0.3634
Kaliti Station operation NS22	0.2114	(Insufficient)	0	0.4362
Lideta Station Operation	0.2975	(Insufficient)	0.1008	0.4293
Meskel Square Station Operation	0.2568	(Insufficient)	0.04530380	0.4180
NS13 Station Operation	0.2033	(Insufficient)	0.01422094	0.3716
NS14 Station operation	0.2249	(Insufficient)	0.01647635	0.4313
NS15 Station operation	0.2163	(Insufficient)	0.01600495	0.4226
NS16 Station Operation	0.2158	(Insufficient)	0.00809552	0.4465
NS17 Station Operation	0.2119	(Insufficient)	0.00290370	0.4354
NS18 Station Operation	0.2126	(Insufficient)	0.00872728	0.4346
NS19 Stattion operation	0.2152	(Insufficient)	0	0.4421
NS2 Station Operation	0.3036	(Insufficient)	0.3036	0.3036
NS20 Station Operation	0.2050	(Insufficient)	0	0.4148
NS21 Station Operation	0.2069	(Insufficient)	0	0.4497
NS3Station Operation	0.2557	(Insufficient)	0.2557	0.2557
NS4 Station Operation	0.2169	(Insufficient)	0.2169	0.2169
NS5 Station Operation	0.2884	(Insufficient)	0.1905	0.3862
NS6 Station Operation	0.2407	(Insufficient)	0.1573	0.3240
NS7 Station Operation	0.2694	(Insufficient)	0.1232	0.4116
Piazza Station Operation	0.3507	(Insufficient)	0.3507	0.3507
Torhyloch Station Operation	0	(Unknown)	0	0

Table16, Result summary of waiting time.

Time per Entity

Total Time Per Entity	Average	Half Width	Minimum	Maximum
Ayat Station operation EW22	0.2120	(Insufficient)	0.01328407	0.4362
CM2 Station Operation	0.2661	(Insufficient)	0.08492657	0.3817
CM3 Station Operation	0.2870	(Insufficient)	0.08431400	0.4460
CM4Station Operation	0.2649	(Insufficient)	0.04364073	0.4372
EW10 Station Operation	0.2278	(Insufficient)	0.1271	0.3078
EW11 Station Operation	0.2329	(Insufficient)	0.1055	0.4217
EW12 Station Operation	0.2327	(Insufficient)	0.07406599	0.4301
EW13 Station Operation	0.2306	(Insufficient)	0.08005571	0.4182
EW14 Station Operation	0.2156	(Insufficient)	0.05135043	0.4120
EW15 Station Operation	0.2246	(Insufficient)	0.03709943	0.4319
EW16 Station Operation	0.2289	(Insufficient)	0.02629369	0.4487
EW17 Station Operation	0.2130	(Insufficient)	0.01952181	0.4098
EW18 Station Operation	0.2245	(Insufficient)	0.02395180	0.4465
EW19 Station Operation	0.2150	(Insufficient)	0.01701172	0.4239
EW2 Station operation	0	(Unknown)	0	0
EW20 Station Operation	0.2137	(Insufficient)	0.01185889	0.4240
EW21 Station Operation	0.2134	(Insufficient)	0.00896997	0.4473
EW8 Station Operation	0.3181	(Insufficient)	0.1837	0.4304
EW9 Station Operation	0.2722	(Insufficient)	0.1601	0.3723
Kaliti Station operation NS22	0.2198	(Insufficient)	0.00812184	0.4439
Lideta Station Operation	0.3057	(Insufficient)	0.1097	0.4372
Meskel Square Station Operation	0.2649	(Insufficient)	0.05244557	0.4254
NS13 Station Operation	0.2119	(Insufficient)	0.02343051	0.3796
NS14 Station operation	0.2328	(Insufficient)	0.02485405	0.4391
NS15 Station operation	0.2248	(Insufficient)	0.02435807	0.4304
NS16 Station Operation	0.2240	(Insufficient)	0.01615170	0.4545
NS17 Station Operation	0.2204	(Insufficient)	0.01011113	0.4446
NS18 Station Operation	0.2211	(Insufficient)	0.01834860	0.4434
NS19 Stattion operation	0.2237	(Insufficient)	0.00930589	0.4509
NS2 Station Operation	0.3118	(Insufficient)	0.3118	0.3118
NS20 Station Operation	0.2132	(Insufficient)	0.00765698	0.4227
NS21 Station Operation	0.2153	(Insufficient)	0.00791835	0.4582
NS3Station Operation	0.2652	(Insufficient)	0.2652	0.2652
NS4 Station Operation	0.2247	(Insufficient)	0.2247	0.2247
NS5 Station Operation	0.2964	(Insufficient)	0.1985	0.3942
NS6 Station Operation	0.2497	(Insufficient)	0.1660	0.3334
NS7 Station Operation	0.2776	(Insufficient)	0.1307	0.4202
Piazza Station Operation	0.3597	(Insufficient)	0.3597	0.3597
Torhyloch Station Operation	0	(Unknown)	0	0

Table 17, Result summary of total waiting time.

Number Waiting	Average	Half Width	Minimum	Maximum
Ayat Station operation EW22.Queue	2.1233	(Insufficient)	0	5.0000
CM2 Station Operation.Queue	0.4408	(Insufficient)	0	2.0000
CM3 Station Operation.Queue	0.6124	(Insufficient)	0	2.0000
CM4Station Operation.Queue	0.6912	(Insufficient)	0	2.0000
EW10 Station Operation.Queue	0.3655	(Insufficient)	0	2.0000
EW11 Station Operation.Queue	0.4191	(Insufficient)	0	2.0000
EW12 Station Operation.Queue	0.5208	(Insufficient)	0	2.0000
EW13 Station Operation.Queue	0.5885	(Insufficient)	0	2.0000
EW14 Station Operation.Queue	0.6335	(Insufficient)	0	2.0000
EW15 Station Operation.Queue	0.7056	(Insufficient)	0	2.0000
EW16 Station Operation.Queue	0.8860	(Insufficient)	0	3.0000
EW17 Station Operation.Queue	0.9829	(Insufficient)	0	3.0000
EW18 Station Operation.Queue	1.1906	(Insufficient)	0	3.0000
EW19 Station Operation.Queue	1.3465	(Insufficient)	0	3.0000
EW2 Station operation.Queue	0.0960	(Insufficient)	0	1.0000
EW20 Station Operation.Queue	1.5681	(Insufficient)	0	4.0000
EW21 Station Operation.Queue	1.8241	(Insufficient)	0	5.0000
EW8 Station Operation.Queue	0.3718	(Insufficient)	0	2.0000
EW9 Station Operation.Queue	0.3165	(Insufficient)	0	2.0000
Hold at Route EW8_S.Queue	0	(Insufficient)	0	0
Hold at Route NS13_S.Queue	0	(Insufficient)	0	0
Kaliti Station operation NS22.Queue	2.1894	(Insufficient)	0	5.0000
Lideta Station Operation.Queue	0.4462	(Insufficient)	0	2.0000
Meskel Square Station Operation.Queue	0.8215	(Insufficient)	0	3.0000
NS13 Station Operation.Queue	0.5264	(Insufficient)	0	2.0000
NS14 Station operation.Queue	0.6436	(Insufficient)	0	2.0000
NS15 Station operation.Queue	0.7318	(Insufficient)	0	2.0000
NS16 Station Operation.Queue	0.8372	(Insufficient)	0	2.0000
NS17 Station Operation.Queue	0.9879	(Insufficient)	0	3.0000
NS18 Station Operation.Queue	1.1785	(Insufficient)	0	3.0000

Table 18, Result summary of number of train waiting.

NS19 Stattion operation.Queue	1.3376	(Insufficient)	0	3.0000
NS2 Station Operation.Queue	0.0911	(Insufficient)	0	1.0000
NS20 Station Operation.Queue	1.5832	(Insufficient)	0	4.0000
NS21 Station Operation.Queue	1.8176	(Insufficient)	0	4.0000
NS3Station Operation.Queue	0.07670678	(Insufficient)	0	1.0000
NS4 Station Operation.Queue	0.1970	(Insufficient)	0	1.0000
NS5 Station Operation.Queue	0.1730	(Insufficient)	0	1.0000
NS6 Station Operation.Queue	0.2494	(Insufficient)	0	1.0000
NS7 Station Operation.Queue	0.2654	(Insufficient)	0	1.0000
Piazza Station Operation.Queue	0.1052	(Insufficient)	0	1.0000
Torhyloch Station Operation.Queue	0	(Insufficient)	0	0

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Busy	Average	Half Width	Minimum	Maximum
Train	0.9767	(Insufficient)	0	1.0000

Number Scheduled	Average	Half Width	Minimum	Maximum
Train	1.0000	(Insufficient)	1.0000	1.0000

Scheduled Utilization	Value
Train	0.9767

Table 19, Result summary of resource utilization.

Process Detail Summary

Time per Entity

	Total Time	VA Time	Wait Time
Ayat Station	0.21	0.01	0.20
CM2 Station	0.27	0.01	0.26
CM3 Station	0.29	0.01	0.28
CM4Station	0.26	0.01	0.26
EW10 Station	0.23	0.01	0.22
EW11 Station	0.23	0.01	0.22
EW12 Station	0.23	0.01	0.22
EW13 Station	0.23	0.01	0.22
EW14 Station	0.22	0.01	0.21
EW15 Station	0.22	0.01	0.22
EW16 Station	0.23	0.01	0.22
EW17 Station	0.21	0.01	0.20
EW18 Station	0.22	0.01	0.22
EW19 Station	0.21	0.01	0.21
EW2 Station	0.00	0.00	0.00
EW20 Station	0.21	0.01	0.21
EW21 Station	0.21	0.01	0.20
EW8 Station	0.32	0.01	0.31
EW9 Station	0.27	0.01	0.26
Kaliti Station	0.22	0.01	0.21
Lideta Station	0.31	0.01	0.30
Meskel Square	0.26	0.01	0.26
NS13 Station	0.21	0.01	0.20
NS14 Station	0.23	0.01	0.22
NS15 Station	0.22	0.01	0.22
NS16 Station	0.22	0.01	0.22
NS17 Station	0.22	0.01	0.21
NS18 Station	0.22	0.01	0.21
NS19 Stattion	0.22	0.01	0.22
NS2 Station	0.31	0.01	0.30
NS20 Station	0.21	0.01	0.21
NS21 Station	0.22	0.01	0.21
NS3Station	0.27	0.01	0.26
NS4 Station	0.22	0.01	0.22
NS5 Station	0.30	0.01	0.29
NS6 Station	0.25	0.01	0.24
NS7 Station	0.28	0.01	0.27
Piazza Station	0.36	0.01	0.35
Torhyloch	0.00	0.00	0.00

Table 20, Result summary of time per Entity.

	Number In	Number Out
Ayat Station	34.00	29.00
CM2 Station	7.00	5.00
CM3 Station	8.00	7.00
CM4Station	10.00	8.00
EW10 Station	5.00	4.00
EW11 Station	6.00	5.00
EW12 Station	7.00	6.00
EW13 Station	8.00	7.00
EW14 Station	10.00	8.00
EW15 Station	12.00	10.00
EW16 Station	13.00	12.00
EW17 Station	15.00	13.00
EW18 Station	18.00	16.00
EW19 Station	21.00	18.00
EW2 Station	1.00	0.00
EW20 Station	25.00	21.00
EW21 Station	29.00	25.00
EW8 Station	4.00	4.00
EW9 Station	4.00	4.00
Kaliti Station	34.00	29.00
Lideta Station	5.00	5.00
Meskel Square	11.00	10.00
NS13 Station	9.00	7.00
NS14 Station	10.00	9.00
NS15 Station	12.00	10.00
NS16 Station	13.00	12.00
NS17 Station	16.00	14.00
NS18 Station	18.00	16.00
NS19 Stattion	21.00	19.00
NS2 Station	1.00	1.00
NS20 Station	25.00	21.00
NS21 Station	29.00	25.00
NS3Station	1.00	1.00
NS4 Station	2.00	1.00
NS5 Station	2.00	2.00
NS6 Station	3.00	2.00
NS7 Station	4.00	3.00
Piazza Station	1.00	1.00
Torhyloch	0.00	0.00

Table 21, Result summary of number of train in and out.

Queue Detail Summary

	Waiting Time
Ayat Station operation EW22.Queue	0.20
CM2 Station Operation.Queue	0.26
CM3 Station Operation.Queue	0.28
CM4Station Operation.Queue	0.26
EW10 Station Operation.Queue	0.22
EW11 Station Operation.Queue	0.22
EW12 Station Operation.Queue	0.22
EW13 Station Operation.Queue	0.22
EW14 Station Operation.Queue	0.21
EW15 Station Operation.Queue	0.22
EW16 Station Operation.Queue	0.22
EW17 Station Operation.Queue	0.20
EW18 Station Operation.Queue	0.22
EW19 Station Operation.Queue	0.21
EW2 Station operation.Queue	0.00
EW20 Station Operation.Queue	0.22
EW21 Station Operation.Queue	0.20
EW8 Station Operation.Queue	0.31
EW9 Station Operation.Queue	0.26
Hold at Route EW8_S.Queue	0.00
Hold at Route NS13_S.Queue	0.00
Kaliti Station operation NS22.Queue	0.21
Lideta Station Operation.Queue	0.30
Meskel Square Station Operation.Queue	0.26
NS13 Station Operation.Queue	0.20
NS14 Station operation.Queue	0.22
NS15 Station operation.Queue	0.22
NS16 Station Operation.Queue	0.22
NS17 Station Operation.Queue	0.21
NS18 Station Operation.Queue	0.21
NS19 Stattion operation.Queue	0.22
NS2 Station Operation.Queue	0.30
NS20 Station Operation.Queue	0.21
NS21 Station Operation.Queue	0.21
NS3Station Operation.Queue	0.26
NS4 Station Operation.Queue	0.22
NS5 Station Operation.Queue	0.29
NS6 Station Operation.Queue	0.24
NS7 Station Operation.Queue	0.27
Piazza Station Operation.Queue	0.35
Torhyloch Station Operation.Queue	0.00

Table 22, Result summary of Queue waiting time.