

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



**DETERMINING THE UTILIZATION OF CAPACITY FOR ADDIS  
ABABA LIGHT RAIL TRANSIT (AA LRT)**

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**A Thesis in Railway Civil Engineering**

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

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## UNDERTAKING

I hereby declare this research work titled “Determining the Utilization of capacity for Addis Ababa Light Rail Transit (AA LRT)” is my own work under the supervision of Mr. Biniam Ayalew (MSc).The work has not been presented elsewhere for assessment. Where material used from other sources it has been properly acknowledged/referred.

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## ABSTRACT

An increasing of the passenger travel demand in Addis Ababa city results to invest a huge budget for construction of the Addis Ababa railway infrastructure to balance the need for the transportation demand. However, constructing the railway infrastructure only will not satisfy the passenger demand rather it also needs a better management system for efficient utilization of railway capacity. But the railway capacity in Addis Ababa light rail transit has utilization gaps like, the same numbers of trains are scheduled in the whole day time where it varies in actual condition so called the peak and off-peak hour demand. In addition, there is train headway time irregularities from the OCC operational schedule of the shared corridor of railway network that can affect to the railway capacity utilization.

Therefore, different literatures have been reviewed on solving of such problems and it is determined that the UIC-cod 405R is an easy and effective way of calculating the capacity consumption with the help of AnyLogic software in consideration of the railway networking effects. It follows on from work that was carried out to forecast rail transport demand for AA LRT in 2047. The capacity utilization rate is stated as the ratio between demand for railway services and the available capacity of the infrastructure. The findings on this thesis show that the capacity utilization rate varies according to the demand-based schedules. Knowing the demand for the railway line is suitable to know the headway time and capacity for the current operational systems too. Therefore, the schedules at the periods of day should be varied such that a peak hour and off-peak hour's headway time and capacity schedules can have.

The quality of service of railway line varies according to the capacity utilization rate where the maximum utilization rate of this line reaches at the year of 2036. At this period, measures like changing railway signaling operation and or changing the train unit to more than two unites can be a solution for theoretical and practical capacity extension from its current maximum value.

*Keywords: railway capacity utilization, demand based headway time, shared corridor capacity, bottleneck block section*

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## ACRONYMY

AA LRT:	Addis Ababa Light Rail Transit
NRNE:	National Railway Network of Ethiopia
Km:	kilometers
CREC:	China Railway Engineering Corporation
US\$:	United States of Dollar
LOS:	Level of Service
UIC:	International Union of Railway Association
OCC:	Operational Controlling Center
GDP:	Gross Domestic Product
ATC:	Automatic Train Controlling
ATP:	Automatic Train Controlling
ERTMS:	European Railway Train Management System
ETCS:	European Train Controlling System
mm:ss :	in minutes : second
NS:	North-South
EW:	East-West
G.C:	Gregorian calendar
CSA:	Central Statistics Agency
ERC:	Ethiopian Railway Corporation
TCQSM:	Transit Capacity and Quality of Service Manual

## 1. INTRODUCTION

### 1.1. Background of the Study

The demand for railway transportation is steadily increasing around the world. The increase in demand generates to an increase in traffic load [1]. All most all of the road lines in Addis Ababa are already used close to their maximum capacity and in order to meet the new demand, actions need to be taken. Such actions include building new railway infrastructure, upgrade existing infrastructure or use existing infrastructure more efficiently. Constructing the new light rail transit in Addis Ababa was one of the actions taken by the Ethiopian government, consists of the East-West Line and the South-North Line. The line is mostly based on the ground line, Elevated line and underground line are adopted in some sections with its total length of the planned line approximately 31.025km of Phase-I Project [2]. Constructing this project costs a huge amount of investment about US\$475 million budget (this budget is only for the construction of the track line, but also there is a cost of operation) [2, 3].

As the result, this railway line capacity must be utilized efficiently to balance the huge amount of cost invested where it can drive a high productivity. Several problems may occur with the utilization of railway capacity, it could be noted that like less occupation time of the railway infrastructure, less operational management of the railway system, less frequent train, high irregularity of train headway and this will lead to passenger dissatisfaction on the mode of the transportation. All those problems, make the railway capacity to be considered as inefficient or underutilized.

There is no simple way to tell what the capacity of a railway infrastructure is because it depends to such a high degree on how it is used [4]. It shows that railway capacity is a trade-off between quantity and quality, i.e. Between the number of trains that are operated and how much delays they will experience. Increased traffic load leads to higher sensitivity to delays with more secondary delays propagating from train to train and therefore railway line needs demand-based schedules for efficient capacity utilization [1].

Therefore, this research study concerns on the development of demand based headway time for maximum railway capacity utilization using the analytical method (UIC– Code 405R) to estimate the line capacity where the validation of this estimated capacity is made using Anylogic software. The multiple regression (econometric forecasting method) analysis with the help of the method of least square is to be used for estimating future travel demand to balance with the supply capacity determined using the (UIC-Code 405R).

## 1.2. Statement of the Problem

As it is described from above the Addis Ababa railway infrastructure is constructed with huge budgets in order to give the transportation service efficiently. But still, there is a problem of the utilization of this infrastructure like:

- The headway time designed on the timetable by the operators on OCC of AA LRT is 15 minutes at peak hours that is implemented at the whole daytime (7:00 AM-19:00 PM). Where this railway line corridor will not have the same traffic intensity in the whole daytime as in the study made on a bankable feasibility study for AA LRT [2].
- The timetable on OCC of the AA LRT does not consider the sequence of trains on the shared corridor there is an irregularity of headway time, but in such kind of railway network, the flow of trains must be designed carefully to have a regular headway time. As the result, the flow of trains on E-W route passing through the shared corridor will not affect for the flow of trains on N-S route passing the shared corridor.

## 1.3. Objectives

### 1.3.1. General Objectives

The general objective of this thesis study is to estimate the demand based train schedules to determine efficient railway capacity utilization of the AA LRT.

### 1.3.2. Specific Objectives

- To determine the demand based headway time for AA LRT.
- To analyze the line capacity of AA LRT using the analytical method (i.e. UIC-cod 405R).
- To develop econometric forecasting models for predicting the passenger demand.
- To introduce a simple simulation using the Anylogic software for validation of the estimated maximum theoretical capacity of the AA LRT.

## 1.4. The scope of the Study

This study is limited on the AA LRT that is a double track railway line with passenger stations and then the methods of UIC-405R is to be used for estimating railway capacity depending on the availability of data on the detail design stage and operational work stage. In addition, this estimated capacity will be validated using the Anylogic simulation

software where the track line will be drawn and trains will be scheduled to estimate the number of trains per hour. Having the passenger demand an econometric forecasting method is to be used to estimate the future demand capacity. The estimated demand capacity will need to determine the hourly varying headway time (peak hour and off-peak hour) scheduling this passenger demand and railway capacity helps for maximum railway capacity utilization.

### **1.5. The significance of the Study**

- It may be a good way to attraction and satisfaction of customers or users in the railway industry.
- It may reduce the government, budget, that may be lost due to less and unmanaged utilization.
- It may increase the time management system on the railway line and can increase the performance or asset utilization of the system.

## **2. LITERATURE REVIEW**

### **2.1. Railway capacity utilization**

The railway capacity is considered as highly utilized if the number of trains serving are nearest to the maximum capacity of the railway line where this can be affected by the number of stations, number of level crossing, number of turnouts, the networking effect of the lines (junction), station dwell time, and demand.

Different methods were developed to estimate railway line capacity where one of the UIC-405R, This method estimates the maximum capacity of railway line in consideration of the timetable on the operational system if the railway line is in service but for new railway lines a rough timetable schedule must first develop [5, 6].

Therefore, to utilize the railway line capacity there should be the balance between the demand and schedules on the operating system such that demand based headway time will be provided on the line. With this schedule, minimum possible headway time on the route is determined when the railway line reaches the saturation level.

### **2.2. Railway Line Capacity**

#### **2.2.1. Definition of Railway Line Capacity**

The railway capacity definition varies in different kinds of literature based on the techniques and objectives of the specific study made and this is why the International Union of Railways has concluded that “Capacity as such does not exist” and “Railway infrastructure capacity depends on the way it is utilized” this means that on two lines of the same characteristic complete different results can occur, if the operational process differs [4]. Therefore, Railway capacity can define as the outcome of the close interaction between different subsystems of the railway: rolling stock, infrastructure and the operational service with a required LOS that link and optimizes these for better utilization [7, 8]. This definition seems the best fit with this thesis work, but in addition to this capacity definition one can be defined according to his analysis in different ways like:

- “Railway line capacity is the maximum number of trains that can be operated over a line in a peak hour.” [9]
- “The maximum number of trains that may be operated using a defined part of the infrastructure at the same time as a theoretical limiting value is not reached in practice.” [10]

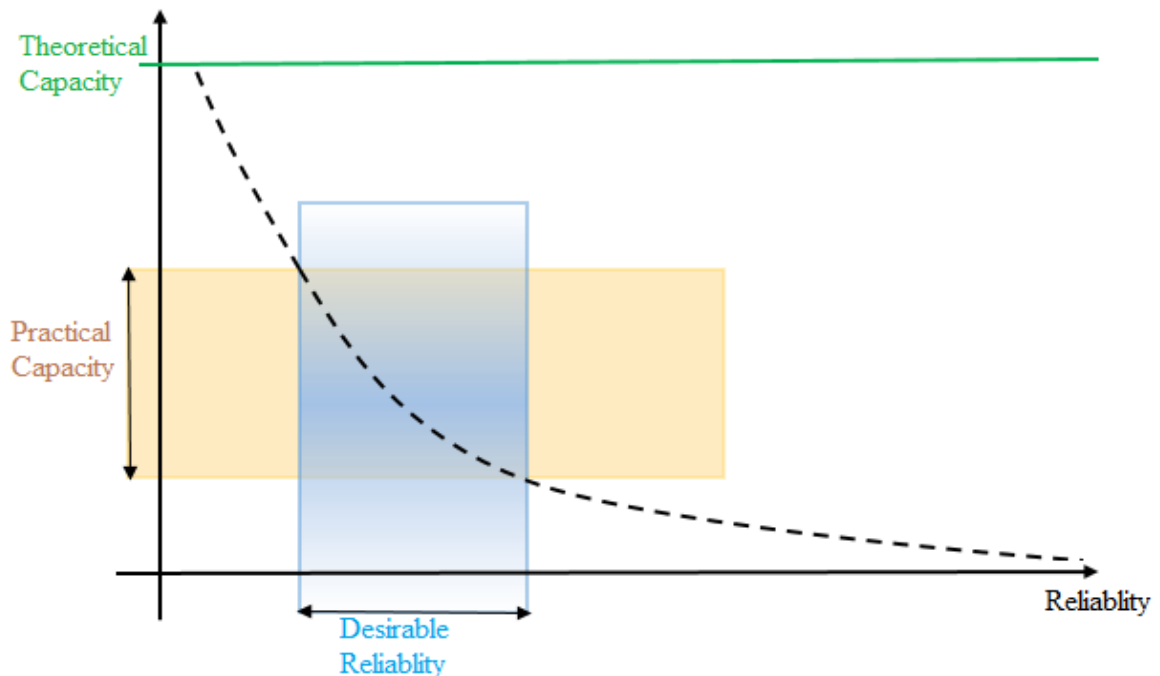
- “Capacity is the level of traffic (i.e. A number of trains per day) that a rail line can accept without exceeding a specified limit of queuing time.” [11]
- “Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan.” [12]
- “Capacity is measured as the count of valid train paths over a fixed time horizon within an optimal master schedule.” [13]
- “The capacity of a line is defined as the number of scheduled trains that can run on the line in the reference time.” [14]
- “The optimal Railway capacity is defined as the flow of traffic on a link that yields a maximum profit for the operator (difference of revenues and costs).” [15]
- “The capacity of an infrastructure facility is the ability to operate the trains with an acceptable punctuality.” [16]
- “The capability of the infrastructures to handle one or several timetable.” [16]

### 2.2.2. Types of Capacity

Different types of capacity usually exist in the railway environment, but the most important ones are categorized into four types of capacity [5, 6, and 12]:

- a. **Theoretical Capacity** is the number of trains that could run over a route, during a specific time interval, mathematically calculated using an empirical formula. It represents an upper limit for line capacity. Frequently, it assumes that traffic is homogeneous, that all trains are identical, and that trains are evenly spaced throughout the day with no disruptions. It ignores the effects of variations in traffic, and operations that occur in reality and it is not possible to run the numbers of trains that can be worked out mathematically [5, 6 and 17]. This capacity estimation type is used for determination of full utilization of the infrastructures, but is not optimized because such capacity is not working on reality, there are some limitations like passenger demand, delay and networking effects of the railway line.
- b. **Practical Capacity** also represents the practical limit of the number of trains (usually considering the current train mix, priorities, traffic bunching, etc.) That moves on a line in order to guarantee a reasonable level of reliability. It is a more realistic measure than theoretical capacity, usually around 60%-75% of the latter [5, 6, and 17]. To calculate practical capacity, the definition of a timetable respecting a required level of service has to be done; for instance, the level of

service may be defined on the admissible delay or percentage of on train time. It doesn't give a unique value to the whole railway network because of complexity and diversification of components (lines, stations or their subparts), which requires different estimation of capacity it. In the case of the network level, it will be possible to estimate a global capacity value by referring to the lower local value [18] (see figure 2.01).



**Figure 2.01: Practical capacity involves the desirable level [5, 6]**

- c. **Used Capacity** is the actual traffic volume over the network, usually lower than the practical capacity.
- d. **Available Capacity** is the difference between the Used Capacity and the Practical Capacity and provides a useful indication of additional trains that could be handled by the network.

### 2.2.3. Railway Capacity Computation Methods

During capacity computation, different parameters are considered. The basic parameters that can influence the capacity consumption are the characteristics of the existing infrastructures like [4]:

- Layout (single or double track)
- Station (overhauling tracks)
- Speed

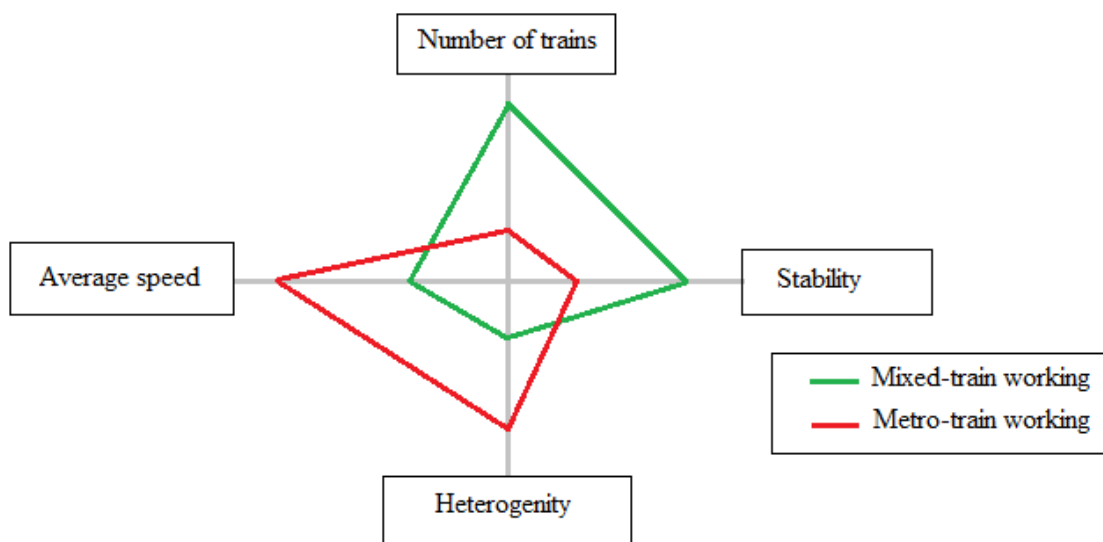
- Signaling
- Curves
- Junctions etc.

In addition, the characteristics of the operational process must be taken into consideration.

Typical operational parameters are [4, 5, and 6]:

- Number of trains (often described as the number of trains/hour or trains/day)
- Average speeds of the trains
- Desired stability (depends often on the number of passenger trains)
- Heterogeneity (number and configuration of slow and fast trains)

UIC also emphasizes that the capacity is affected by interdependencies and the interrelationship between the four major operational elements of the railroad [5] and the relationship between these parameters are normally shown in a so-called capacity balance diagram (see fig. 2.02 below). Each axis represents the value of a parameter and the length of the chord represents the capacity. Increasing capacity means increasing the length of the chords.



**Figure 2.02: Capacity balance according to UIC code 406 definitions [4, 5]**

A higher level of stability requires additional margins and buffer to suppress minor delays (LOS) resulting in fewer trains. More trains running on a line leave less capacity for quality. Differences in acceleration, maximum speed, and train characteristics result in different headways compared to the line with harmonized train runs.

Therefore, the railway capacity computation should consider the above conditions. Those different kinds of literature that define the capacity competition methods differently, but they have a common method, or tool used to analysis capacity are mostly divided into three types: [5] Synthetic or analytical methods, Asynchronous methods or optimization methods and Synchronous methods or simulation methods.

Analytical methods make use of mathematical expressions and formulas of modeling the infrastructure in a simple way, in order to provide results of first approximation to determine theoretical capacity. Simulation methods are more detailed; it is able to reproduce, by means of specific software, the processes of railway operation over the time and build up models representing real-world systems in order to validate the timetable data. Finally, optimization methods are based on obtaining optimal saturated timetables using mathematical programming techniques instead; the main method involved in that category is saturation, where line capacity is obtained by scheduling a maximum number of additional train services in a timetable. This thesis uses to estimate the detailed capacity of the AA LRT using the analytical method and simple simulation of the railway line is to be made in order to validate the capacity estimated using the analytical methods.

#### **2.2.4. Analytical Methods**

Describe the problem by means of mathematical formulae or algebraic excretions and may represent a good start for identifying major capacity constraints; they are mostly applied for determining an initial solution in simple situations, for comparison purposes or as a reference. This method usually obtains theoretical capacities and then practical capacities either as a percentage of the theoretical capacity or by including regularity margins when calculating the theoretical capacity [5, 6]. An example of this method, which performs probabilistic analyses of dispatch patterns, was introduced by Petersen and Taylor (1982) [19] and extended by Kraft (1988) [20]. Martland (1982) [21] introduced the PMAKE analysis, which aims to understand the probabilistic distribution of time that a train spends during its intermediate stops on its way to its destination.

The International Union of Railways, more generally known as the UIC (from its French name, Union Internationale des Chemins de Fer), proposed the UIC method (UIC Leaflet 405-1, 1983) [22]; it calculates capacity in line sections to identify bottlenecks. It takes into account the order of trains, and a buffer time is inserted to achieve an acceptable quality of service. This method was officially dropped some years ago and is no longer

recognized as a standard. It has been superseded by more general recommendations (UIC Leaflet 405R, 1996) [23] that establish a link between railway capacity and railway quality.

This analytical method proposed in its first edition of the International Union of Railway (UIC) in the leaflet 405R [23], officially replaced in 2004 by the compression method (UIC's Leaflet 406) as a standard on capacity estimation, anyway offering an efficient estimation of the capacity of a line. This approach is used in this thesis, because it gives the clarity and the easiness of application and the modest need of data; and it represents a simple but valid method, recognized and appreciated at European level.

The theoretical formula used for capacity determination as per the UIC leaflet 405R is given as;

$$P = \frac{T}{(t_{fm})+(t_r)+(t_{zu})} \text{ Where,}$$

- P is the capacity (daily, hourly, etc.) Index
- T is the reference time (usually 24 hours for the daily capacity);
- $t_{fm}$  is the theoretical (average) minimum headway
- $t_r$  is a buffer time
- $t_{zu}$  is an equivalent buffer time

However, this capacity is an ideal (maximum theoretical) capacity that cannot be consumed to the ground and therefore the practical capacity that considers the secondary delays or LOS must be estimated to know the exact capacity of the railway line using the analytical methods. Train delay is the main operational problem on railway line reliability and punctuality thus different literature studies on the delay to define the relationship on a number of running trains (or directly capacity) and trains delay by developing different queuing models [5, 24, 25, and 26].

Instead of developing a queuing model, an analytical approach for the waiting time as a function of traffic flow, related to waiting time sensitivity (partial derivative of average waiting time with respect to track occupancy) and maximum traffic energy, defined as the product of train intensity and speed was developed [24, 27].

Finally, the simplest method to account the unscheduled trains delay (the secondary delay) is proposed by Landex (2008) [8] approach following an idea by Kaas (1998) [16] where this thesis uses the landex method to account the secondary delay. According to landex, the total amount of delay  $\sum t_d$  along a given train's path can be calculated based on the initial delay  $t_{d,1,i}$  and a delay propagation factor  $y(t_{d,1,i})$ :

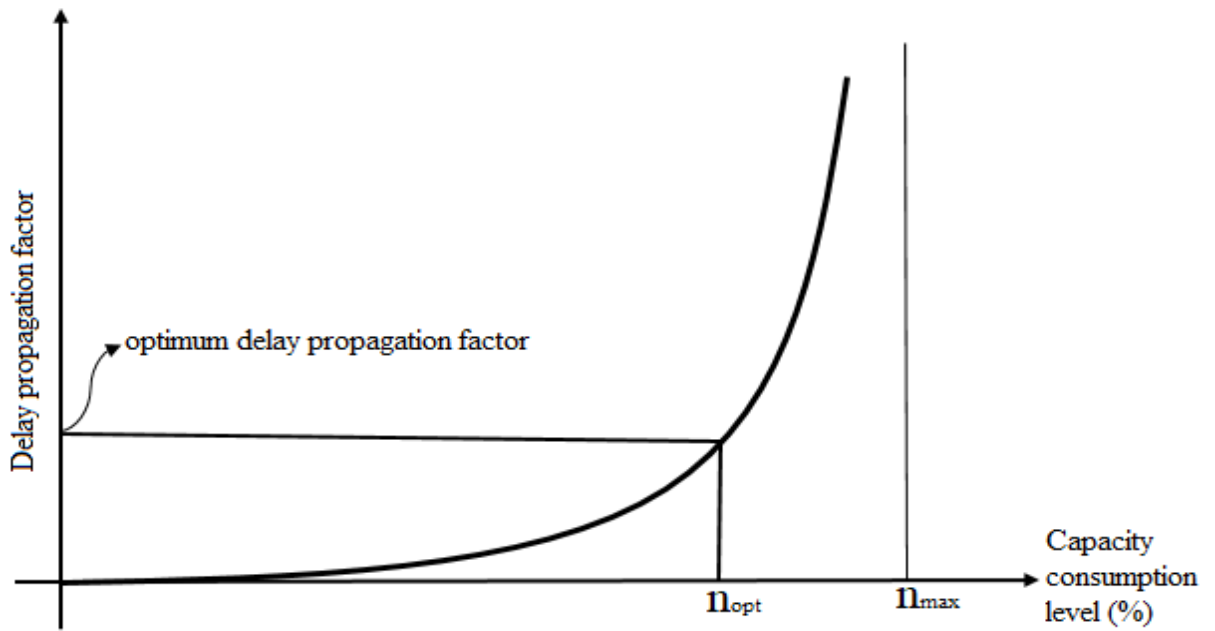
$$\sum t_d = t_{d,1,i} * y$$

By expressing the initial delay  $t_{d,1,i}$  as a multiple of the minimum headway time  $t_{h,min}$ :

$$t_{d,1,i} = n * t_{h,min}$$

Then the delay propagation factor could be calculated as a function of the capacity consumption  $K$  and the size of the minimum headway time  $t_{h,min}$  (By means of  $n$ ), where the optimum capacity consumption will be determined within the point of the dramatic increase of delay propagation factors. Finally, the practical capacity will be as the products of the theoretical supply capacity and the determined optimum capacity consumption of track line.

$$y = \frac{n}{\left(\frac{1}{k} - 1\right)} + 1 - \frac{\left(\frac{1}{k} - 1\right)}{n} \frac{n}{\left|\left(\frac{1}{k} - 1\right)\right|} \left( \frac{n}{\left(\frac{1}{k} - 1\right)} + 1 \right)$$



**Figure 2.03: Relation between capacity consumption level and train delay propagation factor [31]**

### 2.2.5. Simulation methods

A simulation is the imitation of an operation of a real-world process or system over time. It is the representation of the dynamic behavior of a system by moving it from state to state in accordance with well-defined rules. Simulation methods provide a model, which is as close as possible to reality, to validate a given timetable [6].

A modern simulation modeling is made using three methods: discrete event, agent-based, and system dynamics.

In simulation modeling, a method is a framework used to map a real-world system to its model. So that, the method is as a type of language or a sort of "terms and conditions" for model building [29].

Each method serves a specific range of abstraction levels. System dynamics assume very high abstraction, and it's typically used for strategic modeling. Discrete event modeling supports medium and medium-low abstraction. In the middle are agent-based models, which can vary from very detailed models where agents represent physical objects to the highly abstract models where agents represent competing companies or governments [29].

Agent-based modeling is a relatively new method compared to system dynamics and discrete event modeling. There is no standard language for agent-based modeling, and an agent-based model's structure comes from graphical editors or scripts. There are many ways to specify an agent's behavior. Frequently, agent, has a notion of state and its actions and reactions depend on the state; then the behavior is best defined with state charts. Sometimes behavior is defined in rules executed upon special events [29], where the simulation modeling method used in this thesis is an agent-based model the agents in this thesis are also railway track line as main agent and trains that should have a notion of states in order to travel on the railway line are the second agents.

### **2.3. Transport Demand Estimation**

#### **2.3.1. Passenger Transportation Demand Forecasting**

Forecasting represents the process of predicting or estimating the future. It provides information about the potential future events and their consequences for an organization. It may not reduce the complications and uncertainty of the future, but it increases the confidence of the management to make important decisions [30].

Railway companies use forecasting methods in order to anticipate potential issues and results for the business in the upcoming months and years. The essence of railway transportation planning and management is to match the transport supply with railway demand. The concept of demand and supply are fundamental to the economic theory and is widely applied in the field of transport economics (Jean Paul, 2013) [31]. In the area of travel demand and the associated supply of transport infrastructure, the notion of demand and supply could be applied (Jean Paul, 2013) [31]. As per Jean, Transport demand is Transport needs, which can be expressed in terms of a number of people, volume, or tons

per unit of time and space and Transport supply is the capacity of transportation infrastructures and modes, generally over a geographically defined transport system and for a specific period of time.

A thorough understanding of the existing pattern of railway customers is the key for identifying and analyzing existing railway traffic-related problems. Detailed data on current pattern and railway traffic volumes are needed also for developing demand forecasting/prediction models. The prediction of future demand is an essential task of the long-range railway transportation planning process for determining strategies for accommodating future needs. These strategies may include land use policies, pricing programs, and expansion of transportation, supply high-speed railway lines and express services [30].

The demand model is a base of railway transport forecasts. Via this model, a possible causal relationship can be found between the subject of forecasting process (number of passenger trains on a railway line) and the factors influencing on it (GDP, population, unemployment, quality of service, travel times, prices, etc.). After determining the causalities and checking for statistical and logical validity, the model can be used for the forecast of railway demand in future [30].

### **2.3.2. Methods of Travel Demand Forecasting**

Forecasting methods used for railway demand modeling can include both quantitative data and qualitative observations. The chief advantage of qualitative methods is that the main source of data derives from the experiences of qualified executives and employees. On the other hand, projections of quantitative forecasting methods rely on the strength of past data [30]. Where in this thesis work the forecasting method made here is using the quantitative data of the AA LRT.

#### **2.3.2.1. Quantitative Methods**

Quantitative forecasting methods make formal use of historical data and a forecasting model [32]. The model formally summarizes patterns in the data and expresses a statistical relationship between previous and current values of the variable. Then the model is used to project the patterns in the data into the future. In other words, the forecasting model is used to extrapolate past and current behavior into the future. There are two types of forecasting models in general use – econometric and general time series models. Econometric models make use of relationships between the variable of interest and one or

more related predictor variable. Sometimes econometric models are called causal forecasting models because the predictor variables are assumed to describe the forces that cause or drive the observed values of the variable of interest. General time series models employ the statistical properties of the historical data to specify a formal model and then estimate the unknown parameters of this model (usually) by least squares [30, 33]. Where this thesis will use the econometric forecasting method.

**a. Econometric (causal) forecasting model**

The implementation of econometric models has become increasingly fashionable in transport demand modeling. The main reason for this is that nowadays transportation demand can involve the analysis of large amounts of data on revealed preferences, such as population size, service quality, ticket price, car ownership, GDP per capita, unemployment, and income of individuals etc., And stated preferences such as opinions, attitudes, and intentions for a particular. These different indices are included in the econometric analysis and the regression method is most used tools for this econometric method, where this regression method can be a univariate or multivariate regression [30].

The implementation of this method in the transportation demand analysis was first occurred in the 1950s [34] Having found the relationship between dependent and independent variables by regression, transportation experts are able to predict future demand generated by each traffic zone and the relationship between variables is expressed as in below.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

Where

- **y** is the dependent variable, the demand to be forecasted in the number of passenger/day.
- **X<sub>1</sub>; X<sub>2</sub> ... and X<sub>k</sub>** are independent econometric variables that have effects on passenger demand,
- **β<sub>0</sub>, β<sub>1</sub>, β<sub>2</sub>... and β<sub>k</sub>** called the regression parameters or coefficients, which are unknown constants to be determined from the data.

These variables are estimated by forecasting the actual data gathered, as well as other sources such as organizations and governmental agencies those are responsible for providing socioeconomic information.

### **3. METHODOLOGY AND DATA COLLECTION**

#### **3.1. Introduction**

This thesis work is focusing on studying the railway line capacity utilization determination in Ethiopia, in particular, the Addis Ababa light rail transit by estimating the supply capacity (number of trains that can serve along the infrastructure) and demand capacity (number of trains needed for the given passenger demand) so as to schedule a demand based the headway time. Therefore, the maximum supply capacity will be determined in terms of the number of trains by the analytical methods (UIC-405R). The data needed to estimate this capacity is like, existing timetable, spacing of the block-sections, station locations, the number of intermediate block section, location of the signal lighting, and the number will be used as an input data where the validation of the capacity analyzed is made by using AnyLogic software. Whereas the demand capacity is estimated by converting the estimated passenger demand to the number of trains, using the multiple regression methods from the existing data that will include the socioeconomic analysis of the routes and develop a demand model to predict/forecast future passenger demand trends.

#### **3.2. UIC's Analytical Method – Code 405R**

In the literature review, different analytical methods and procedures that can be applied in the calculation of railway capacity are discussed, but In this study, set of procedures provided by UIC's Analytical Method – Code 405R for calculating the supply capacity are found to be convenient depending on the data availability. This method is the theoretical bases in order to assess the analysis of a rail network; the suggested approach proposes the evaluation of the capacity and utilization for each element of the system. The capacity measure and utilization rate for each line can be estimated from the smallest values calculated (bottleneck) for its constituents.

The main reasons for selecting the procedures of this code are:

- ❖ The ease of analysis is simple to compute and can be presented using Microsoft Excel spreadsheet without applying simulation tools. This fits with the scope and budget of the research. Excel has several advantages: it's widely available, it's very easy to use, and it allows to add scripts to the formulas as the spreadsheet's logic becomes increasingly sophisticated.
- ❖ The manual is developed as an international document for capacity estimation and therefore, the method can be used by any country because the analytic equations are developed using basic distance, time and speed equation used in the general

law of motion that can be directly applicable in Ethiopia. The equations can be simply modified with the actual condition of the railway line. The input parameters of the equations are taken from the actual design of AA LRT.

- ❖ The railway network of Addis Ababa city is a simple type (i.e. Only two routes) so, capacity estimation of this simple network will not quite difficult with this analytical method.

### 3.3. Approach for Determination of Capacity

Two types of analysis approach are used for the determination of railway capacity:

- Demand capacity
- Supply capacity

#### 3.3.1. Theoretical Supply Capacity Estimation Method

In this case, the railway system is designed for maximum supply capacity (i.e. Capacity based on the maximum throughput of the line). This maximum line capacity is directly related to the total number of trains that can serve on the route with their possible design headway time. This headway time is related to the signaling system so is the minimum possible design headway time on the route.

An analytical method (i.e. UIC-Cod 405R) that describe trains running starting from infrastructural data and timetable, but they are not able to define the waiting time generated by single conflicts between trains; they can only give some significant values of these delays.

In the same case, this method also has as such properties and this method defines the capacity as:

$$P = \frac{T}{(t_{fm})+(t_r)+(t_{zu})} \text{-----} 3.01$$

- P is the capacity (daily, hourly, etc.) index
- T is the reference time (usually 24 hours for the daily capacity);
- $t_{fm}$  is the theoretical (average) minimum headway
- $t_r$  is a buffer time or expansion margin estimated on the basis of the queuing theory and considers the possibility of queues of trains waiting for entering in the block section because of delay of previous trains;

- $t_{zu}$  is empirically defined and it considers global effects of traffic (it is defined taking into account the amount of block sections in the critical section of line). Thus, the extra time based on the number ‘a’ of the intermediate block sections of the line is calculated by means of the formula  $t_{zu}=0.25*a$ . Velocities, grades, stopping areas, operational properties of the train, and location of physical elements such as switches and stations are the main factors used to calculate the block length. Once the block lengths have been calculated, signals are physically placed on the guide way to instruct the driver on scheduling and routing information [35]. In this case, stations are used as a reference to calculate the blocking lengths and to determine the number of intermediate block sections having the signaling positions.

**a. Reference time (T)**

A reference time is the service hours on the railway line per a day. Currently, the AA LRT has sixteen (16hrs) service hours, but this will be expected to increase as per the economic growth where the industry sector development is increased highly such that the numbers of passengers traveling to the industry at a day and night time will increase too. This thesis analysis will consider the assumption of railway service hours (T) is increased by 2 hours in every 5 years. Considering the 2018G.C is an initial period for forecasting the travel demand with the current railway reference time of 16hrs for the next 30 years the reference time will be as in table 3.01.

**Table 3.01: Assumed Values of the reference time**

From-to years	Reference time (T) (hr)	From-to years	Reference time (T) (hr)
2018-2022	16	2033-2037	22
2023-2027	18	2038-2042	24
2028-2032	20	2042-2047	24

**b. Average minimum headway time ( $t_{fm}$ )**

Headway time is “the minimum time between trains that the signaling will permit so that the train ahead does not affect the following train.” [36]

The average minimum headway for each line is calculated by using a weighted average of the minimum headway between two consecutive trains of the same category: [37]

$$t_{fm} = \frac{\alpha_L * t_{fmL} + \alpha_R * t_{fmR} + \alpha_M * t_{fmM}}{\alpha_L + \alpha_R + \alpha_M} \text{-----} 3.02$$

The procedure considers three different typologies of train: long-distance passenger trains (L), local/regional passenger trains (R) and freight trains (M, this last category encloses

also out-of-service and empty runs); of course the factors  $\alpha_L$ ,  $\alpha_R$  and  $\alpha_M$  in the previous formula represent the percentages of the categories on the total of trains. However, since the Addis Ababa LRT has only passenger trains with homogeneous type service, same performance and short distance travel of trains serving on the two double track routes, with the local passenger trains (R) service category only is serving. To calculate the minimum headways for the given category of convoy and for each segment of double-track lines (and per direction), the line is provided with an automatic block signaling system (ATP or ATC) with three aspects. It means that the minimum spatial distance between two consecutive trains is constituted by;

- A first-block section to guarantee the braking distance of the train (and thus safety conditions).
- The second block section used to guarantee the not disrupted circulation (i.e. A running train should always find the approaching signal ‘clear’ to avoid unnecessary acceleration/deceleration phases and disturbed circulation), plus a distance for the sight of the signal and the clearing of the section, and
- A distance equal to the train length for the release of the block system (the rear of the train must pass the clearing point). This average minimum headway time is also estimated for single and double track service routes differently and for the double track railway line the formulae are given by; [37]

The headways are calculated based on the scheduled running times between stations, i.e. Each line section between consecutive stations (and per direction in case of double track lines) in one direction can be occupied only by a single train, neglecting the missing infrastructure information related to the characteristics of the block sections.

$$t_{fmR} = \frac{2 * L_b + L_s}{V_{fmR}} + t_s \text{-----} 3.03$$

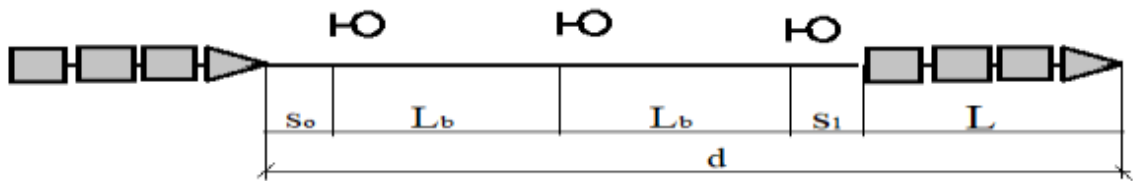
Where,

- $L_b$  -represents the length of the block section (actual or assumed as described better in the case studies)  $L_b = \frac{V^2}{2 * a}$ ,
- $L$  -the length of the Rolling Stock or station length,

- $V_{fmR}$  -the speed relative to the considered category. Where, this is computed from the distance in between stations.
- $d=2*L_b + S_0 + S_1 + L$ -----3.04
- $t_s$  -the sum of the sighting and clearing times.
- $S_0, S_1$ - is the sighting and clearing distances respectively.

$$t_{fm} = \frac{d}{V} = \frac{2*L_b + S_0 + S_1 + L}{V} \text{-----} 3.05$$

The optimum travel speed of the train is determined when the minimum headway time is as short as possible.



**Figure 3.01: Figural representative of the headway time computation**

**c. Expansion margin or buffer time and scheduled train delay**

The expansion margin  $t_r$  is calculated applying queuing theory to the relevant section, which is treated as a service. The most used approach involves an M/M/1 queuing system, where arrivals to the section are modeled as a Poisson process, service (transit) times have an exponential distribution and, obviously, the whole system works on a FIFO (first-in, first out) basis. In particular, the length of the queue for entering the block section is equal to the number of trains encountering a disturbance (the delay) and it depends on the intensity of traffic  $\Psi$ . The track occupation rate of the single channel is given by the ratio between the average number of arriving trains  $\lambda = 1/(t_{fm} + t_r)$ , (i.e. The inverse of the expected inter-arrival time) and the maximum number of trains that utilize the section are  $\mu = 1/t_{fm}$ , (i.e. Inverse of expected service time):

$$\psi = \rho = \frac{\lambda}{\mu} = \frac{t_{fm}}{t_{fm} + t_r} \text{-----} 3.06$$

$$\Psi = \frac{\text{Blocking time (s)}}{\text{Inter-arrival time (s)}} \text{-----} 3.07$$

An extensive test campaign, carried out by UIC, led to the identification of the following threshold values for  $\Psi$ :

- 0.60 (corresponding to 1.5 users waiting in the queue) valid for an unlimited period of time (normal operation of the system), hence the condition  $t_r \geq 0.67 t_{fm}$  ----3.08
- 0.75 (corresponding to 3.1 users waiting in the queue) valid for a short period of time (peak hours), hence the condition  $t_r \geq 0.33 t_{fm}$  -----3.09

Assuming an M/M/1 system, the mean queue length (average number of delayed trains) is equal to:

$$L_q = \frac{\rho}{1-\rho} \text{-----3.10}$$

While the average waiting time (average delay per train) is evaluated as:

$$w = \frac{\rho}{\mu - \lambda} = (t_{fm} + t_r) \frac{\rho^2}{1-\rho} \text{-----3.11}$$

The above approach is based on simple formulas and does not require a large amount of data besides values such as a number of trains, reference period, train schedule, etc. That is usually available. However, the length (or the travel time) of the relevant block section of the line should be measured, where this information involves a detailed knowledge of the infrastructure.

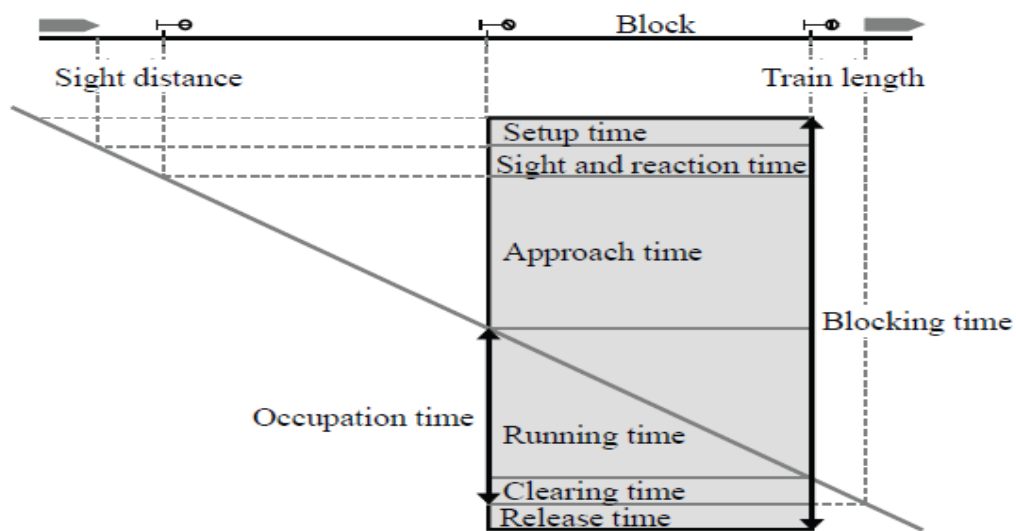


Figure 3.02: Scheme for the calculation of the blocking time for double-track lines [4, 37]

**3.3.1.1. Rolling Stocks for AA LRT**

The rolling stock serving on Addis Ababa Light Rail Transit is designed to maintain high safety, advanced performance, economic utility, convenient maintenance, favorable shape as well as a comfortable ride [38].

The atmosphere around the rolling stock equipment has mild acidity and contains some light dust. In addition, the rainfall sometimes in Addis Ababa is quite great. Therefore, the equipment should be able to bear heavy wind, high temperature, high humidity, high vibration, heavy noise, the contamination from detergent, dust, rodent infestation and fires. Considering of all those factors the design life of train in service is estimated to be used for 30 years [38].

As the passenger demand increases with time it is expected to increase the length of the train too from which it is at the initial stage. Therefore, this thesis assumes the outside dimensions of the train into two stages, which are the Initial Stage and long-term stages dimensions, with the consideration of 6 person/m<sup>2</sup> loading capacity. The tramcar dimensions and capacity of the first stage are assumed to be implemented until the railway line will be saturated with a single unit train, the long-term stage will also be implemented after the saturation level of a railway network with a single unit train, and the table below shows different indices about these two stages.

**Table 3.02: different indices of the tramcar operation**

Indices	Initial stage	Long-term stage
Tramcar marshaling	One unite	Two units
Length of the train (m)	30	60
Number of seats	64	128
Rated passengers (passengers/tramcar)	286	572

Source: [38]

**3.3.2. Practical Supply Capacity Estimation Method**

This practical capacity is estimated as it is stated in the literature reviews, by application of the queuing theory, a direct interrelation between operating quality and capacity of a railway infrastructure can be estimated. The theoretical or maximum capacity consumption ( $n_{max}$ ) of a railway infrastructure is the number of trains that can be processed with the specification of a defined route and safety standards, but with an unlimited storage capacity in front of the infrastructure [39].

Delay propagation and delays grow to infinity with maximum consumption level ( $n_{max}$ -Scenario). Regarding this, only operations with a considerably reduced number of trains are possible on a railway line. The optimal capacity consumption ( $n_{opt}$ ) is the number of train paths, reducing the average train delay or delay propagation factor to an expected value in conformity with the market expectation ( $y(t_{d,1,i})$ – “Level of service”). Delay propagation is used as a quality measure with reference to the capacity consumption of a railway line [39] (see figure 2.03).

The formula used to estimate the delay propagation factor ( $y$ ) is as in below, where  $k$ - is track consumption level in percentage and  $n$ - delay as a multiple of the minimum headway time.

$$y = \frac{n}{\left(\frac{1}{k}-1\right)} + 1 - \frac{\left(\frac{1}{k}-1\right)}{n} \left| \frac{n}{\left(\frac{1}{k}-1\right)} \right| \left( \frac{n}{\left(\frac{1}{k}-1\right)} + 1 \right) \dots\dots\dots 3.12$$

Optimum (Practical) capacity = Theoretical capacity \* optimum consumption level ( $n_{opt}$ )

### **3.4. Simulation of Railway Operation Using Anylogic Software for UIC-cod 405R Capacity Validation**

Simulation modeling requires special software tools that use simulation-specific languages. While it needs to do simulation modeling well, save time and effort are rewarded in order to, the model offers a high-quality analysis of a dynamic system.

The model developed in this thesis is the simplest model that does not represent the complete dynamic analysis of the railway line of AA LRT. However, it will be modeled and analyzed to show the flow of trains on the roughly modeled railway track line, so as to know the number of trains operating on the route per hours in the shared corridor of the railway line using the agent-based model of Anylogic software.

The agent (train) will be scheduled to operate on the modeled railway line of AA LRT where the model will focus on the capacity estimation of the AA LRT shared corridor.

### **3.5. Demand Capacity Estimation**

In this approach, the capacity of the railway line is determined based on the peak hour passenger volume at a critical station or point. The capacity of the line is designed economically for the minimum planned train headway, rather than the minimum possible train headway. The traffic studies for identifying the recommended alignment and

forecasting the future traffic for the alignment was carried out based on primary and secondary data collection, where this thesis is based on secondary data. The transportation planning process primarily consists of the development of a set of formulae/equations that are referred to the models, enabling a forecast of future travel demand and traffic characteristics.

The forecast method is extrapolative and is connected to the application of a multifactor regression analysis (see section 3.5.1) with the main factors being – chosen macroeconomic indices (population and Unemployment). In order to obtain the unknown quotients in the chosen relationships, with which the actual demand will be forecasted.

To obtain the unknown quotients in the chosen mathematical regression dependencies the method of least squares is applied.

**3.5.1. Multiple Regression Model for Forecasting Transportation Demand**

In the literature review, the qualitative and quantitative forecasting methods and procedures that can be applied in the calculation of traffic demand is discussed, but In this study, set of procedures provided by multiple regression (quantitative) for calculating the demand capacity are found to be convenient depending on the data availability. Multivariate regression analysis is performed to investigate the extent of the change in predictive power that resulted from combining two or more of the independent variables into multiple linear regression functions and the relationship between variables is expressed as in below.

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k \text{-----} 3.13$$

Where

- $y$  is the dependent variable, the transportation demand needed to be forecasted is the number of passenger/day
- $X_{i1}$ ;  $X_{i2}$  ... and  $X_{ik}$  are independent econometric variables that have an effect on passenger demand,
- $\beta_0$ ,  $\beta_1$ ,  $\beta_2$ ... and  $\beta_k$  called the regression parameters or coefficients, which are unknown constants to be determined from the available actual data using the least square method.

These variables are estimated by forecasting the actual data gathered, as well as other sources such as organizations and governmental agencies those are responsible for providing socioeconomic information.

**3.5.1.1. Method of Least-Square for Estimation of the Model Parameters**

In the model of multiple linear regression, the method of least squares can be used to estimate the regression coefficients. Suppose that  $n > k$  observations are available, and let  $y_i$  denote the  $i^{\text{th}}$  observed response and  $x_{ij}$  denote the  $i^{\text{th}}$  observation or level of regressor  $x_j$ . The regress (which can be either the endogenous variable or a transformation of the endogenous variables) is a linear function of  $k$  regressors corresponding to the explanatory variables or their transformations and of a random disturbance or error. The model also has an intercept. Designating the regress and by  $y$ , the regressors by  $X_1, X_2... X_k$  and the disturbance or the random disturbance by  $u$ , the population model of multiple linear regression is given by the formulae equation 3.10 in above.

It is more convenient to deal with multiple regression models if they are expressed in matrix notation. This allows a very compact display of the model, data, and results and therefore can be written as;

$$Y = X\beta + \epsilon \quad \text{Where,}$$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \quad X = \begin{bmatrix} 1 & x_{11} & x_{12} & \dots & x_{1k} \\ 1 & x_{21} & x_{22} & \dots & x_{2k} \\ \cdot & \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \cdot & \dots & \cdot \\ n & x_{n1} & x_{n2} & \dots & x_{nk} \end{bmatrix} \quad \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \vdots \\ \beta_n \end{bmatrix}$$

In general,  $Y$  is an  $n \times 1$  vector of the observations,  $X$  is an  $n \times k$  matrix of the levels of the repressors variables,  $\beta$  is a  $k \times 1$  vector of the regression coefficients, and  $\epsilon$  is an  $n \times 1$  vector of random errors.

Lastly the unknown parameter are determined using the simplified formula so called least-square normal equation given by;

$$\beta = (X'X)^{-1}X'Y \text{-----3.14}$$

**3.5.1.2. The Goodness of Fit for the Data's Used**

The degree of fitness of the two relating dependent and independent data is measured using the coefficient of determination ( $R^2$ ).  $R^2$  is probably the most popular measure of how well a regression model fits the data.  $R^2$  may be defined either as a ratio or a percentage. Since we use the ratio form, its values range from zero to one. A value of  $R^2$  near zero (less than 0.5) indicates no linear relationship, while a value near one (greater than 0.5) indicates a perfect linear fit. The goodness of fit for the data used in this thesis is checked using the SPSS software.

### 3.6. Data Collection

To make the analysis, the basic data collection method that is used is the secondary data collection method. The data that are taken from the source of published or unpublished documents is the secondary data. The source of this data like Central Statistics Agency (CSA), Ethiopian Railway Corporation (ERC), and Others. Primary data collection will not be considered since it requires a large volume of data involving a huge amount of finance and time.

The secondary data collected from the above institutions are like passenger travel demand of Addis Ababa railway line, population, and an unemployment rate of Addis Ababa city.

#### 3.6.1. Passenger Travel Demand Data of AA LRT

Studies were made to estimate value of passenger demand along the AA LRT routes and then the maximum unidirectional section passenger flow on the road section from Lideta Light to La Gare (bottleneck section) at the shared corridor of the routes in the initial stage, short-term and long-term are 38462 persons/day, 70308 persons/day and 115385 persons/day respectively. The Forecasting year is proposed to be that initial stage is 2014, short-term is 2021 and long-term is 2036 [38]. Having these passenger demand values the passenger demand for the year 2014, 2015, 2016, and 2017 can be estimated by interpolations (see table 3.03).

**Table 3.03: Average Daily Railway Passenger Demand of AA LRT**

Year	Passenger demand per day
2014	38462
2015	42437
2016	46590
2017	50918

#### 3.6.2. Population Data of Addis Ababa

The population is the driving force for the economic development of any country due to the influence of their day-to-day activity and, therefore, an organized transportation facility must be supplied for such more populated countries or cities. Then this population size is one of the most important input data for travel demand modeling. Stratified population and socioeconomic data of the study area is needed to utilize it in the model.

The Addis Ababa City is divided into Ten Sub-cities and are further divided into Ninety-Nine Kebeles. Based on the 2007 Population and Housing Census Report, There is a difference in sub-city population distribution which shows uneven distribution. The whole Populations are urban dwellers. As it is stated in the statistical report of Addis Ababa, the general population of Addis Ababa according to 2007 housing and population survey was 2,739,551 with an average household size of 4.1 persons. Additionally, Kebele level population data were collected upon the request of the author from the Central Statistics Agency for the year 2014 – 2017 and aggregated in sub-city level as it is shown in table 3.04 below.

**Table 3.04: The Addis Ababa City Population Distribution by Sub Cities**

No.	Sub cities	Number of kebele	Year			
			2014	2015	2016	2017
1	Akaki kality	8	211,380	216,538	221,759	227,182
2	Nefas Silk-Lafto	10	368,883	377,892	387,017	396,486
3	kolfe Keranyo	10	500,163	512,369	524,729	537,561
4	Gullele	10	312,096	319,712	327,426	335,434
5	Lideta	9	235,246	240,988	246,805	252,842
6	Kirkos	11	258,035	264,337	270,721	277,346
7	Arada	10	246,680	252,705	258,808	265,142
8	Addis Ketema	9	297,794	305,058	312,414	320,053
9	Yeka	11	404,336	414,212	424,217	434,599
10	Bolle	11	360,387	369,189	378,104	387,355
	Sum	99	3,195,000	3,273,000	3,352,000	3,434,000

Source: (CSA-2013) [40]

### 3.6.3. Unemployment Rate Data of Addis Ababa

The unemployment rate is one of the indicators that have been used to measure the extent of unutilized human resource in the economy in a given area or region in a certain period. The unemployment rate will have an inverse relation with that of the transportation demand, the lower unemployment rate shows that an economy of good performance and higher job opportunities, and high rate of mobility in transportation perspective also. According to the CSA Unemployment Survey (2016), the Unemployment rate is computed as the percentage of the unemployed population over the total number of economically active population.

Out of the total population, an age group of ten years and above unemployment rate for Addis Ababa city administration is in a 2010(26.9%), 2011(25.1%) ,2012(23%), 2013(24.2%), 2014(23.5%), 2015(21.2%) and 2016(21%) in person which is given as in below where, its detail is on the appendix B.1-6.

**Table 3.05: Unemployment rate in Addis Ababa**

Year	Unemployment rate (%)		
	Male	Female	Total
2010	17.9	36.1	26.9
2011	17.3	33.7	25.1
2012	15.6	31.1	23.0
2013	15.8	33.0	24.2
2014	15.9	31.8	23.5
2015	14.4	28.6	21.2
2016	12.4	30.0	21.0

Source: CSA [41]

### 3.7. Travel Demand Dynamics on Hours of Day

Travel demand is dynamic each second, hour, day and even seasons, but most of the planners were planned the transportation system by evenly distributing of the total demand estimated. However, this thesis will consider the hourly travel demand varied on the AA LRT for estimation of the peak and off-peak hour demand, the peak hours are 3 hours of morning (07:20 AM-10: 02 AM), and 3 hours of evening (16:20 AM-19:20 AM) total of 6hr peak hours in the day. In addition to this, the study also shows around 45% of the travel demand is at peak hours [3]. Then the off-peak hour time per day is as in table 3.06.

**Table 3.06: Off-peak hour time per day.**

From-to year	Reference time (T) (hr)	Peak hour time (hr)	Off-peak hour time (hr)	From-to year	Reference time (T) (hr)	Peak hour time (hr)	Off-peak hour time (hr)
2018-2022	16	6	10	2033-2037	22	6	16
2023-2027	18	6	12	2038-2042	24	6	18
2028-2032	20	6	14	2042-2047	24	6	18

## 4. ANALYSIS AND RESULTS

### 4.1. Theoretical supply capacity Estimation for AA LRT

#### 4.1.1. Theoretical Supply Capacity for the East-West Corridor

This section describes the practical application of capacity estimation methodology presented in Section 3, in particular, the UIC-code 405R. In addition, to this capacity estimation parameters like, blocking time, buffer time, equivalent buffer time, track occupation rate, average number of delayed trains and scheduled average waiting time of trains at each block sections is estimated first. In determination of those, all parameters, a clear block section length among stations, the number of intermediate block sections and timetable from OCC of AA LRT are used as an imputes. The capacity estimation in below is an example on how it is determined in a single block section of railway line considering the up and down flow of trains, where the up direction is the travel from Ayat (EW1)-Torhailoch (EW22) and the opposite travel of trains is down direction travel.

- Theoretical Capacity estimation example at a single blocking section between station Ayat (EW1)-Meri (EW2)

#### Up-direction travel capacity

- *Blocking section length*=1260m from
- *Blocking time*= 2:19 (mm:ss) =139 seconds from timetable in the Up-direction
- *Buffer time*( $t_r$ ); based on the theory of UIC-405 code the values of buffer time vary on the peak and off-peak hours of travel time where it can be estimated as in below.

Buffer time at off-peak hours ( $t_r$ ) =0.67\*blocking time ( $t_{fm}$ ) =0.67\*139s =1:33minutes

Buffer time at rush hours ( $t_r$ ) =0.33\*blocking time ( $t_{fm}$ ) =0.33\*139s =45secondes

- *Estimation of equivalent buffer time* ( $t_{zu}$ ); This is an extra time based on the number of the intermediate block sections 'a' on the line and is calculated by means of the formula  $t_{zu} = 0.25 * 'a'$ .

The number of intermediate block sections in between stations Ayat-Meri on both the up-direction and down-direction is a=2 so that the equivalent buffer time is  $t_{zu} = 0.25 * 2 = 0.5seconds =30seconds$

- *Train inter-arrival time*; this is determined from the timetable that is the pure train –train separation

During off-peak hours= 20 minutes =1200 seconds

During rush hours= 15 minutes = 900 seconds

- *Estimation of track intensity (track occupation rate)( $\Psi$ );* Equation 3.06 and 3.07 of section 3.3.1 gives a formula for determination of track occupation rate

$$\Psi = \frac{t_{fm}(new)}{t_{fm} + t_r}$$

Where,  $t_{fm}(new)$  is the Blocking time and

$t_{fm} + t_r$  is the current total headway time on the timetable during peak or off-peak hours.

During peak hours, the actual track occupation rate is  $\Psi = \frac{139 \text{ s}}{900 \text{ s}} = 0.154$  (i.e. Track section is occupied 15.4%)

During off-peak hours, the actual track occupation rate is  $\Psi = \frac{139 \text{ s}}{1200 \text{ s}} = 0.1158$  (i.e. Track section is occupied 11.58%)

- *Assuming a M/M/1 system, the mean queue length (average number of delayed trains) is estimated using the equation 3.10 of section 3.3.1.*

During peak hours,  $L_q = \frac{\Psi}{1-\Psi} = \frac{0.154}{(1-0.154)} = 0.182$  numbers of trains.

During off-peak hours,  $L_q = \frac{\Psi}{1-\Psi} = \frac{0.1158}{(1-0.1158)} = 0.131$  numbers of trains.

- *Scheduled average waiting time (average delay per train) is also estimated using equation 3.11 of section 3.3.1.*

Actual waiting time of the train where  $t_{fm}=15\text{min}=900$  seconds at peak hours and  $t_{fm}=20\text{min}=1200$  seconds at off-peak hours.

During peak hours,  $w = (900\text{s}) \frac{(0.154)^2}{(1-0.154)} = 25$  seconds/train/6hr

During off-peak hours,  $w = (1200\text{s}) \frac{(0.1158)^2}{(1-0.1158)} = 18$  seconds/train/10hr

In addition, assuming that the track is saturated the track occupation rate will be 60% in the off-peak hours and 75% of the peak hours. During this saturated track nature, the blocking time and buffer time will also become the headway time of the track section, so that the new train waiting time at the saturated track can be computed as follows:

During peak hours,  $t_{fm}=139$  seconds,  $t_r=45$  seconds

$w = (139 + 45) \frac{(0.75)^2}{(1-0.75)} = 6:54$  minutes/train/6hr

During off-peak hours,  $t_{fm}=139$  seconds,  $t_r=93$  seconds

$$w = (139 + 93) \frac{(0.6)^2}{(1-0.6)} = 3:28 \text{ minutes/train/10hr}$$

- *Line capacity estimation*; the railway capacity of this track section is computed by using the above estimated capacity parameters as an impute for both the peak and off-peak hour travels.

During peak hours,  $t_{fm}=139$  Sec,  $t_r=45$  Sec,  $t_{zu}=30$  Sec,

$$t_{fm} + t_r + t_{zu}=139+45+30 =3:34 \text{ min (total headway time) } =0.0594 \text{ hrs.}$$

$$\text{Capacity (P for T=6hr)} = \frac{T}{t_{fm}+t_r+t_{zu}} = \frac{6 \text{ hr}}{0.0594 \text{ hr}} = \underline{101 \text{ trains}} \quad (\text{see equation 3.01})$$

During off peak hours,  $t_{fm}=139$  Sec,  $t_r=93$  Sec,  $t_{zu}=30$  Sec,

$$t_{fm} + t_r + t_{zu}=139+93+30 =4:22 \text{ min (total headway time) } =0.073 \text{ hrs.}$$

$$\text{Capacity (P for T=10hr)} = \frac{T}{t_{fm}+t_r+t_{zu}} = \frac{10 \text{ hr}}{0.073 \text{ hr}} = \underline{138 \text{ trains}} \quad (\text{see equation 3.01})$$

The total number of trains serving on this track section on up-direction per a day is the sum of the two =101+138=239 trains /day

### **Down-direction travel capacity**

- *Blocking section length*=1260m from
- *Blocking time*= 3:06 (mm: ss) =186 seconds from timetable in the Down-direction
- *Buffer time*( $t_r$ ); based on the theory of UIC-405 code the values of buffer time vary on the peak and off-peak hours of travel time where it can be estimated as in below.

Buffer time at off-peak hours ( $t_r$ ) =0.67\*blocking time ( $t_{fm}$ ) =0.67\*186s =2:04minutes

Buffer time at rush hours ( $t_r$ ) =0.33\*blocking time ( $t_{fm}$ ) =0.33\*186s =1:01minutes

- *Estimation of equivalent buffer time* ( $t_{zu}$ ); This is an extra time based on the number of the intermediate block sections 'a' on the line and is calculated by means of the formula  $t_{zu} = 0.25 * 'a'$ .

The number of intermediate block sections in between stations Ayat-Meri on both the up-direction and down-direction is a=2 so that the equivalent buffer time is  $t_{zu} = 0.25 * 2 = 0.5\text{seconds} =30\text{seconds}$

- *Train inter-arrival time*; this is determined from the timetable that is the pure train –train separation

During off-peak hours= 20 minutes =1200 seconds

During rush hours= 15 minutes = 900 seconds

- *Estimation of track intensity (track occupation rate)( $\Psi$ );* Equation 3.06 and 3.07 of section 3.3.1 gives a formula for determination of track occupation rate

$$\Psi = \frac{t_{fm}(new)}{t_{fm} + t_r}$$

Where,  $t_{fm}(new)$  is the Blocking time and

$t_{fm} + t_r$  is the current total headway time on the timetable during peak or off-peak hours.

During peak hours, the actual track occupation rate is  $\Psi = \frac{186 \text{ s}}{900 \text{ s}} = 0.2067$  (i.e. Track section is occupied 20.67%)

During off-peak hours, the actual track occupation rate is  $\Psi = \frac{186 \text{ s}}{1200 \text{ s}} = 0.155$  (i.e. Track section is occupied 15.5%)

- *Assuming a M/M/1 system, the mean queue length (average number of delayed trains)* is estimated using the equation 3.10 of section 3.3.1.

During peak hours,  $L_q = \frac{\Psi}{1-\Psi} = \frac{0.2067}{(1-0.2067)} = 0.26$  numbers of trains.

During off-peak hours,  $L_q = \frac{\Psi}{1-\Psi} = \frac{0.155}{(1-0.155)} = 0.183$  numbers of trains.

- *Scheduled average waiting time (average delay per train)* is also estimated using equation 3.11 of section 3.3.1.

Actual waiting time of the train where  $t_{fm}=15\text{min}=900$  seconds at peak hours and  $t_{fm}=20\text{min}=1200$  seconds at off-peak hours.

During peak hours,  $w = (900\text{s}) \frac{(0.2067)^2}{(1-0.2067)} = 48$  seconds/train/6hr

During off-peak hours,  $w = (1200\text{s}) \frac{(0.155)^2}{(1-0.155)} = 34$  seconds/train/10hr

In addition, assuming that the track is saturated the track occupation rate will be 60% in the off-peak hours and 75% of the peak hours. During this saturated track nature, the blocking time and buffer time will also become the headway time of the track section, so that the new train waiting time at the saturated track can be computed as follows:

During peak hours,  $t_{fm}=186$  seconds,  $t_r= 61$  seconds

$$w = (186 + 61) \frac{(0.75)^2}{(1-0.75)} = 9:15 \text{ minutes/train/6hr}$$

During off-peak hours,  $t_{fm}=186$  seconds,  $t_r=124$  seconds

$$w = (186 + 124) \frac{(0.6)^2}{(1-0.6)} = 4:39 \text{ minutes/train/10hr}$$

- *Line capacity estimation*; the railway capacity of this track section is computed by using the above estimated capacity parameters as an impute for both the peak and off-peak hour travels.

During peak hours,  $t_{fm}=186$  Sec,  $t_r=61$  Sec,  $t_{zu}=30$  Sec,

$$t_{fm} + t_r + t_{zu}=186+61+30 =4:37\text{min (total headway time)} =0.07694 \text{ hrs.}$$

$$\text{Capacity (P for T=16hr)} = \frac{T}{t_{fm}+t_r+t_{zu}} = \frac{6 \text{ hr}}{0.07694 \text{ hr}} = \underline{78 \text{ trains}} \quad (\text{see equation 3.01})$$

During off peak hours,  $t_{fm}=186$  Sec,  $t_r=124$  Sec,  $t_{zu}=30$  Sec,

$$t_{fm} + t_r + t_{zu}=186+124+30 =5:40 \text{ min (total headway time)} =0.0944 \text{ hrs.}$$

$$\text{Capacity (P for T=16hr)} = \frac{T}{t_{fm}+t_r+t_{zu}} = \frac{10 \text{ hr}}{0.0944 \text{ hr}} = \underline{106 \text{ trains}} \quad (\text{see equation 3.01})$$

The total number of trains serving on this track section on down-direction per day is the sum of the two = $78+106=\underline{184 \text{ trains per day}}$

All the above estimated capacities and parameters at the up and down direction travel are tabulated on the below tables 4.01 and 4.02 at the row of EW1-EW2. In the same way, for all track block sections capacity is computed on the tables with different reference times (T) (16hr, 18hr) at the tables 4.01 and 4.02 and the capacity results for reference time (T) (20hr, 22hr, and 24hr) are at the appendix C. In this reference times, 6hrs are the peak hour times and its capacity is estimated by assuming the track is occupied 75% (maximum saturation level).

The need for determination of each block section capacity is just to know the bottleneck-block section and this bottleneck block section is characterized with least sectional capacity and scheduled waiting time but maximum headway time. For instance, according the analysis in the table 4.01 for the E-W railway line capacity analysis the bottleneck block sections are at the row of EW7-EW6 (Gurd shola-1 to Management Institute) in the up direction with its value of 86 trains and at the row of EW2-EW1 (Meri-Ayat) with the value of 78 trains at the peak hour time. In addition, the shared corridors bottleneck block

section is at the row EW19-EW18 (Tegbared-Mexico) with the value of 145 trains in up and 143 trains in down direction travel where observed at the peak hour time. As we can see from those results, the bottleneck block sections are with a least capacity but higher headway time this is because of these block section are congested first before the other block sections and finally it can reaches at the level where it can not give service (very low level of services).

Therefore, the capacity determined at this block section is considered as the capacity of the total length of the railway line and the corresponding headway time is also taken as the minimum possible headway time that can be implemented on the railway line. One can concludes from this the bottleneck block section is the governing section for the maximum train schedules on the total length of the railway line. In the same way, the above bottleneck block sections are found as governing section in the table 4.02, and tables at the appendix C.

**Table 4.01: Theoretical capacity of E-W corridor at peak hours (T=6hr)**

Stations from-to [1]	Track direction [2]	No. intermediate block section 'a' [3]	Inter-arrival time (mm:ss) [4]	Blocking time (mm:ss) [5]	$t_r=[0.3 \cdot 3^*$ column 5 ] (mm:ss) [6]	$t_{zu}=[0.2 \cdot 5^*$ 'a'] (mm:ss) [7]	Actual values					$\Psi=0.75,$ $Lq=3.1$
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)	
EW22- EW21	Up	2	15:00	01:42	0:33	00:30	0.113	0.128	00:13	131	05:03	
	Down	2	15:00	01:49	0:35	00:30	0.121	0.138	00:15	125	05:24	
EW21- EW20	Up	3	15:00	01:39	0:32	00:45	0.11	0.124	00:12	123	04:54	
	Down	2	15:00	01:28	0:29	00:30	0.098	0.108	00:09	147	04:23	
EW20- EW19	Up	1	07:17	01:24	0:27	00:15	0.192	0.238	00:19	172	04:09	
	Down	1	08:14	01:23	0:27	00:15	0.168	0.202	00:16	173	04:07	
EW19- EW18	Up	1	07:17	01:41	0:33	00:15	0.231	0.301	00:30	145	05:01	
	Down	1	08:14	01:43	0:33	00:15	0.209	0.263	00:27	143	05:06	
EW18- EW17	Up	1	07:17	01:29	0:29	00:15	0.204	0.256	00:22	163	04:25	
	Down	1	08:14	01:38	0:32	00:15	0.198	0.247	00:24	149	04:52	
EW17- EW16	Up	1	7:17	01:06	0:21	0:15	0.151	0.178	00:11	212	3:15	
	Down	1	08:14	01:14	0:24	00:15	0.159	0.176	00:13	191	03:40	
EW16- EW15	Up	2	15:00	01:34	0:31	00:30	0.104	0.117	00:10	140	03:01	
	Down	3	15:00	01:21	0:26	00:45	0.09	0.099	00:08	142	04:00	

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Stations from-to [1]	Track directi on [2]	No. inter mediate block section 'a' [3]	Inter- arrival time (mm:ss) [4]	Blocking time (mm:ss) [5]	$t_r=[0.3$ 3* column 5 ] (mm:ss) [6]	$t_{zu}=[0.2$ 5* 'a'] (mm:ss) [7]	Actual values			$\Psi=0.75,$ Lq=3.1	
							$\Psi$	Lq	w (mm: ss)	P	w (mm: ss)
EW15- EW14	Up	1	15:00	01:22	0:27	00:15	0.091	0.1	00:08	174	04:05
	Down	1	15:00	01:19	0:26	00:15	0.088	0.096	00:07	180	03:56
EW14- EW13	Up	1	15:00	01:17	0:25	00:15	0.086	0.094	00:07	185	03:49
	Down	1	15:00	01:25	0:28	00:15	0.094	0.104	00:08	169	04:14
EW13- EW12	Up	1	15:00	01:49	0:35	00:15	0.121	0.138	00:15	136	05:24
	Down	1	15:00	01:56	0:38	00:15	0.129	0.148	00:17	128	05:46
EW12- EW11	Up	1	15:00	01:19	0:26	00:15	0.088	0.096	00:07	180	03:56
	Down	1	15:00	01:46	0:34	00:15	0.118	0.134	00:14	140	05:15
EW11- EW10	Up	1	15:00	01:25	0:28	00:15	0.094	0.104	00:08	169	04:14
	Down	1	15:00	01:32	0:30	00:15	0.102	0.114	00:10	158	04:34
EW10- EW9	Up	1	15:00	01:37	0:32	00:15	0.108	0.121	00:11	150	04:50
	Down	1	15:00	01:46	0:34	00:15	0.118	0.134	00:14	140	05:15
EW9- EW8	Up	1	15:00	01:34	0:31	00:15	0.104	0.117	00:10	155	04:41
	Down	1	15:00	01:29	0:29	00:15	0.099	0.11	00:09	163	04:15
EW8- EW7	Up	2	15:00	02:16	0:44	00:30	0.084	0.092	00:07	103	06:45
	Down	2	15:00	02:05	0:41	00:30	0.139	0.161	00:20	111	06:13
EW7- EW6	Up	3	15:00	02:36	0:51	00:45	0.173	0.21	00:32	86	07:45
	Down	3	15:00	02:13	0:43	00:45	0.148	0.173	00:23	98	06:36
EW6- EW5	Up	1	15:00	01:18	0:25	00:15	0.153	0.181	00:24	183	03:51
	Down	1	15:00	01:24	0:27	00:15	0.093	0.103	00:08	172	04:09
EW5- EW4	Up	1	15:00	01:54	0:37	00:15	0.127	0.145	00:16	130	05:39
	Down	1	15:00	02:14	0:44	00:15	0.149	0.175	00:23	112	06:40
EW4- EW3	Up	1	15:00	01:35	0:31	00:15	0.106	0.118	00:11	153	04:43
	down	1	15:00	01:37	0:32	00:15	0.108	0.121	00:11	150	04:50
EW3- EW2	Up	3	15:00	02:10	0:42	00:45	0.144	0.169	00:21	100	06:27
	Down	3	15:00	02:22	0:46	00:45	0.158	0.187	00:26	93	07:03
EW2- EW1	Up	2	15:00	02:19	0:45	00:30	0.154	0.183	00:25	101	06:54
	Down	2	15:00	03:06	1:01	00:30	0.207	0.261	00:48	78	09:15

**Table 4.02: Theoretical capacity of E-W corridor at off peak hours (T=10hr) (2018-2022)**

year

Stations from-to [1]	Track direction [2]	No. intermediate block section 'a' [3]	Inter-arrival time (mm:ss) [4]	Blocking time from timetable (mm:ss) [5]	Buffer time ( $t_r$ )=[0.33 * column5] (mm:ss) [6]	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) [7]	Actual values			$\Psi=0.6,$ Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
EW22- EW21	Up Down	2 2	20:00 20:00	01:42 01:49	01:08 01:13	00:30 00:30	0.085 0.09	0.093 0.1	00:09 00:10	180 170	02:33 02:43
EW21- EW20	Up Down	3 2	20:00 20:00	01:39 01:28	01:06 00:58	00:45 00:30	0.082 0.073	0.09 0.079	00:08 00:06	172 205	02:28 02:11
EW20- EW19	Up Down	1 1	09:17 10:30	01:24 01:23	00:56 00:55	00:15 00:15	0.150 0.108	0.178 0.123	00:14 00:10	232 236	02:06 02:04
EW19- EW18	Up Down	1 1	09:17 10:30	01:41 01:43	01:07 01:09	00:15 00:15	0.181 0.134	0.221 0.155	00:22 00:16	197 193	02:31 02:34
EW18- EW17	Up Down	1 1	09:17 10:30	01:29 01:38	00:59 01:05	00:15 00:15	0.159 0.128	0.19 0.147	00:16 00:14	221 202	02:13 02:26
EW17- EW16	Up Down	1 1	09:17 10:30	01:06 01:14	00:44 00:49	00:15 00:15	0.118 0.097	0.134 0.107	00:08 00:07	288 261	01:39 01:50
EW16- EW15	Up Down	2 3	20:00 20:00	01:34 01:21	01:02 00:54	00:30 00:45	0.078 0.068	0.085 0.072	00:07 00:05	194 200	02:20 02:01
EW15- EW14	Up Down	1 1	20:00 20:00	01:22 01:19	00:54 00:52	00:15 00:15	0.068 0.067	0.073 0.07	00:06 00:05	239 247	02:02 01:57
EW14- EW13	Up Down	1 1	20:00 20:00	01:17 01:25	00:51 00:56	00:15 00:15	0.064 0.071	0.069 0.076	00:05 00:06	252 231	01:55 02:06
EW13- EW12	Up Down	1 1	20:00 20:00	01:49 01:56	01:13 01:17	00:15 00:15	0.091 0.097	0.1 0.107	00:10 00:12	183 173	02:43 02:53
EW12- EW11	Up Down	1 1	20:00 20:00	01:19 01:46	00:52 01:11	00:15 00:15	0.066 0.088	0.07 0.097	00:05 00:10	247 188	01:57 02:39
EW11- EW10	Up Down	1 1	20:00 20:00	01:25 01:32	00:56 01:01	00:15 00:15	0.071 0.077	0.076 0.083	00:06 00:07	231 214	02:06 02:17
EW10- EW9	Up Down	1 1	20:00 20:00	01:37 01:46	01:04 01:11	00:15 00:15	0.081 0.088	0.088 0.097	00:08 00:10	205 188	02:24 02:39
EW9- EW8	Up Down	1 1	20:00 20:00	01:34 01:29	01:02 00:59	00:15 00:15	0.078 0.074	0.085 0.08	00:07 00:07	211 221	02:20 02:13
EW8- EW7	Up Down	2 2	20:00 20:00	2:16 02:05	01:31 01:23	00:30 00:30	0.113 0.104	0.128 0.116	00:17 00:14	140 151	03:24 03:07

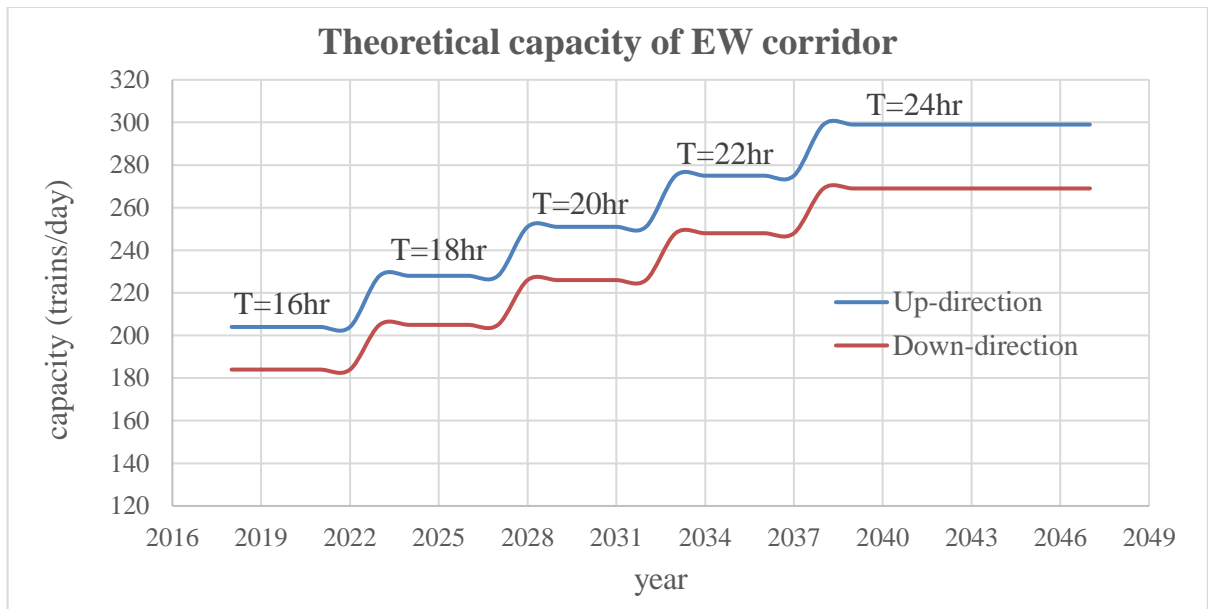
Stations from-to [1]	Track direction [2]	No. intermediate block section 'a' [3]	Inter-arrival time (mm:ss) [4]	Blocking time from timetable (mm:ss) [5]	Buffer time ( $t_r$ )=[0.33 * column5] (mm:ss) [6]	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) [7]	Actual values					$\Psi=0.6,$ $Lq=1.5$
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)	
EW7- EW6	Up	3	20:00	02:36	01:44	00:45	0.13	0.15	00:23	118	03:54	
	Down	3	20:00	02:13	01:29	00:45	0.111	0.125	00:16	135	03:19	
EW6- EW5	Up	1	20:00	01:18	00:52	00:15	0.065	0.07	00:05	248	01:57	
	Down	1	20:00	01:24	00:56	00:15	0.07	0.075	00:06	232	02:06	
EW5- EW4	Up	1	20:00	01:54	01:16	00:15	0.095	0.105	00:11	176	02:51	
	Down	1	20:00	02:14	01:29	00:15	0.112	0.126	00:16	151	03:20	
EW4- EW3	Up	1	20:00	01:35	01:03	00:15	0.079	0.086	00:08	208	02:22	
	down	1	20:00	01:37	01:04	00:15	0.081	0.088	00:08	205	02:24	
EW3- EW2	Up	3	20:00	02:10	01:27	00:45	0.108	0.121	00:15	138	03:15	
	Down	3	20:00	02:22	01:35	00:45	0.118	0.134	00:19	128	03:33	
EW2- EW1	Up	2	20:00	02:19	01:33	00:30	0.116	0.131	00:18	138	03:28	
	Down	2	20:00	03:06	02:04	00:30	0.155	0.183	00:34	106	04:39	

**4.1.1.1. Interpretation of Results of East-West Corridor**

The capacity analysis results for the bottleneck block sections in between Management Institute (EW6) to Gurd Shola-1 (EW7) in the up-direction and Ayat (EW1) to Meri (EW2) in the down-direction shown on above tables 4.01, 4.02 and tables on the appendix C their result summery is as expressed at table 4.03.

**Table 4.03: Theoretical capacity at bottlenecks section of E-W corridor**

Bottleneck sections	Travel direction	Current capacity	Year interval	Capacity on peak hours	Capacity on off-peak hours	Total capacity per day
EW6- EW7	Up- direction	60	2018-2022	86	118	204
			2023-2027	86	142	228
			2028-2032	86	165	251
			2032-2037	86	189	275
			2038-2047	86	213	299
EW1- EW2	Down- direction	60	2018-2022	78	106	184
			2023-2027	78	127	205
			2028-2032	78	148	226
			2032-2037	78	170	248
			2038-2047	78	191	269



**Figure 4.01: the Total theoretical capacity of E-W corridor**

The table 4.03 and fig.4.01 are the tabular and graphical representation of the theoretical supplied capacity or capacity from the throughput of railway infrastructure and this maximum capacity can vary with in the variation of reference time or the service time of railway line per a day. In this figure, the line with blue color is the capacity when train travels in Up-direction (ayat-Torhailoch) taken from the EW7-EW6 bottleneck blocking section of E-W railway line results and the line with the red color is the capacity when train travels to the Down-direction (Torhailoch-Ayat) taken from the EW2-EW1 bottleneck blocking section of E-W railway line results. The variation in capacity on this two directional travel is due to variation in train speed limit and location and numbers of signal lighting, but both directions have same blocking length then this tow blocking sections gets the saturation level of the traffic flow for that reason its call as bottleneck block sections.

Comparing the outcomes of the UIC-Cod 405R when saturated and the current traffic, they are quite different; the actual delay at peak hour increases by 93% from 32sec/train/6hr (actual) to 7:45 min/trains/6hr (on saturation) on the bottleneck EW6-EW7 section of up-direction. Moreover, the actual utilization rate ( $\Psi$ ) at this section increases by 76.9% from 17.3% (actual) to 75% (on saturation) at peak hour (see table 4.04).

**Table 4.04: Brief comparison of the UIC-code 405 main results with the actual traffic on the E-W corridor**

Nature of traffic	Item No.	Comparison indices	EW6- EW7	EW1- EW2	EW18-EW19 (on the shared corridor)	
			Up- direction	Down- direction	Up- direction	Down- direction
Actual (Current) traffic	A	Delay at peak hour	0:32	0:48	0:30	0:27
	B	Delay at off-peak hour	0:23	0:34	0:22	0:16
	C	Actual utilization ( $\Psi$ ) at peak hour	17.30%	20.70%	23.10%	20.90%
	D	Actual utilization ( $\Psi$ ) at off-peak hour	13%	15.50%	18.10%	13.40%
During saturation of traffic	E	Delay at peak hour	7:45	9:15	5:01	5:06
	F	Delay at off-peak hour	3:54	4:39	2:31	2:34
	G	Optimum utilization ( $\Psi$ ) at peak hour	75%	75%	75%	75%
	H	Optimum utilization ( $\Psi$ ) at off-peak hour	60%	60%	60%	60%
Relative deviation		(E-A)/E	93%	91.40%	90%	91.20%
		(F-B)/F	90%	87.80%	84.50%	89.60%
		(G-C)/G	76.90%	72.40%	69.20%	72.10%
		(H-D)/H	78.33%	74.20%	69.80%	77.67%

#### 4.1.2. Theoretical Supply Capacity for the North-South Corridor

The capacity estimation in here is also uses the timetable, length of blocking section and number and location of signal lighting as in the capacity estimation in the East-West directions at above section 4.1.1. the computed results are also as it is tabulated in the below table 4.05 and 4.06 with the reference times (T) (16hr, 18hr) but for the reference times (T) (20hr, 22hr, 24hr) results are as in the appendix D.

In this North-South capacity analysis results as shown in the table 4.05 the rows of EW16-NS15 (stadium- Meshouleky) on the up direction with its value of 70 trains and NS12-NS11 (Lancha-Nefas silk 2) with its capacity value of 73 train on the down direction are determined as the bottleneck block sections of the N-S railway line. Where the up-direction travel is from Kality to Menilik-II Square and the reverse direction travel is down direction travel. . In addition, the shared corridor capacity and governing block section is same as in the E-W capacity analysis.

**Table 4.05: Theoretical capacity of N-S corridor at peak hours (T=6hr)**

Section from-to (1)	Track direction (2)	No. inter-mediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column (5)] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25*'a'] (mm:ss) (7)	Actual values			$\Psi=0.75$ , Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
NS27-NS26	Up	2	15:00	3:07	1:01	0:30	0.208	0.262	0:49	77	9:18
	Down	2	15:00	2:42	0:53	0:30	0.18	0.22	0:35	88	8:03
NS26-NS25	Up	1	15:00	1:47	0:35	0:15	0.119	0.135	0:14	137	5:19
	Down	1	15:00	1:19	0:26	0:15	0.088	0.096	0:07	180	3:56
NS25-NS24	Up	1	15:00	1:28	0:29	0:15	0.098	0.108	0:09	163	4:23
	Down	1	15:00	1:25	0:28	0:15	0.094	0.104	0:08	168	4:14
NS24-NS23	Up	1	15:00	2:50	0:56	0:15	0.189	0.233	0:39	89	8:28
	Down	1	15:00	2:13	0:43	0:15	0.148	0.173	0:23	113	6:36
NS23-NS22	Up	1	15:00	1:42	0:33	0:15	0.113	0.128	0:13	144	5:03
	Down	1	15:00	1:37	0:32	0:15	0.108	0.121	0:11	150	4:50
NS22-NS21	Up	1	15:00	2:28	0:48	0:15	0.164	0.197	0:29	102	7:21
	Down	1	15:00	2:16	0:44	0:15	0.151	0.178	0:24	110	6:45
NS21-EW20	Up	3	15:00	2:37	0:51	0:45	0.174	0.211	0:33	85	7:48
	Down	2	15:00	2:36	0:51	0:30	0.173	0.21	0:32	91	7:45
EW20-EW19	Up	1	7:17	1:24	0:27	0:15	0.169	0.203	0:17	171	4:09
	Down	1	8:14	1:23	0:27	0:15	0.178	0.217	0:17	173	4:07
EW19-EW18	Up	1	7:17	1:41	0:33	0:15	0.203	0.255	0:25	145	5:01
	Down	1	8:14	1:43	0:33	0:15	0.221	0.284	0:29	143	5:06
EW18-EW17	Up	1	7:17	1:29	0:29	0:15	0.179	0.218	0:19	162	4:25
	Down	1	8:14	1:38	0:32	0:15	0.21	0.266	0:26	149	4:52
EW17-EW16	Up	1	7:17	1:06	0:21	0:15	0.133	0.153	0:10	211	3:15
	Down	1	8:14	1:14	0:24	0:15	0.159	0.189	0:13	191	3:40
EW16-NS15	Up	3	15:00	3:16	1:04	0:45	0.282	0.393	1:39	70	9:45
	Down	2	15:00	2:52	0:56	0:30	0.191	0.236	0:40	83	8:33
NS15-NS14	Up	1	15:00	1:08	0:22	0:15	0.076	0.082	0:05	205	3:22
	Down	1	15:00	1:14	0:24	0:15	0.082	0.09	0:06	191	3:40

DETERMINING THE UTILIZATION OF CAPACITY FOR AA LRT

Section from-to (1)	Track direction (2)	No. inter-mediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column 5] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ ) = [0.25*'a'] (mm:ss) (7)	Actual values			$\Psi=0.75$ , Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
NS14-NS13	Up	1	15:00	1:23	0:27	0:15	0.092	0.102	0:08	172	4:07
	Down	1	15:00	1:25	0:28	0:15	0.094	0.104	0:08	168	4:14
NS13-NS12	Up	2	15:00	1:25	0:28	0:30	0.094	0.104	0:08	151	4:14
	Down	2	15:00	1:31	0:30	0:30	0.101	0.112	0:10	143	4:32
NS12-NS11	Up	3	15:00	3:09	1:02	0:45	0.264	0.36	1:25	72	9:24
	Down	3	15:00	3:07	1:01	0:45	0.208	0.262	0:49	73	9:18
NS11-NS10	Up	1	15:00	1:46	0:34	0:15	0.118	0.134	0:14	139	5:15
	Down	1	15:00	1:42	0:33	0:15	0.113	0.128	0:13	144	5:03
NS10-NS9	Up	3	15:00	2:53	0:57	0:45	0.192	0.238	0:41	78	8:37
	Down	3	15:00	2:06	0:41	0:45	0.14	0.163	0:20	101	6:15
NS9-NS8	Up	2	15:00	1:14	0:24	0:30	0.082	0.09	0:06	168	3:40
	down	2	15:00	1:23	0:27	0:30	0.092	0.102	0:08	154	4:07
NS8-NS7	Up	2	15:00	2:53	0:57	0:30	0.192	0.238	0:41	83	8:37
	Down	2	15:00	2:24	0:47	0:30	0.16	0.19	0:27	97	7:09
NS7-NS6	Up	1	15:00	3:04	1:00	0:15	0.204	0.257	0:47	83	9:09
	Down	1	15:00	3:12	1:03	0:15	0.213	0.271	0:52	80	9:33

**Table 4.06: Theoretical capacity of N-S corridor at off peak hours (T=10hr) (2018-2022)**

year

Section from-to (1)	Track direction (2)	No. inter-mediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column 5] (mm:ss) (9)	Equivalent Buffer time ( $t_{zu}$ ) = [0.25*'a'] (mm:ss) (10)	Actual values			$\Psi=0.6$ , Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
NS27-NS26	Up	2	20:00	3:07	2:05	0:30	0.156	0.185	0:34	105	11:42
	Down	2	20:00	2:42	1:48	0:30	0.135	0.156	0:25	120	10:07

DETERMINING THE UTILIZATION OF CAPACITY FOR AA LRT

Section from-to (1)	Track direction (2)	No. inter-mediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (9)	Equivalent Buffer time( $t_{zu}$ ) =[0.25* 'a'] (mm:ss) (10)	Actual values			$\Psi=0.6,$ Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
NS26-NS25	Up	1	20:00	1:47	1:11	0:15	0.089	0.098	0:10	186	6:40
	Down	1	20:00	1:19	0:52	0:15	0.066	0.07	0:05	247	4:54
NS25-NS24	Up	1	20:00	1:28	0:58	0:15	0.073	0.079	0:06	223	5:28
	Down	1	20:00	1:25	0:56	0:15	0.071	0.076	0:06	231	5:17
NS24-NS23	Up	1	20:00	2:50	1:53	0:15	0.142	0.165	0:28	121	10:36
	Down	1	20:00	2:13	1:29	0:15	0.111	0.125	0:16	152	8:19
NS23-NS22	Up	1	20:00	1:42	1:08	0:15	0.085	0.093	0:09	195	6:22
	Down	1	20:00	1:37	1:04	0:15	0.081	0.088	0:08	205	6:02
NS22-NS21	Up	1	20:00	2:28	1:39	0:15	0.123	0.141	0:20	138	9:15
	Down	1	20:00	2:16	1:31	0:15	0.113	0.128	0:17	149	8:30
NS21-EW20	Up	3	20:00	2:37	1:45	0:45	0.131	0.151	0:23	117	9:49
	Down	2	20:00	2:36	1:44	0:30	0.13	0.149	0:23	124	9:45
EW20-EW19	Up	1	9:17	1:24	0:56	0:15	0.151	0.178	0:14	232	5:15
	Down	1	12:46	1:23	0:55	0:15	0.108	0.122	0:10	235	5:10
EW19-EW18	Up	1	9:17	1:41	1:07	0:15	0.181	0.221	0:22	197	6:18
	Down	1	12:46	1:43	1:09	0:15	0.134	0.155	0:16	193	6:27
EW18-EW17	Up	1	9:17	1:29	0:59	0:15	0.16	0.19	0:16	221	5:33
	Down	1	12:46	1:38	1:05	0:15	0.128	0.147	0:14	202	6:06
EW17-EW16	Up	1	9:17	1:06	0:44	0:15	0.114	0.129	0:08	288	4:07
	Down	1	12:46	1:14	0:49	0:15	0.097	0.107	0:07	261	4:36
EW16-NS15	Up	3	20:00	3:16	2:11	0:45	0.163	0.195	0:38	97	12:15
	Down	2	20:00	2:52	1:55	0:30	0.143	0.167	0:28	134	10:45
NS15-NS14	Up	1	20:00	1:08	0:45	0:15	0.057	0.06	0:04	281	4:14
	Down	1	20:00	1:14	0:49	0:15	0.062	0.066	0:04	261	4:36
NS14-NS13	Up	1	20:00	1:23	0:55	0:15	0.069	0.074	0:06	235	5:10
	Down	1	20:00	1:25	0:56	0:15	0.071	0.076	0:06	231	5:17
NS13-NS12	Up	2	20:00	1:25	0:56	0:30	0.071	0.076	0:06	211	5:17
	Down	2	20:00	1:31	1:01	0:30	0.076	0.082	0:07	198	5:42

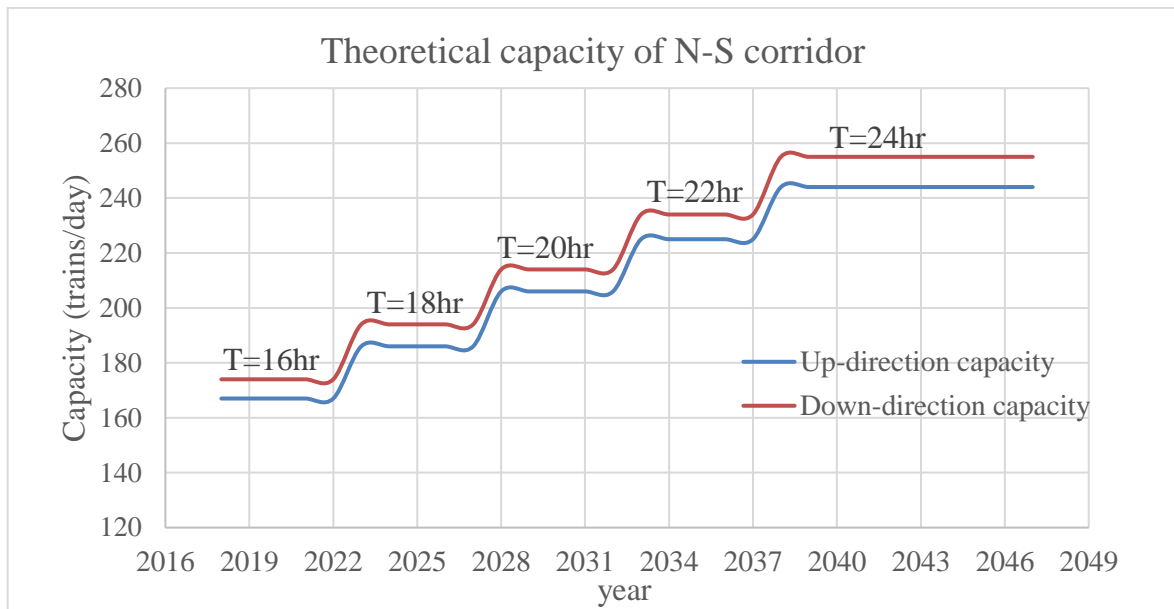
Section from-to (1)	Track direction (2)	No. inter-mediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (9)	Equivalent Buffer time( $t_{zu}$ ) =[0.25* 'a'] (mm:ss) (10)	Actual values			$\Psi=0.6,$ Lq=1.5	
							$\Psi$	Lq	w (mm:ss)	P	w (mm:ss)
NS12-NS11	Up	3	20:00	3:09	2:06	0:45	0.158	0.187	0:35	100	11:48
NS11-NS10	Down	3	20:00	3:07	2:05	0:45	0.156	0.185	0:34	101	11:42
NS11-NS10	Up	1	20:00	1:46	1:11	0:15	0.088	0.097	0:10	188	6:38
NS10-NS9	Down	1	20:00	1:42	1:08	0:15	0.085	0.093	0:09	195	6:22
NS10-NS9	Up	3	20:00	2:53	1:55	0:45	0.144	0.168	0:29	108	10:48
NS9-NS8	Down	3	20:00	2:06	1:24	0:45	0.105	0.117	0:14	141	7:52
NS9-NS8	Up	2	20:00	1:14	0:49	0:30	0.062	0.066	0:04	235	4:36
NS8-NS7	down	2	20:00	1:23	0:55	0:30	0.069	0.074	0:06	214	5:10
NS8-NS7	Up	2	20:00	2:53	1:55	0:30	0.144	0.168	0:29	113	10:48
NS7-NS6	Down	2	20:00	2:24	1:36	0:30	0.12	0.136	0:19	134	9:00
NS7-NS6	Up	1	20:00	3:04	2:03	0:15	0.153	0.181	0:33	112	11:30
NS6-NS5	Down	1	20:00	3:12	2:08	0:15	0.16	0.19	0:36	108	12:00

#### 4.1.2.1. Interpretation of Results of North-South Corridor

The bottlenecks in the North-South corridor is in between the block sections Meshoulekyia (NS15) to Stadium (NS16) in the up-direction and Nefas silk (NS11) to Lancha (NS12) in the down-direction with its result summary at the table 4.07.

**Table 4.07: The theoretical capacity of bottlenecks on N-S corridor**

Bottleneck sections	Travel direction	Current capacity	Year interval	Capacity on peak hours	Capacity on off-peak hours	Total capacity per day
NS15-NS16	up-direction	60	2018-2022	70	97	167
			2023-2027	70	116	186
			2028-2032	70	136	206
			2032-2037	70	155	225
			2038-2047	70	174	244
NS11-NS12	down-direction	60	2018-2022	73	101	174
			2023-2027	73	121	194
			2028-2032	73	141	214
			2032-2037	73	161	234
			2038-2047	73	182	255



**Figure 4.02: Total theoretical capacity of N-S corridor**

Figure 4.02 is the graphical representation of the N-S railway line and it have slight variation in capacity for the up and down direction capacity of the bottleneck block sections and this is due to the variation of the speed limit and numbers and locations of signal lighting at each blocking sections.

In the same way, as in table 4.03 of the section 4.1.1.1, the comparison also applied to the N-S south route and the Comparison have quite different results of the UIC-code 405 on saturated and the current traffic. The actual delay time increases by 81.3% from 1:39 min/train/6hr (actual) to 9:45 min/trains/6hr (on saturation) on the bottleneck EW16-NS15 section of up-direction. Moreover, the track utilization rate ( $\Psi$ ) at this section increases by 62.4% on the peak hour and 72.8% of the off-peak hours (see table 4.18). The comparison for the shared corridor is the same as in the comparison made on E-W.

**Table 4.08: Brief comparison of the UIC-code 405 main results with the actual traffic on the N-S corridor**

Nature of traffic	Item No.	Comparison indices	EW16-NS15	NS11-NS12
			Up-direction	Down-direction
Actual (Current) traffic	A	Delay at peak hour	1:39	0:49
	B	Delay at off-peak hour	0:38	0:34
	C	Actual utilization ( $\Psi$ ) at peak hour	28.20%	20.80%

	D	Actual utilization ( $\Psi$ ) at off-peak hour	16.30%	15.60%
During saturation of traffic	E	Delay at peak hour	9:45	9:18
	F	Delay at off-peak hour	12:15	11:42
	G	Optimum utilization ( $\Psi$ ) at peak hour	75%	75%
	H	Optimum utilization ( $\Psi$ ) at off-peak hour	60%	60%
Relative deviation		(E-A)/E	83.10%	91.20%
		(F-B)/F	94.80%	95.20%
		(G-C)/G	62.40%	72.30%
		(H-D)/H	72.80%	74%

#### 4.1.3. Theoretical Supply Capacity on Shared Corridor

The capacity of the shared corridor is the sum of the capacity on the East-West and North-South corridors and this capacity will be less than of the computed bottleneck capacity of shared corridor Mexico (EW18) to Tegbared (EW19).

The theoretical capacity of the E-W corridor on the up-direction at peak hour is 86 trains/6hr (see table 4.01) and the theoretical capacity of the N-S corridor of up-direction at peak hour is 70 trains/6hr (see table 4.05).

Shared corridor up-direction capacity at peak hour = EW corridor capacity of up-direction at peak hour + NS corridor capacity of up-direction at peak hour =  $86+70=156$  trains/6hr, But the maximum theoretical capacity of up-direction at peak hour on the shared corridor is 145 trains/6hr which is less than of the summed values. Therefore, the bottleneck section of the shared corridor is the overall governing bottleneck block section to estimate the capacity for both routes. A fifty-fifty sharing of this capacity on a shared corridor the capacity of the two routes will be 72.5 trains/6hr at peak hour.

The capacity 72.5 train/6hr is greater than the maximum capacity of the N-S corridor, which is 70 trains/6hr so that 70 trains/6hr is taken as the capacity of the N-S route, and 75 trains/6hr on EW route to give a total of 145 trains/6hr on the shared route. In the same way, table 4.09 shows the capacity of each route at both the peak and off-peak hours and on the two directions of travels.

**Table 4.09: Distribution of the theoretical capacity of a shared corridor to E-W and N-S routes**

Bottleneck sections	Travel direction	Year interval	Capacity at peak hours of the shared corridor	Maximum capacity of EW corridor at peak hour	Maximum capacity of NS corridor at peak hour	Capacity at off-peak hours of the shared corridor	The theoretical capacity of EW corridor at an off-peak hour	The theoretical capacity of NS corridor at an off-peak hour
EW18- EW19	Up-direction	2018-2022	145	75	70	197	100	97
		2023-2027	145	75	70	236	120	116
		2028-2032	145	75	70	276	140	136
		2032-2037	145	75	70	315	159	156
		2038-2047	145	75	70	354	180	174
EW18- EW19	Down-direction	2018-2022	143	72	71	193	97	96
		2023-2027	143	72	71	231	116	115
		2028-2032	143	72	71	270	135	135
		2032-2037	143	72	71	308	154	154
		2038-2047	143	72	71	347	174	173

As we can see from the above table 4.09, the capacity of E-W and N-S corridors determined within the consideration of the networking effect, and this is decreased from the separate computation results on the railway line (see table 4.03 and 4.07). The capacities per day at the shared corridor in above will help to estimate the capacity per hour by dividing the capacity per day at peak hour with peak hour time and the capacity per hour at off-peak by off-peak hour time (see table 4.10). Table 4.10 in below shows, the maximum possible theoretical capacity at peak and off-peak hour times are 24 trains and 20 trains respectively.

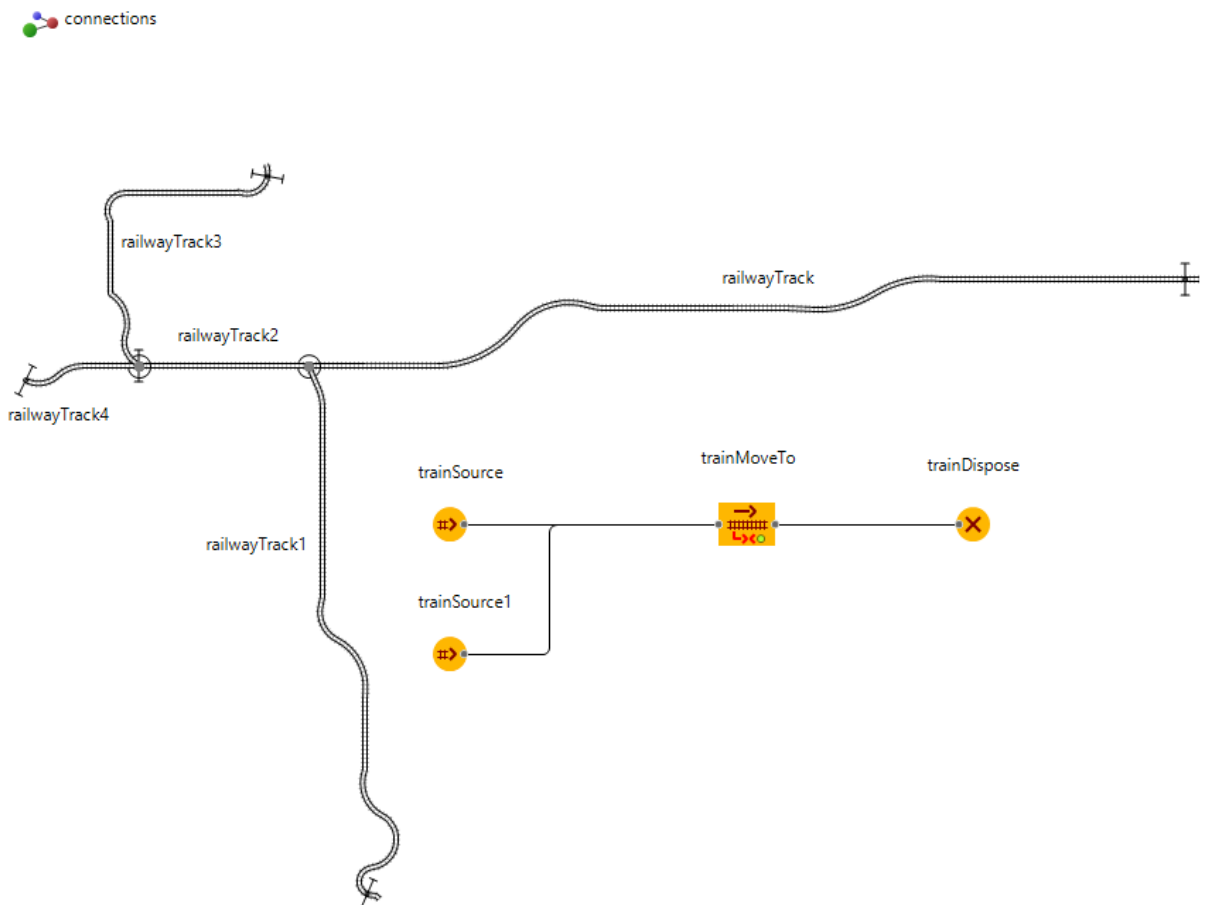
**Table 4.10: capacity per hour at peak and off-peak hours of the shared corridor**

Bottleneck sections	Travel direction	Year interval	Capacity at peak hours of the shared corridor	peak hour times	Capacity at peak hour per hour	Capacity at off-peak hours of the shared corridor	Off-peak hours times	Capacity at an off-peak hour per hour
EW18- EW19	Up-direction	2018-2022	145	6	24	197	10	20
		2023-2027	145	6	24	236	12	20
		2028-2032	145	6	24	276	14	20

		2032-2037	145	6	24	315	16	20
		2038-2047	145	6	24	354	18	20
EW18- EW19	Down- direction	2018-2022	143	6	24	193	10	20
		2023-2027	143	6	24	231	12	20
		2028-2032	143	6	24	270	14	20
		2032-2037	143	6	24	308	16	20
		2038-2047	143	6	24	347	18	20

## 4.2. Validation of UIC-Cod 405R Theoretical capacity Result Using AnyLogic Simulation Software

AnyLogic simulation software results



**Figure 4.03: modeled railway track and schedule of AnyLogic software**

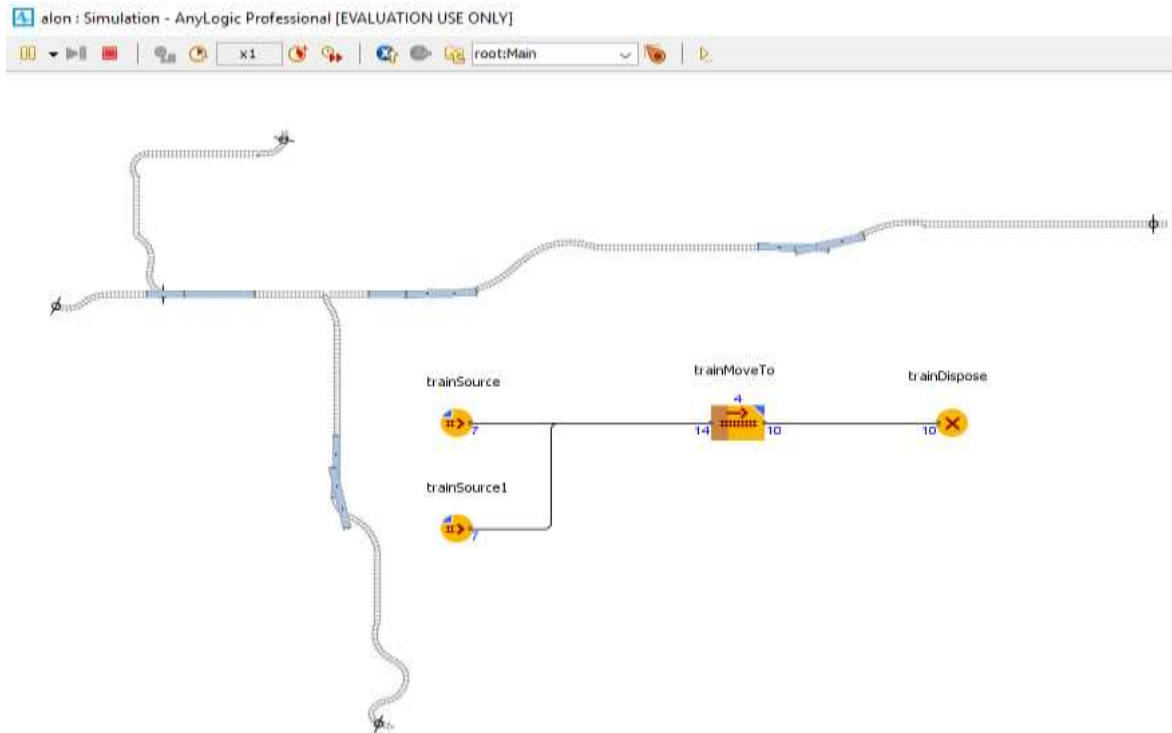


Figure 4.04: train flow on the simulation desk of AnyLogic software

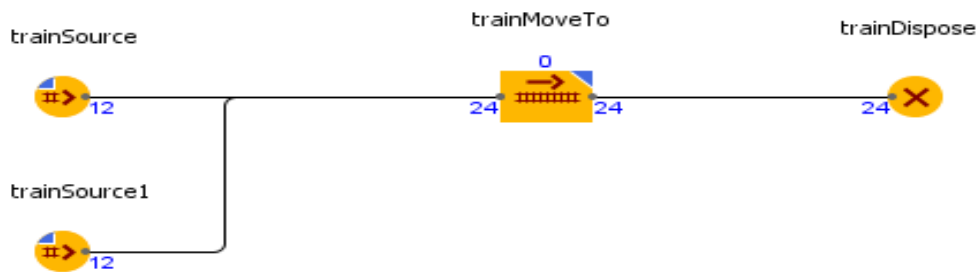


Figure 4.05: schedule diagram when the train flow is completed

As we can see, on the above fig. 4.05 represents the number of trains that can flow through the route. On the left side of the figure, the number of trains counted is 12 trains and this represents the capacity of the incoming routes to the shared corridors, but on the shared corridor, the capacity is counted as 24 train/hr. Therefore, the capacity estimated using the UIC-cod 405R is validated using this simulation software, but these capacity estimation methods do not consider the secondary delay of the train flow and the section 4.3 in below will account such delay to estimate the practical capacity of the railway line.

### 4.3. Practical Supply Capacity Estimation for AA LRT

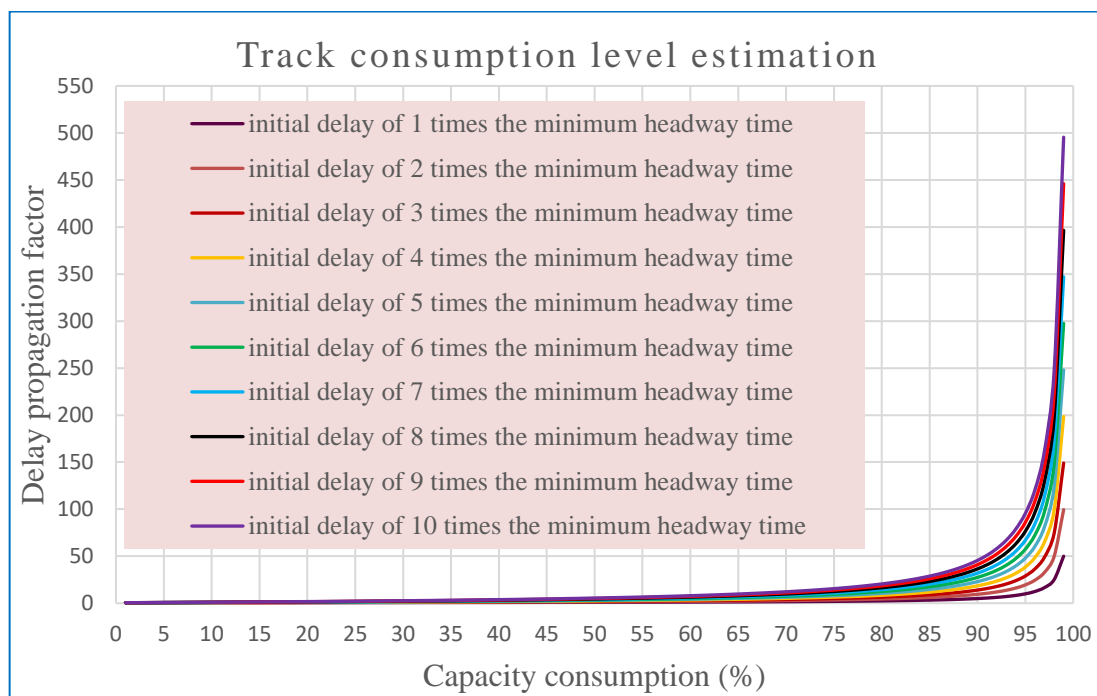
The theoretical supply capacity computed on section 4.1 is simply an ideal capacity, which cannot be consumed as it is, this is because of the unscheduled delays (the secondary delay) that affect the flow of trains is not considered in the analysis but it only accounts the scheduled delay (the initial delay) of trains. Therefore, to account the secondary delay, the

delay propagation factor must compute to estimate the optimum track consumption level and then the practical capacity as a multiple of the optimum track consumption level.

To predict the optimum maximum consumption level of the railway the equation 3.12 of section 3.3.2 is used.

$$y = \frac{n}{\left(\frac{1}{k} - 1\right)} + 1 - \frac{\left(\frac{1}{k} - 1\right)}{n} \left| \frac{1}{\left(\frac{1}{k} - 1\right)} \right| \left( \frac{n}{\left(\frac{1}{k} - 1\right)} + 1 \right)$$

In this the value of ‘n’ (initial delay) is an assumed value which is as multiple of the headway time see legends of fig. 4.06 and the capacity consumption level ‘k’ will also be varied from 0-100% consumption level, with this values the delay propagation factor and track consumption level relationship is developed as in below fig.4.06.



**Figure 4.06: delay propagation factor and track consumption relationship**

Figure 4.06 shows the delay propagation factor of the railway line Varies largely after the consumption level of 80%-85% but the delay below the consumption level of 80% is almost same in its value. When the delay is smaller, there is high level of service and the track line is consumed efficiently, but if the track consumption level is above 80% there is large delay time and this will also disturbs to the track line level of service.

Taking the 80% as a critical condition where it means only 80% of the theoretical capacity is consumed or implemented on the railway line such that, optimum capacity and minimum delay will be recorded.

**4.3.1. Practical Supply Capacity Estimation at Shared Corridor**

Practical supply capacity = theoretical supply capacity \* 0.8 (80% track consumption level), where the theoretical capacity is taken from section 4.1.3 table 4.10 for the shared corridors. Therefore, with this analysis, the practical capacities are 20 trains/hr at peak hour and 16 trains/hr at off-peak hours (see table 4.11).

**Table 4.11: Practical Capacity Estimation of shard Corridor**

Bottleneck sections	Travel direction	Year interval	Theoretical capacity on peak hours	Practical Capacity at peak hours =(24*0.8)	Theoretical capacity at off-peak hours	Practical capacity at off-peak hours =(20*0.8)
EW18- EW19	Up-direction	2018-2022	24	20	20	16
		2023-2027	24	20	20	16
		2028-2032	24	20	20	16
		2032-2037	24	20	20	16
		2038-2047	24	20	20	16
	Down-direction	2018-2022	24	20	20	16
		2023-2027	24	20	20	16
		2028-2032	24	20	20	16
		2032-2037	24	20	20	16
		2038-2047	24	20	20	16

**4.3.2. Practical Supply Headway Time Estimation at Shared Corridor**

This practical headway time is the minimum possible headway time provided for safe operation of trains during optimum capacity consumption. For instance, the practical headway time for the reference time 16hr (6hr at peak and 10hr at off-peak) can be computed as in below;

Up-direction headway time calculation

$$\text{Practical Headway time at peak hour} = \frac{60\text{min}}{20 \text{ trains/hr}} = \underline{3:00 \text{ minutes}}$$

$$\text{Practical Headway time at off-peak hour} = \frac{60\text{min}}{16 \text{ trains/hr}} = \underline{3:45 \text{ minutes}}$$

Table 4.12 shows the estimation of headway time for the E-W and N-S routes from the shared corridor like in the capacity estimation but unlike in the capacity estimation.

**Table 4.12: headway time at E-W and N-S routes**

Headway time in minutes	At shared corridor	At E-W corridor	At N-S corridor
At peak hour	3:00	6:00	6:00
At off-peak hour	3:45	7:30	7:30

#### 4.4. Demand Capacity Estimation for AA LRT

A future passenger demand is estimated using the econometric forecast method with the selected forecasting independent variables (i.e. Population and unemployment rate).

The relation among the independent and dependent variable is made by the multiple regression method with the formula of;

$$\text{Passenger demand} = \beta_0 + \beta_1(\text{Population}) + \beta_2(\text{Unemployment rate})$$

$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2$ , To determine the passenger demand for the next 30 years of the AALRT, the forecasting of the population and unemployment rate of Addis Ababa for the forecasting periods is must with the help of SPSS software.

##### 4.4.1. Population Forecasting Model

In section 3 the population data for the last 4 years are taken from the central statistics agency and these can be represented by exponential relations in order to forecast the population of Addis Ababa for the next 30 years using relation developed.

##### Results of SPSS software

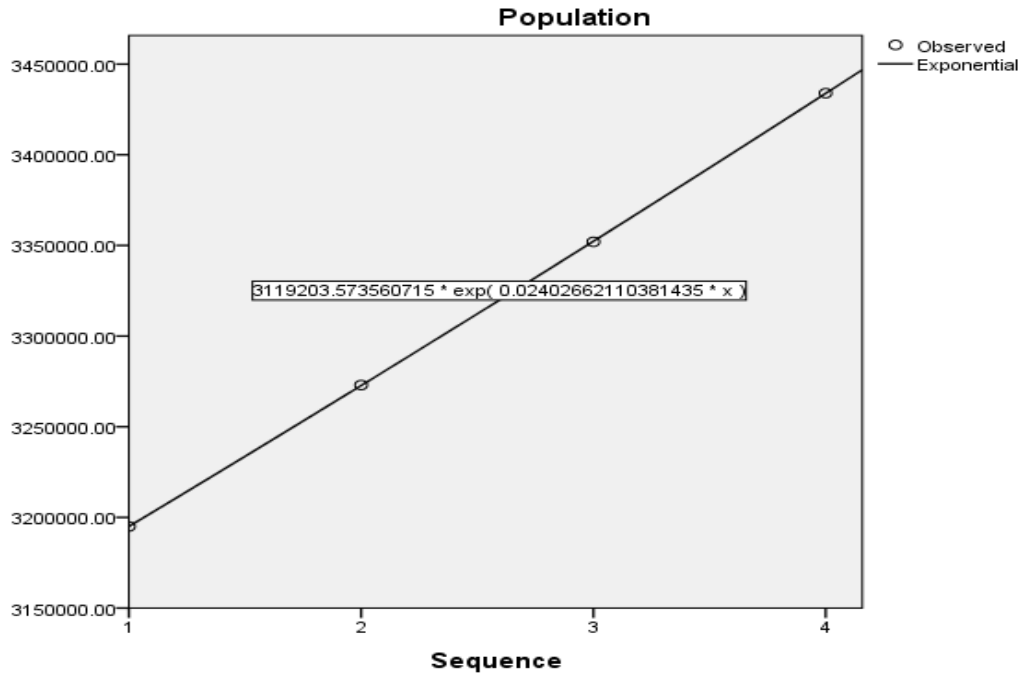
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/PLOT FIT.
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##### **Curve Fit**

##### **Model Summary and Parameter Estimates**

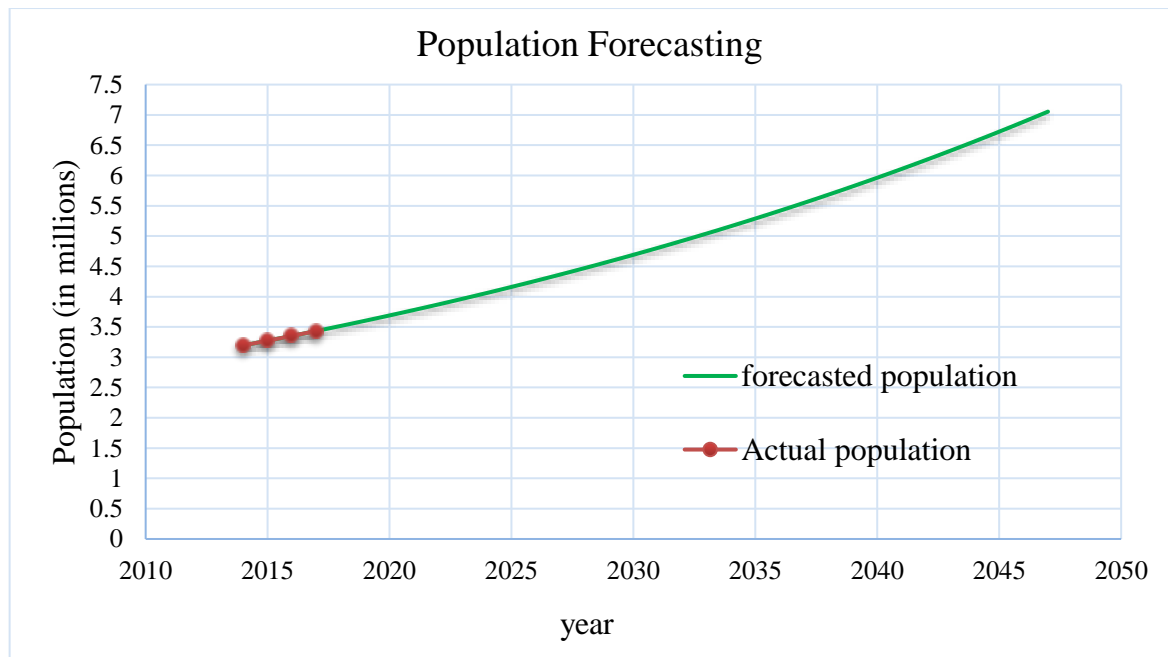
Dependent Variable: Population

Equation	R Square	Model Summary				Parameter Estimates	
		F	df1	df2	Sig.	Constant	b1
Exponential	1.000	322752.413	1	2	.000	3119203.574	.024



**Figure 4.07: Actual population of Addis Ababa in relation with sequence time (year) (2014-2017G.C)**

Having the above formula  $y = 3119203e^{0.024x}$ , where x is the sequence of years, for the next 30 years population number can be estimated. This figure (fig.4.07) also shows the relation determined by the exponential equation is 100% fitted and this will help us to predict the passenger demand in future.



**Figure 4.08: Actual and forecasted population results of Addis Ababa**

Figure 4.08 is the graphical representation of the forecasted population with their results as in the appendix E for the next 30 year and this forecasted population has an effect on passenger demand estimation.

#### 4.4.2. Unemployment Rate Forecasting Model

Unemployment rate affects the travel demand in the case of the work based travel of passengers and therefore the estimation of the unemployment rate is considered in this thesis work. As it is discussed in section 3, the values of actual unemployment rates can have an influence in transportation demand and the relations can be estimated using the SPSS software.

**Table 4.13: Actual unemployment rate of Addis Ababa**

The sequence of years	Year	Unemployment rate (%)
1	2010	26.9
2	2011	25.1
3	2012	23
4	2013	24.2
5	2014	23.5
6	2015	21.2
7	2016	21

#### Results of SPSS software

```
* Curve Estimation.
TSET NEWVAR=NONE.
CURVEFIT
/VARIABLES=Unemployment
/CONSTANT
/MODEL=POWER
/PLOT FIT.
```

#### **Curve Fit**

##### Model Description

Model Name		MOD_1
Dependent Variable	1	Unemployment
Equation	1	Power <sup>a</sup>
Independent Variable		Case sequence
Constant		Included

Variable Whose Values Label Observations in Plots	Unspecified
---	-------------

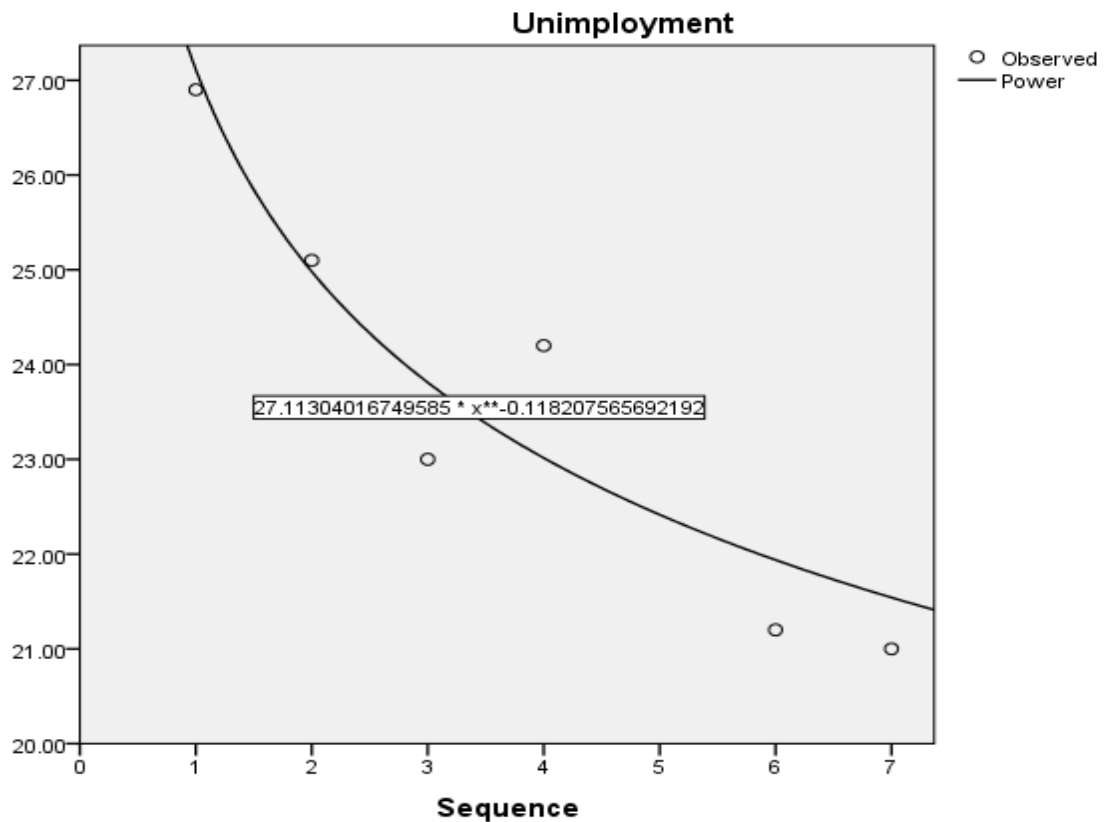
a. The model requires all non-missing values to be positive.

**Model Summary and Parameter Estimates**

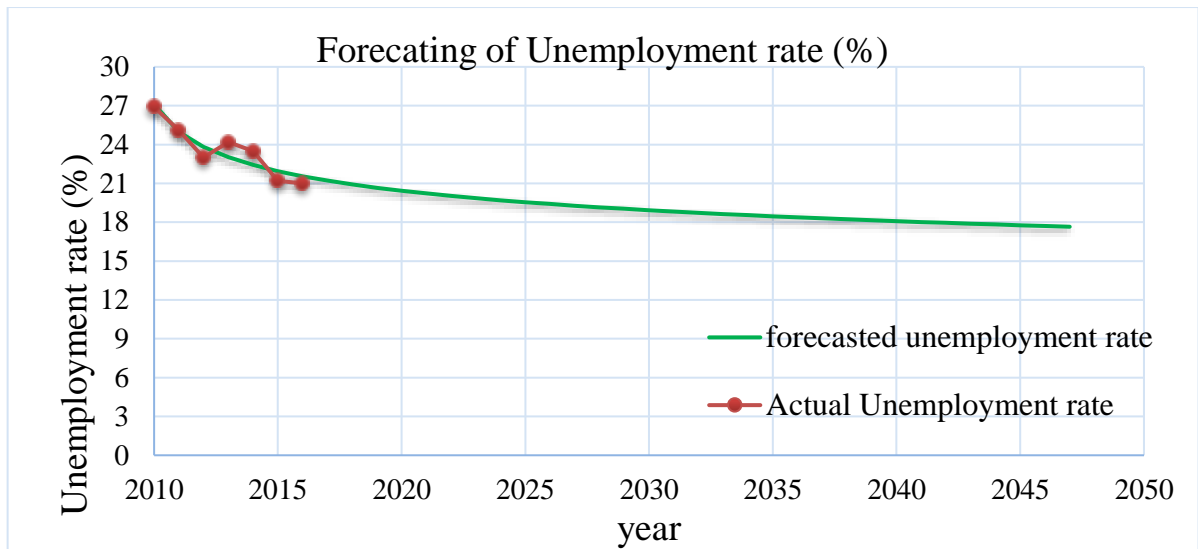
Dependent Variable: Unemployment

Equation	R Square	Model Summary				Parameter Estimates	
		F	df1	df2	Sig.	Constant	b1
Power	.833	25.020	1	5	.004	27.113	-.118

Using the equation determined from the relation in fig. 4.09,  $y = 27.113X^{-0.118}$ , the dependent and independent variables are 83.35% fitted and with this power relation, the unemployment rate is forecasted to predict the future unemployment rate (see appendix E and fig. 4.10).



**Figure 4.09: Actual unemployment rate relations with the sequence of time (year) (2010-2016G.C)**



**Figure 4.10: Forecasted unemployment rate results of Addis Ababa**

#### 4.4.3. Railway Passenger Demand Forecasting

This railway passenger forecasting uses the forecasted population and unemployment rate as inputs and estimates the unknown variables of the multiple regression with the help of least square method.

Having the data in table 3.07 the modal share for railway passenger demand is just the ratio of the actual railway passenger demand to the total passenger demand at a given year.

In the same way, the future railway modal share can be estimated and do so the actual total passenger demand and total passenger demand must forecast using the multiple regression methods with the help of list square methods.

Using equation 3.10 for multiple regression and equation 3.11 method of least square the values of unknown parameters will be determined.

Year	Actual passenger demand	Population in millions	Unemployment rate
2015	38462	3.273	21.946
2016	42437	3.352	21.550
2017	46590	3.434	21.214

$$X = \begin{bmatrix} 1 & 3.273 & 21.946 \\ 1 & 3.352 & 21.550 \\ 1 & 3.434 & 21.214 \end{bmatrix}, \text{ and } Y = \begin{bmatrix} 38462 \\ 42437 \\ 46590 \end{bmatrix}$$

$$X' = \begin{bmatrix} 1.0000 & 1.0000 & 1.0000 \\ 3.2730 & 3.3520 & 3.4340 \\ 21.946 & 21.550 & 21.214 \end{bmatrix},$$

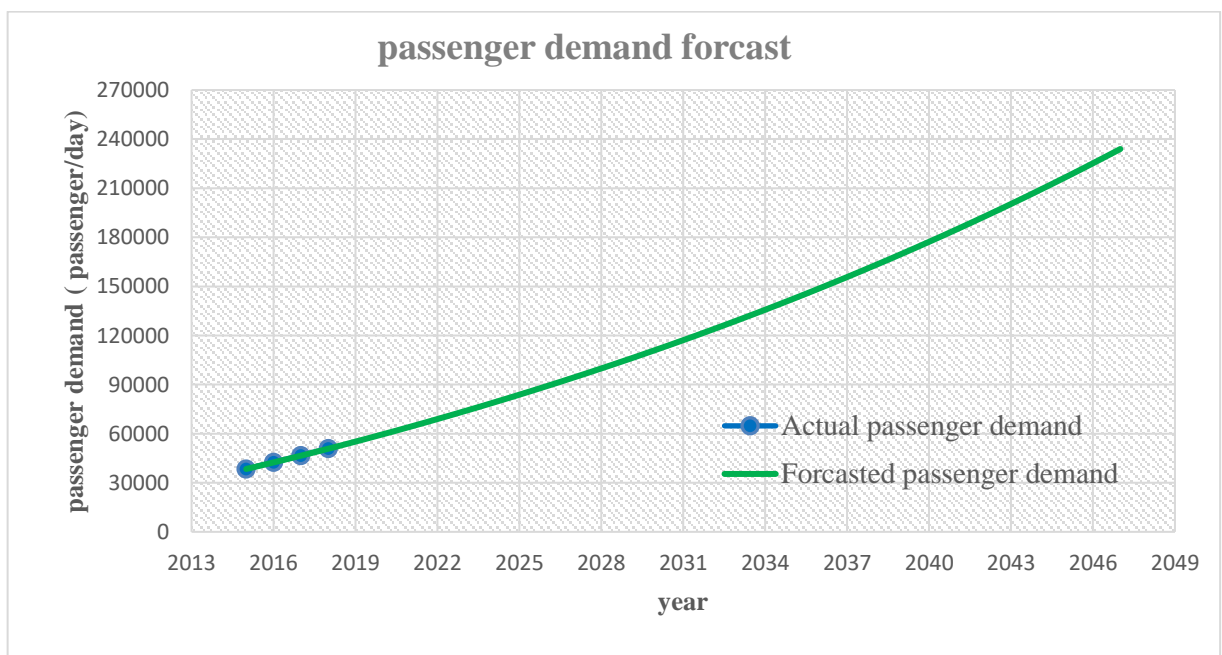
$$(X'X)^{-1} = 1 * 10^6 * \begin{bmatrix} 1.4998 & -0.1853 & -0.0407 \\ -0.1853 & 0.02290 & 0.00500 \\ -0.0407 & 0.00500 & 0.00110 \end{bmatrix},$$

$$X'Y = 1 * 10^6 * \begin{bmatrix} 0.1275 \\ 0.4281 \\ 2.7470 \end{bmatrix},$$

$$\begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} = (X'X)^{-1}X'Y = 1 * 10^5 * \begin{bmatrix} -1.4005 \\ 0.5212 \\ 0.0036 \end{bmatrix} \text{ these are the values of unknown variables or}$$

separately there value is  $\beta_0 = -140050$ ,  $\beta_1 = 52120$ , and  $\beta_2 = 360$

$y_{1,2015} = \beta_0 + \beta_1 X_{1,2015} + \beta_2 X_{2,2015} = -140050 + (52120 * 3.434) - (360 * 21.214) = 46540$   
 total passenger demand at shared corridor and this estimated value is similar to the actual value of 46590-passenger demand at 2017 a year. In some way, having the variables determined here and the forecasted values of independent variables (population and unemployment rate) in above the passenger demand can be forecasted for the next 30 year with its results of represented in fig. 4.11 below.



**Figure 4.11: forecasted passenger Demand at the Shared Corridor of the unidirectional travel**

#### 4.4.4. Demand Capacity and Headway Time Estimation from the Shared Corridor

The demand capacity and headway time is estimated from the forecasted passenger demand for the shared corridor of the unidirectional travel in consideration of the peak and off-peak hour ratios. These passenger demands can be hauled by single or two unit train, where the single unit train is used until the track is saturated and then the two unit trains are replaced later. In the estimation of those the peak hour times per day is 6hr, and off-peak hour times per day varies with every five years with the variation of reference time (see table 3.11).

- Demand capacity and headway time at peak hours of shard corridor:

$$\begin{aligned} \text{Demand capacity at 2015G.C} &= \frac{\text{total passenger demand}}{\text{internal train capacity}} \\ &= \frac{38462 \text{ passengers/day}}{286 \text{ passengers/train}} = 134.325 \text{ trains/day} \end{aligned}$$

From this capacity, around 45% are traveled on the peak hours as stated in section 3.7 and 55% of them are traveled at off-peak hours.

- Demand capacity at peak hours is computed as;

$$134.325 \text{ trains/day} * 0.45 = 60.4463 \text{ trains/6hr}$$

$$\text{Demand capacity per hour at peak hour} = \frac{60.4463 \text{ trains/6hrs}}{6\text{hrs}} = 10.0744 \text{ trains/hour}$$

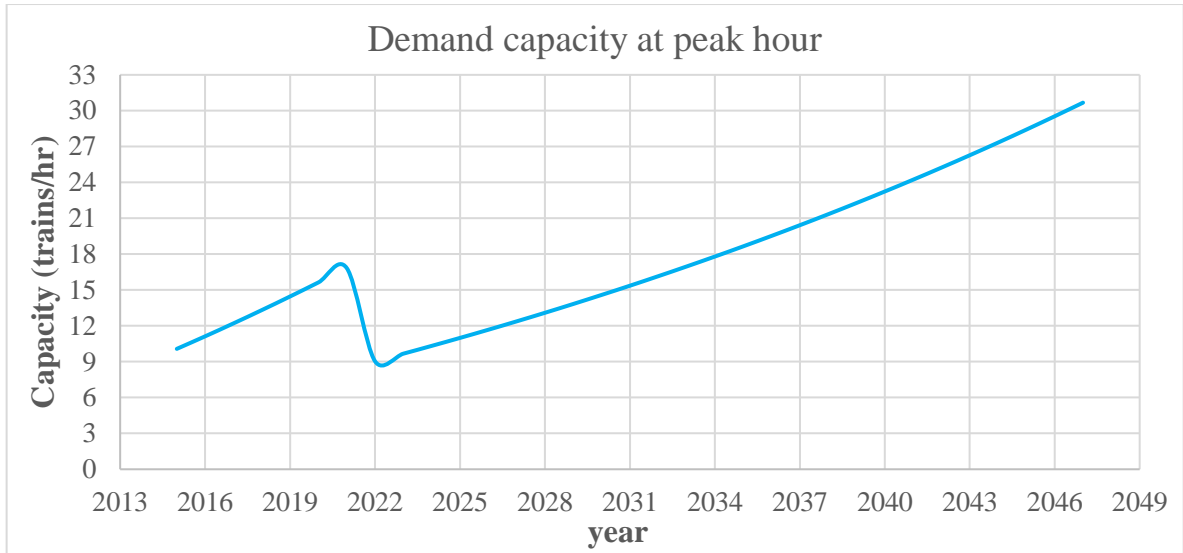
- Demand headway time is also computes as;

$$\text{Demand headway time} = \frac{60 \text{ minutes}}{10.0744 \text{ trains/hr}} = 5.956 = 5:57 \text{ minutes and for the rest}$$

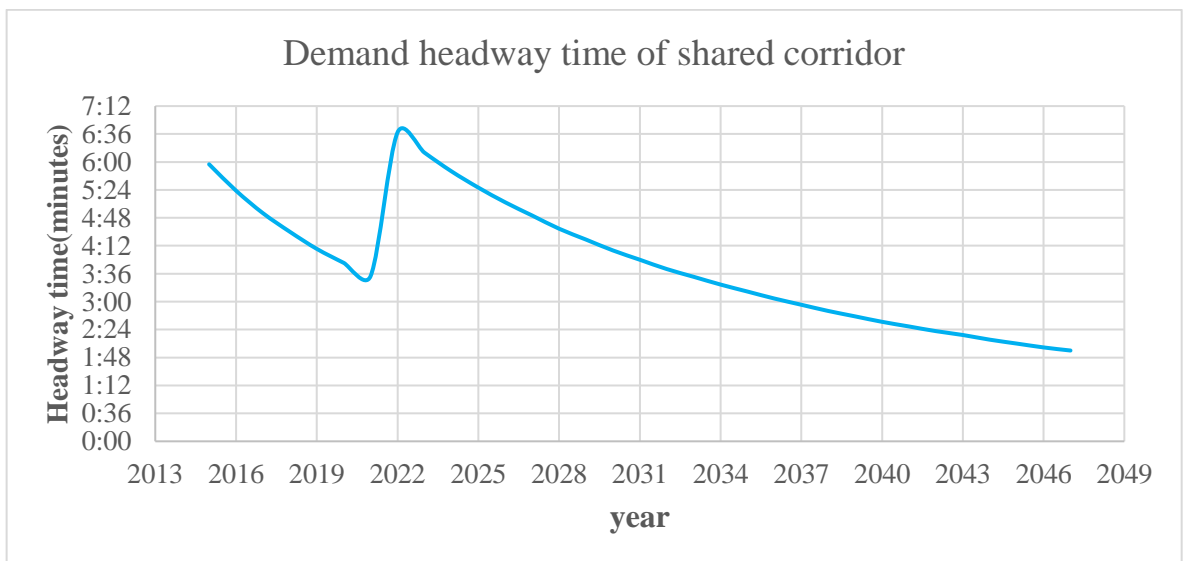
forecasting periods the result are as in the table 4.14.

**Table 4.14: Demand capacity and headway time at the peak hour of the shared corridor of the unidirectional travel**

Year	Passenger demand	Total capacity per day	Capacity at peak hour per day	Peak hour time	Number of train per hour	Headway time
2015	38417	134.325	60.4463	6	10.0744	5:57
2016	42417	148.311	66.74	6	11.1233	5:23
2017	46540	162.727	73.2273	6	12.2045	4:54
2018	50781	177.556	79.9002	6	13.3167	4:30
2019	55141	192.801	86.7603	6	14.4601	4:08
2020	59618	208.455	93.8045	6	15.6341	3:50
2021	64214	224.524	101.036	6	16.8393	3:33
2022	68931	120.509	54.2289	6	9.03816	6:38
2023	73769	128.967	58.0351	6	9.67251	6:12
2024	78731	137.642	61.9387	6	10.3231	5:48
2025	83819	146.537	65.9415	6	10.9903	5:27
2026	89036	155.657	70.0458	6	11.6743	5:08
2027	94384	165.007	74.2531	6	12.3755	4:51
2028	99866	174.591	78.5659	6	13.0943	4:24
2029	105484	184.413	82.9857	6	13.8309	4:20
2030	111243	194.481	87.5163	6	14.5861	4:06
2031	117144	204.797	92.1587	6	15.3598	3:54
2032	123191	215.369	96.916	6	16.1527	3:42
2033	129388	226.203	101.791	6	16.9652	3:32
2034	135737	237.302	106.786	6	17.7977	3:22
2035	142243	248.677	111.904	6	18.6507	3:13
2036	148909	260.33	117.149	6	19.5248	3:04
2037	155739	272.271	122.522	6	20.4203	2:56
2038	162737	284.505	128.027	6	21.3379	2:48
2039	169906	297.038	133.667	6	22.2779	2:41
2040	177251	309.879	139.446	6	23.241	2:34
2041	184776	323.035	145.366	6	24.2276	2:28
2042	192485	336.512	151.431	6	25.2384	2:22
2043	200383	350.32	157.644	6	26.274	2:17
2044	208474	364.465	164.009	6	27.3349	2:11
2045	216762	378.955	170.53	6	28.4216	2:06
2046	225253	393.799	177.21	6	29.5349	2:01
2047	233952	409.007	184.053	6	30.6755	1:57



**Figure 4.12: Demand capacity at the peak hour of the shared corridor on the unidirectional travel**



**Figure 4.13: Demand Headway Time at Peak Hour of Shared Corridor on the Unidirectional Travel**

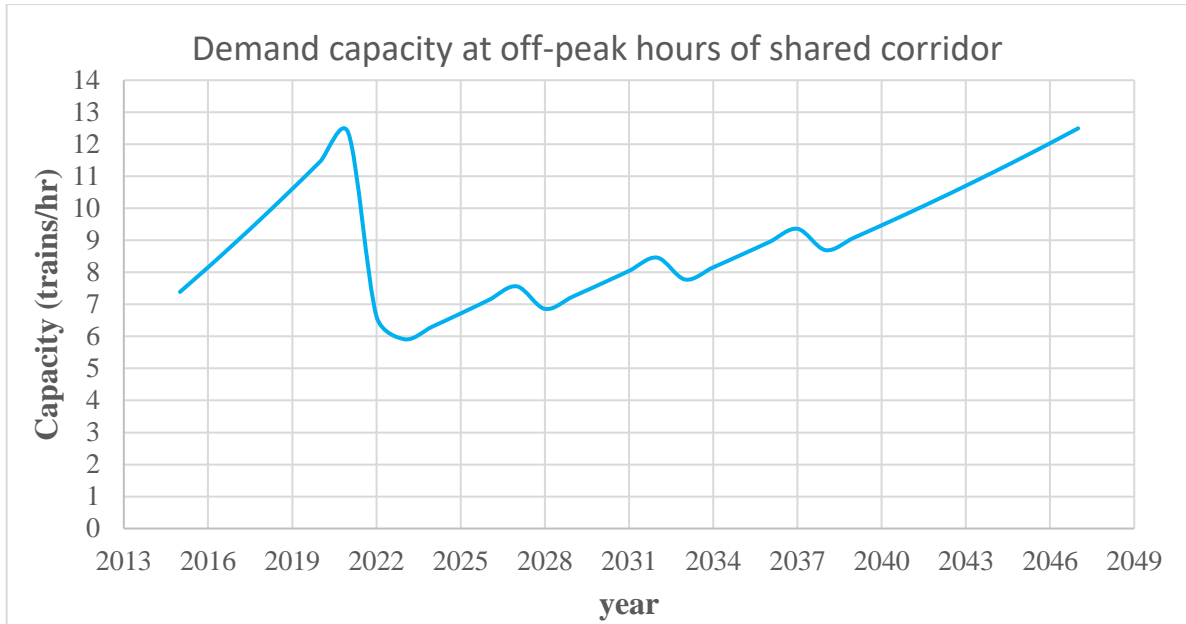
The variation in graph continuity for both the capacity and headway time shown in the above graphical representation of demand capacity and headway time fig. 4.12 and fig. 4.13 is due to the change of one-unit train to two-unit trains at the year of 2022G.C.

**Demand capacity and headway time at off-peak hours of the shared corridor**

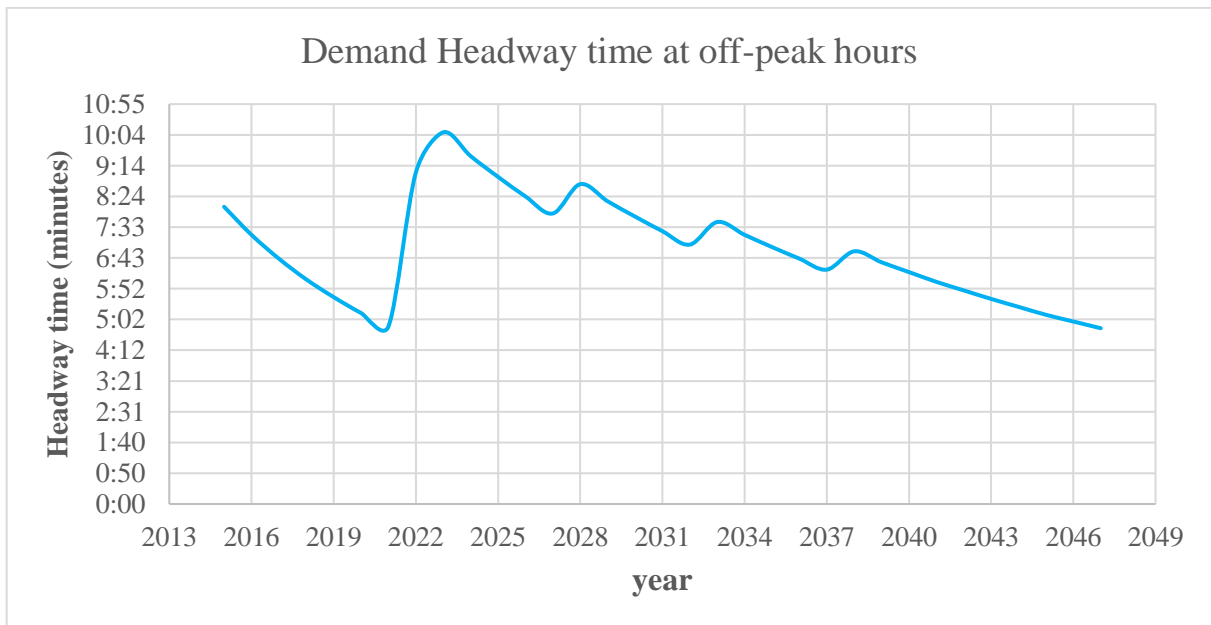
The off-peak hour time demand capacity and headway time is computed in same way in the peak hour demand capacity and headway time computation where in this case 55% of the total passenger demand is traveled at the off-peak hours.

**Table 4.15: Demand capacity and headway time in off-peak hours of the shared corridor**

Year	Passenger demand	Total capacity per day	Capacity at off-peak per day	at hour	Reference time	Peak hour time	Number of train per hour	Headway time
2015	38417	134.325	73.8788		16	10	7.38788	8:07
2016	42417	148.311	81.5712		16	10	8.15712	7:21
2017	46540	162.727	89.5		16	10	8.95	6:42
2018	50781	177.556	97.6558		16	10	9.76558	6:08
2019	55141	192.801	106.04		16	10	10.604	5:39
2020	59618	208.455	114.65		16	10	11.465	5:13
2021	64214	224.524	123.488		16	10	12.3488	4:51
2022	68931	120.509	66.2798		16	10	6.62798	9:03
2023	73769	128.967	70.9317		18	12	5.91098	10:09
2024	78731	137.642	75.7029		18	12	6.30857	9:30
2025	83819	146.537	80.5952		18	12	6.71627	8:56
2026	89036	155.657	85.6115		18	12	7.13429	8:24
2027	94384	165.007	90.7538		18	12	7.56282	7:56
2028	99866	174.591	96.025		20	14	6.85893	8:44
2029	105484	184.413	101.427		20	14	7.24478	8:16
2030	111243	194.481	106.964		20	14	7.64032	7:51
2031	117144	204.797	112.638		20	14	8.0456	7:27
2032	123191	215.369	118.453		20	14	8.46092	7:05
2033	129388	226.203	124.412		22	16	7.77572	7:42
2034	135737	237.302	130.516		22	16	8.15727	7:21
2035	142243	248.677	136.772		22	16	8.54826	7:01
2036	148909	260.33	143.182		22	16	8.94886	6:42
2037	155739	272.271	149.749		22	16	9.35931	6:24
2038	162737	284.505	156.478		24	18	8.69322	6:54
2039	169906	297.038	163.371		24	18	9.07618	6:36
2040	177251	309.879	170.434		24	18	9.46854	6:20
2041	184776	323.035	177.669		24	18	9.87051	6:04
2042	192485	336.512	185.082		24	18	10.2823	5:50
2043	200383	350.32	192.676		24	18	10.7042	5:36
2044	208474	364.465	200.456		24	18	11.1364	5:38
2045	216762	378.955	208.425		24	18	11.5792	5:10
2046	225253	393.799	216.589		24	18	12.0327	4:59
2047	233952	409.007	224.954		24	18	12.4974	4:48



**Figure 4.14: Demand Capacity at Off-Peak Hour of Shared Corridor on the Unidirectional Travel**



**Figure 4.15: Demand headway time at the off-peak hour of the shared corridor on the unidirectional travel**

The results represented in the fig. 4.14 and 4.15 shows a line continuity variation that is due to the change of reference time by 2hrs of each 5 years and train unite change is also observed in the year of 2022G.C.

#### 4.5. Relating Demand and Supply Capacity and Headway Time of the Shared Corridor

The demand capacity and headway time computed in above using the econometric forecasting methods must not be beyond the practical supply capacity and headway time in order to have an acceptable minimum delay and save operating system. However, as the demand on the corridor increases after years in future the demand capacity will extends than that of the maximum supply capacity where other solutions are to be used to maximize the supply capacity at that time and therefore knowing of that critical year is must for a better utilization management.

##### Demand capacity and headway time at peak hours of the shared corridor:

The demand and supply capacity and headway time estimated on tables 4.11,4.12, 4.14 at peak hours of the shard corridor are related on the demand Vs supply curve of capacity and headway time and the critical period where the point of equilibrium (optimum) capacity or headway time is determined (see figure 4.16 and 4.17). With this demand and supply curve, the equilibrium point is determined in the year of 2036G.C as the result the track line reaches a saturation in traffic intensity along the shard corridor of the AA LRT with this capacity analysis and forecasting method.

The available capacity is the difference in between practical supply capacity and actual demand capacity with this in the year of 2036G.C the available capacity becomes zero, where it indicates there is 100% consumption level at this year.

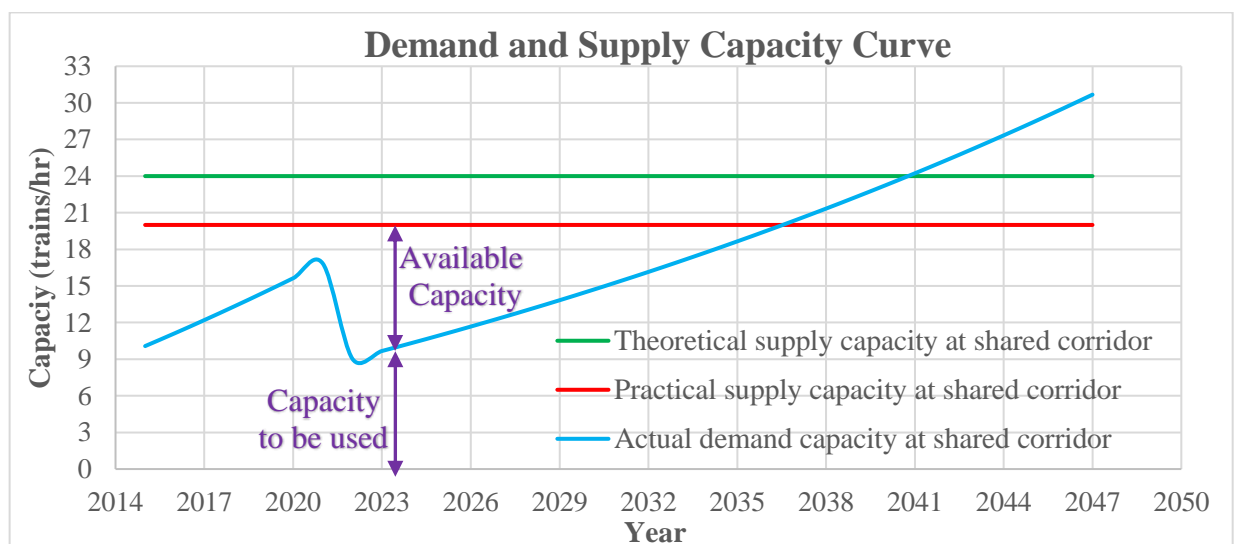
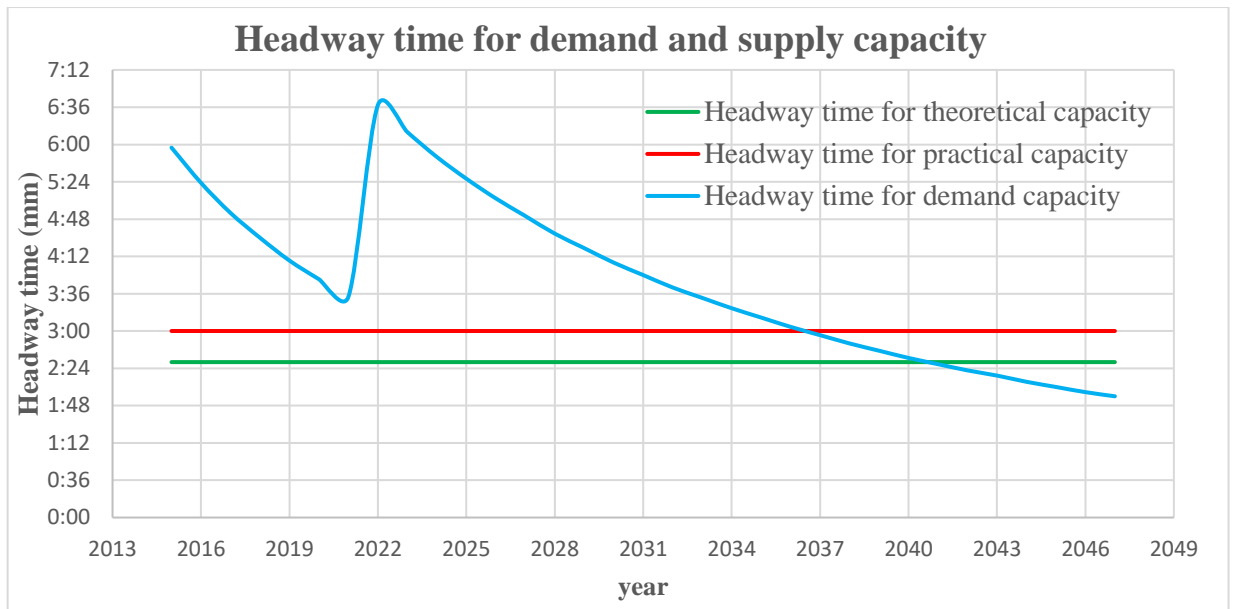


Figure 4.16: Demand and Supply Capacity Curve at Peak Hours of the Shared Corridor



**Figure 4.17: Demand and Supply headway time curve at peak hours of the shared corridor**

The demand capacity and headway time estimated from forecasted passenger demand need realization and careful implementation of these estimated values must be made. Then the capacity and headway time results that must be to be implemented for both the peak and off-peak hours of East-West and North-South corridor are estimated from in consideration of the networking effect at the shard corridors is as in the table 4.16 below.

**Table 4.16: Actual Capacity and Headway Time at the Shared Corridor of the Unidirectional Travel**

Year	Period of day	At shared corridor		At E-W corridor		At N-S corridor	
		Capacity (Trains/hr)	Headway time (mm:ss)	Capacity (Trains/hr)	Headway time (mm:ss)	Capacity (Trains/hr)	Headway time (mm:ss)
2018	At Peak hours	14	4:17	7	8:34	7	8:34
	At off-Peak hours	10	6:00	5	12:00	5	12:00
2019	At Peak hours	14	4:17	7	8:34	7	8:34
	At off-Peak hours	10	6:00	5	12:00	5	12:00
2020	At Peak hours	16	3:45	8	7:30	8	7:30
	At off-Peak hours	12	5:00	6	10:00	6	10:00
2021	At Peak hours	16	3:45	8	7:30	8	7:30
	At off-Peak hours	12	5:00	6	10:00	6	10:00
2022	At Peak hours	8	7:30	4	15:00	4	15:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2023	At Peak hours	10	6:00	5	12:00	5	12:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00

Year	Period of day	At shared corridor		At E-W corridor		At N-S corridor	
		Capacity (Trains/hr)	Headway time (mm:ss)	Capacity (Trains/hr)	Headway time (mm:ss)	Capacity (Trains/hr)	Headway time (mm:ss)
2024	At Peak hours	10	6:00	5	12:00	5	12:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2025	At Peak hours	12	5:00	6	10:00	6	10:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2026	At Peak hours	12	5:00	6	10:00	6	10:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2027	At Peak hours	12	5:00	6	10:00	6	10:00
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2028	At Peak hours	12	5:00	6	10:00	6	10:00
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2029	At Peak hours	14	4:17	7	8:34	7	8:34
	At off-Peak hours	6	10:00	3	20:00	3	20:00
2030	At Peak hours	14	4:17	7	8:34	7	8:34
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2031	At Peak hours	16	3:45	8	7:30	8	7:30
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2032	At Peak hours	16	3:45	8	7:30	8	7:30
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2033	At Peak hours	16	3:45	8	7:30	8	7:30
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2034	At Peak hours	18	3:19	9	6:38	9	6:38
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2035	At Peak hours	18	3:19	9	6:38	9	6:38
	At off-Peak hours	8	7:30	4	15:00	4	15:00
2036	At Peak hours	20	3:00	10	6:00	10	6:00
	At off-Peak hours	10	6:00	5	12:00	5	12:00

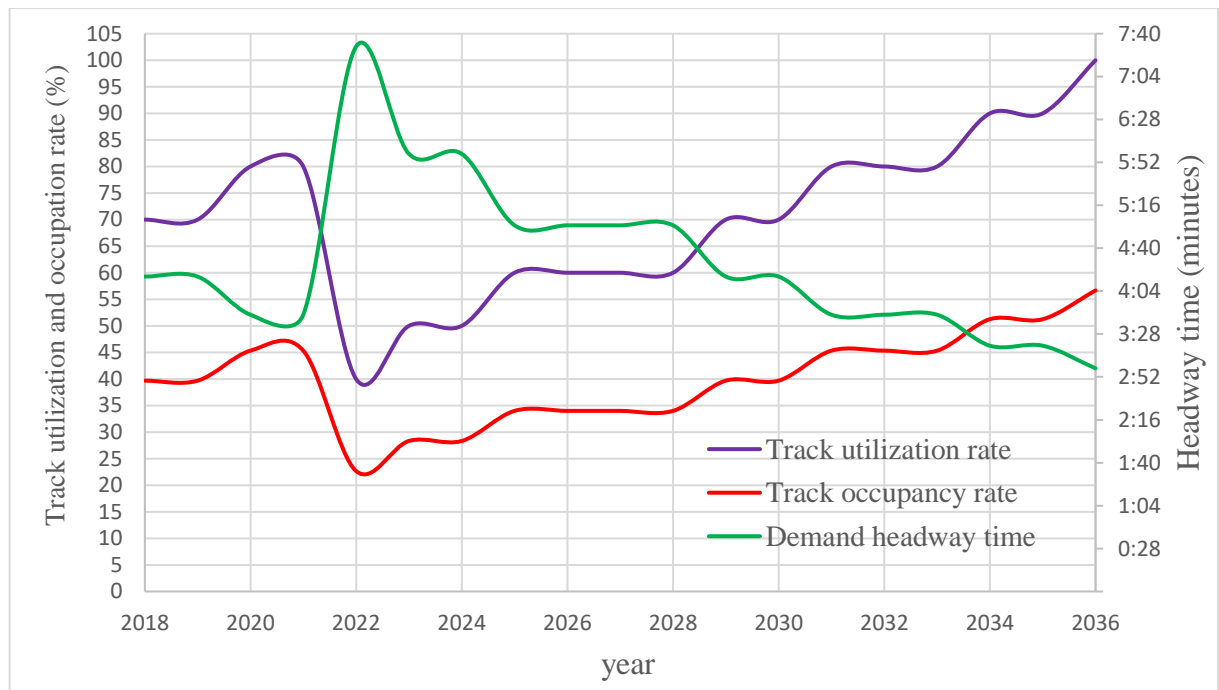
#### 4.6. Track Occupation Rate Estimation

As discussed in the literature review the track occupation rate is the direct measure of the track utilization rate, an increase of the traffic density (demand capacity) on infrastructure, the higher the utilization rate is determined. The track occupancy rate for the demand capacity can estimate using the equation 3.06 of section 3.3.1.

- The blocking time at bottleneck block sections is as in the table 4.01 of E-W line and 4.03 N-S line of shared corridor 1:42 minute at both up and down direction
- The demand headway time is 4:17 minutes (see table 4.16) at the peak hours of the year 2018G.C.

Track occupation rate at peak hours ( $\Psi$ ) at 2018G.C =  $\frac{1:42 \text{ minutes}}{4:17 \text{ minutes}} = 39.7\%$  on both the up and down directions and

In the same way, this track occupation rate can be estimated for each year until the optimum utilization rate of the year of 2036G.C and the results are as represented in the figure 4.18 in relation with headway time. In addition, The track utilization rate is estimated as the percentage ratio of actual or capacity to be used with the maximum practical capacity of the routes.



**Figure 4.18: track occupation rate, track utilization rate and headway time relationships at the peak hour time**

Figure 4.18 shows as there is a relationship among the headway time and track occupation rate and track utilization rate, a larger track occupation rate or track utilization rate is determined if there is an improved minimum possible headway time. At the year of 2022 G.C all the single unite trains are changed to double unite train and due to the large internal capacity of trains (double unite) the number of trains moving will be reduced resulted for an increase of the headway time at this year to the 7:30 mm:ss peak value. At this maximum headway time, a minimum track utilization rate and track occupation rate is recorded. However, when this headway time is reduced to its minimum value of 3:00 mm:ss at the year of 2036 G.C due to the increase of passenger demand, the track

occupation rate will also be improved to 56.67% with this track occupation rate the track utilization rate will also meets a 100% utilization.

Therefore, from this, one can understand, as headway time is a direct measure of the track occupation rate and track utilization rates and with this analysis, 100% (optimum) utilization rate is recorded in the year of 2036G.C with its minimum headway time of 3:00 minutes at the shared corridor of AA LRT.

#### **4.7. Discussion of Results**

All the results represented with figures and tables in the above sections for both East-West, North-south and shared corridor is within the consideration of the networking effect of the two LRT route lines, analysis are made using the UIC - 405R capacity estimator of the supplied infrastructure where it is validated using the Anylogic simulation software. In addition, by forecasting the actual passenger demand from the OCC of the AA LRT routes to estimate the future effects on the planning of the operating system of the LRT for about the next 30 years.

According to the capacity analysis of UIC – 405R the Ayat (EW1) - Meri (EW2) on down-direction and Management Institute (EW6) - Gurd Shala-2 (EW7) on up-directions along the East-West route, and the Meshoulekyia (NS15)- Stadium (NS16) on the up-direction and Nefas Silk-2 (NS11) – Lancha (NS12) on down-direction along the North-south are determined as bottleneck block sections. However, the two corridors have a networking effect on the shared corridor from the Stadium to Lideta with the overall bottleneck block section of the network is on the section Mexico (EW18) – Tegbared (EW19) both on the up-direction and on down-direction. This is because of the sum of capacities of bottleneck section of E-W and N-S corridors are greater than to that of the capacity on shared corridor. Therefore, the maximum theoretical capacity is taken from the overall bottleneck block sections of the shared corridor and dividing these capacities into two is the capacity of the two separate routes of LRT.

With this analysis method, the maximum practical supply capacity of the shared corridor at the peak hours is determined 20 train/hr (10 trains on E-W and 10 trains on N-S) at both the up and down direction (see table 4.11) with their headway time of 3:00 minutes at the bottleneck section in between EW18-EW19 are determined. The capacities and headway time estimated results at off-peak hours in this corridor are also 16trains/hr and 3:45 minute (see table 4.11 and 4.12).

These maximum practical supply capacity and minimum headway time determined at the shared corridors both at the peak and off-peak hours are the extreme values where the demand capacity must not beyond this maximum practical supply capacity and the minimum demand headway time must not less than of the practical supply headway time. Nevertheless, after sometime within an increase of the passenger demand the demand capacity and headway time will extend to this limiting value determined by UIC-405R where other solutions can be provided in that critical period, then knowing of that period is good for proper operational management of the railway system.

Comparing the results of the demand and supply capacity and headway time the critical or year of the saturation in traffic intensity is determined at the peak hours is at the year of 2036G.C, however the traffic does not reach the saturation level at off-peak hours with this forecasting period. Finally, the capacity and headway time that could be implemented at the E-W and N-S routes are as in the table 4.16.

The decrease in capacity and the increase in headway time of the year of 2022G.C from that of 2021G.C both at the peak and off-peak hours shows the conversion of single unit tramcar to two-unit tramcar and therefore starting from the year 2022G.C the two-unit tramcar is used.

The current track occupation rate at peak hours ( $\Psi$ ) at the shared corridors of the railway route from the timetable of AA LRT were estimated at the tables 4.01 and 4.03 with their results of 23.8% and 20.2% at the up and down directions respectively. In addition, at the off-peak hours of 22.1% and 15.5% at up and down directions respectively were determined. But the track occupation rate from the demand based analysis is determined 39.7% at peak hours and 34% at off-peak hours are estimated for the year of 2018G.C and this shows as it is improved from the track occupation rate on the timetable. Finally, the track occupation rate reaches 56.67% in the year of 2036G.C and this is resulting to an optimum utilization rate of 100% in the year of 2036 G.C at the shared corridor (see fig.4.18).

## 5. CONCLUSION and RECOMMENDATION

### 5.1. Conclusion

This thesis has used a literature review to provide an overview of the utilization of railway capacity. In addition to the macro and micro railway capacity utilization measures, the velocity and track occupation rate are also the major measures to this capacity utilization, where this thesis work focuses on the track occupation rate by estimating minimum demand based headway time for the timetable and consequently this increases capacity consumption of railway line.

A timetable should meet various requirements, such as the restrictions considering for the operational feasibility like the networking effect of routes that are not considered during the development of a timetable of the AA LRT. In consideration of this networking effect on the shared corridors of the two LRT routes, an analytical method (UIC-405) with the help of Anylogic software determines a finale result of headway time and capacity as in the table 4.16. For instance, headway time at 2018G.C determined using this analysis is 8:34 minutes with 7 trains/hr at peak hours and 12:00 minutes with 5 trains/hr at the off-peak hours on both E-W and N-S routes. However, the current headway time at the E-W and N-S routes is 15 minutes at the peak hours (whole daytime) and 20 minutes at off-peak hours (nighttime) are implementing on the timetable of AA LRT with the irregular headway time at shared corridors, this shows a clear improvement on capacity and headway time when demand based schedule is held.

Consequently, the track occupation rate ( $\Psi$ ) at shared corridor has improved to 39.3% at peak hours, 28.1% at off-peak hours on both travel directions, but the current track occupation rate of 23.8% up and 20.2% down at peak hours and 22.1% up and 15.5% down at off-peak hours estimated at the tables of 4.01 and 4.02 from the AA LRT.

Finally, the critical year period of maximum utilization railway line is determined at 2036G.C at the peak hour time. To maximize the supply capacity at this critical year the existing railway signaling system of ATP must upgrade to the ERTMS or ETCS level 1, 2, and then level 3, and then the saturation period of the line can be extended. In addition, the period of railway saturation level can also be extended by increasing the longitudinal length of the station platform more than from the existing 60m. Consequently, more than two unit trains (length of 60m) can be used on the railway line and the longer train can increase track occupation rate, infrastructure utilization rate and can also hauls the larger number of passengers at a time.

## 5.2. Recommendations of Further Studies

To improve the railway capacity utilization it is important to have a thorough knowledge about how to estimate the optimum train velocity and maximum track occupation rate. This thesis is a step towards improving the track occupation rate by determining the demand based headway time within the consideration of networking effect of the two routes. However, the train velocity and the dwell time at the station are kept constant as in the timetable of AA LRT and for better optimum utilization of railway line, a method must develop to account an optimum velocity of trains at each block section and dwell time at each station must also be studied along this railway route.

To improve this railway capacity utilization, the analytical method and a simple simulation method are used for estimation of railway capacity, but optimization and a detail simulation method need to be adapted to this LRT route. Therefore, further research has to be studied on capacity estimation method. The analytical method of UIC - 405R is used in this thesis work, rather than using the UIC – 406R with the simulation methods that shows an actual flow of trains with the detail simulation and other optimization method for the capacity estimations.

This thesis uses the analytical methods to estimate railway capacity within the homogeneous train services (only local/regional passenger trains) are serving on the LRT route, but a maximum railway line capacity and less travel time can be determined if studies are made on the railway line that introduces the train heterogeneity if it is feasible to use.

This thesis analysis, concludes as there is the higher utilization of train (rolling stock) with the increase in their numbers by proving minimum headway time at the railway line, rather a detailed study is made of the standing and sitting seats for improvement of the internal capacity of the train. Therefore, studies should be made to account such utilization of trains and train loading diversity can estimated.

Passenger travel demand is dynamic that varies on each hour of the day, days of the week and seasons of the year, to satisfy this variable passenger travel a variable headway time must be implemented on the timetable. Where this thesis estimates hourly varying headway time for peak hours and off-peak hours, but studies must also be made seasonally varying headway time for optimum utilization of the railway system.

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**APPENDIX A**

location and center-to-center distance among stations

Appendix A.1: Distance among stations and their position along the E-W route

No.	Station name	Length of central lines	Right line coordinates of the station center	Distance between stations	Distance between centers of tracks	Elevation of station center	Station type
1	Origin	YDK5+483.00	X-996862.2995 Y-469474.0755	52	5		
2	EW22	YDK5+535.00	X-996839.1058 Y-469520.6163	769	5.00 (side)	2357.930	Ground station
3	EW21	YDK6+304.00	X-996911.0019 Y-470225.6892	732	4.00 (side)	2344.895	Ground station
4	EW20	YDK7+036.00	X-996835.8709 Y-470953.7219	735	4.00 (side)	2368.193	Elevated common rail station
5	EW19	YDK7+771.00	X-996741.9782 Y-471682.7001	688	4.00 (side)	2354.928	Elevated common rail station
6	EW18	YDK8+459.00	X-996801.1117 Y-472358.4619	560	4.00 (side)	2366.198	Elevated common rail station
7	EW17	YDK9+019.00	X-996887.5591 Y-472906.9799	445	4.00 (side)	2359.776	Elevated common rail station
8	EW16	YDK9+464.00	X-996902.5663 Y-473348.1557	640	4.00 (side)	2350.067	Elevated common rail

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							station
9	EW15	YDK10+ 104.00	X-996795.6393 Y-473978.9619	593	4.00 (side)	2350.033	Elevate d station
10	EW14	YDK10+ 697.00	X-996726.4625 Y-474567.5919		675	4.00 (side)	2333.711
11	EW13	YDK11+ 372.00	X-996789.6514 Y-475223.6982	963		8.4 (island)	2342.382
12	EW12	YDK12+ 335.00	X-997201.6457 Y-476091.8807		758	4.00 (side)	2362.002
13	EW11	YDK13+ 093.00	X-997371.7463 Y-476830.3757	746		4.00 (side)	2351.348
14	EW10	YDK13+ 839.00	X-997557.3654 Y-477552.2791		776	4.00 (side)	2365.876
15	EW9	YDK14+ 615.00	X-997745.0504 Y-478303.7177	829		8.95 (island)	2371.893
16	EW8	YDK15+ 444.00	X-997812.0607 Y-479122.4389		1083.6	4.00 (side)	2378.329
17	EW7	YDK16+ 530.00	X-997685.5967 Y-480196.9975	970		4.00 (side)	2371.315
18	EW6	YDK17+ 500.00	X-997879.8411 Y-481125.6722		724.82	4.00 (side)	2380.134
19	EW5	YDK18+ 225.00	X-997975.1137 Y-481831.3394	860		4.00 (side)	2387.226
20	EW4	YDK19+ 085.00	X-997939.3444 Y-482690.5893		863	4.00 (side)	2381.913

21	EW3	YDK19+948.00	X-997893.5336 Y-483552.3376	1092	4.00 (side)	2386.685	Ground station
22	EW2	YDK21+040.00	X-997849.2514 Y-484643.1008		1260	4.00 (side)	2401.463
23	EW1	YDK22+300.00	X-997912.7097 Y-485901.1314	182		4.00 (side)	2403.268
24	Terminal	YDK22+482.00	X-997923.4631 Y-486082.8134			4	

Source: [42]

Appendix A.2: Distance among stations and their position along the N-S route

No	Station name	Length of central line	Right line coordinates of the station center	The distance between stations (m)	The distance between centers of tracks	Elevation of station center	Station type
1	Origin	YDK1+731.00	X-999889.0115 Y-472815.9335	196	4.5		
2	NS27	YDK1+927.00	X-999700.6192 Y-472762.1360		743	4.50 (side)	2462.805
3	NS26	YDK2+670.00	X-999410.2998 Y-472165.5605	945		4.00 (side)	2443.945
4	NS25	YDK3+615.00	X-999369.2328 Y-471230.2225		604.88	4.00 (side)	2452.019
5	NS24	YDK4+228.00	X-999349.2542 Y-470634.6507	667		4.00 (side)	2467.723
6	NS23	YDK4+895.00	X-998744.4611 Y-470631.8092		812.71	4.00 (side)	2442.499
7	NS22	YDK5+706.00	X-997936.5527 Y-470674.0686	739		4.00 (side)	2406.728
8	NS21	YDK6+	X-997287.2727			4.00	2376.051

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		445.00	Y-470816.1044	591	(side)		
9	EW20	YDK7+ 036.00	X-996835.8709 Y-470953.7220	735	4.00 (side)	2368.193	Elevated common rail station
10	EW19	YDK7+ 771.00	X-996741.9782 Y-471682.7001	688	4.00 (side)	2354.928	Elevated common rail station
11	EW18	YDK8+ 459.00	X-996801.1117 Y-472358.4619	560	4.00 (side)	2366.198	Elevated common rail station
12	EW17	YDK9+ 019.00	X-996887.5591 Y-472906.9799	445	4.00 (side)	2359.776	Elevated common rail station
13	EW16	YDK9+ 464.00	X-996902.5663 Y-473348.1558	908	4.00 (side)	2350.067	Elevated common rail station
14	NS15	YDK10 +372.00	X-996122.2103 Y-473471.6420	481.12	4.00 (side)	2341.643	Ground station
15	NS14	YDK10 +835.00	X-995641.5645 Y-473450.2915	610	4.00 (side)	2330.220	Ground station
16	NS13	YDK11 +445.00	X-995052.7711 Y-473574.2988	555	4.68 (side)	2310.969	Ground station
17	NS12	YDK12 +000.00	X-994512.1123 Y-473512.3357	1971.66	4.00 (side)	2299.214	Ground station
18	NS11	YDK13 +969.00	X-992605.4106 Y-473681.0584	861	4.00 (side)	2285.645	Ground station
19	NS10	YDK14 +830.00	X-991785.3588 Y-473921.5131	995	4.00 (side)	2275.680	Ground station
20	NS9	YDK15 +825.00	X-990799.5069 Y-474019.5967	535	4.00 (side)	2244.587	Ground station

21	NS8	YDK16 +360.00	X-990266.8328 Y-473969.7656	845	4.12 (side)	2230.767	Ground station
22	NS7	YDK17 +205.00	X-989489.3270 Y-474284.5594	950	4.00 (side)	2210.650	Ground station
23	NS6	YDK18 +155.00	X-988719.9841 Y-473930.0774	269	5.00 (side)	2190.960	Ground station
24	Terminal 1	YDK18 +424.00	X-988497.5328 Y-474081.3269		5		

Source: [42]

## APPENDIX B

Addis Ababa population data from CSA

Appendix B.1: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2010

Age Group	Economically Active			Unemployed			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
All Ages	1,597,712	806,610	791,101	429,492	143,989	285,503	26.9	17.9	36.1
10-14	12,592	1,823	10,769	1,250	617	633	9.9	33.8	5.9
15-19	136,059	40,386	95,673	39,112	14,967	24,145	28.7	37.1	25.2
20-24	307,371	142,767	164,603	109,051	40,903	68,148	35.5	28.7	41.4
25-29	354,126	177,393	176,733	102,758	37,216	65,541	29.0	21.0	37.1
30-34	232,736	122,341	110,395	59,065	14,729	44,336	25.4	12.0	40.2
35-39	185,718	99,774	85,944	43,229	9,888	33,342	23.3	9.9	38.8
40-44	93,391	52,424	40,968	15,206	4,623	10,583	16.3	8.8	25.8
45-49	103,528	62,809	40,719	17,079	4,798	12,281	16.5	7.6	30.2
50-54	64,854	35,847	29,007	15,002	3,053	11,948	23.1	8.5	41.2
55-59	41,185	24,675	16,510	11,468	4,521	6,948	27.8	18.3	42.1
60-64	33,845	22,972	10,872	7,403	4,705	2,698	21.9	20.5	24.8
65+	32,306	23,398	8,908	8,868	3,969	4,899	27.4	17.0	55.0

Source: [47]

Appendix B.2: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2011

Age Group	Economically Active			Unemployed			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
All Ages	1,533,291	807,307	725,984	384,317	139,334	244,982	25.1	17.3	33.7
10-14	14,839	3,561	11,278	3,524	1,189	2,335	23.7	33.4	20.7
15-19	118,673	43,870	74,803	34,626	13,491	21,134	29.2	30.8	28.3
20-24	269,660	132,803	136,857	88,017	39,177	48,839	32.6	29.5	35.7
25-29	331,299	168,407	162,892	83,267	26,336	56,931	25.1	15.6	35.0
30-34	213,032	123,953	89,079	47,111	19,058	28,054	22.1	15.4	31.5
35-39	189,427	97,431	91,996	39,242	11,533	27,709	20.7	11.8	30.1
40-44	109,171	65,493	43,678	27,618	7,491	20,128	25.3	11.4	46.1
45-49	95,017	49,242	45,774	20,348	4,500	15,848	21.4	9.1	34.6
50-54	82,390	46,684	35,705	16,663	5,155	11,508	20.2	11.0	32.2
55-59	39,780	23,643	16,137	7,754	2,400	5,353	19.5	10.2	33.2
60-64	31,375	21,992	9,383	7,415	3,123	4,292	23.6	14.2	45.7
65+	38,628	30,228	8,400	8,732	5,881	2,851	22.6	19.5	33.9

Source: [41]

Appendix B.3: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2012

Age Group	Economically Active			Unemployed			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
All Ages	1,625,468	839,892	785,576	374,626	130,686	243,940	23.0	15.6	31.1
10-14	12,300	3,582	8,718	2,423	1,384	1,038	19.7	38.6	11.9
15-19	114,076	29,832	84,244	25,488	8,923	16,564	22.3	29.9	19.7
20-24	273,481	117,270	156,211	93,482	35,314	58,168	34.2	30.1	37.2
25-29	365,840	183,509	182,330	87,535	28,830	58,705	23.9	15.7	32.2
30-34	244,892	139,844	105,048	54,507	18,026	36,481	22.3	12.9	34.7
35-39	204,612	115,698	88,914	33,520	9,473	24,046	16.4	8.2	27.0
40-44	126,925	75,899	51,025	22,412	5,192	17,220	17.7	6.8	33.7
45-49	95,390	51,268	44,122	17,560	5,445	12,115	18.4	10.6	27.5
50-54	78,907	45,315	33,592	13,738	5,176	8,562	17.4	11.4	25.5
55-59	41,798	28,407	13,392	8,835	4,331	4,504	21.1	15.2	33.6
60-64	31,524	19,721	11,804	7,770	2,273	5,497	24.6	11.5	46.6
65+	35,723	29,547	6,176	7,356	6,318	1,038	20.6	21.4	16.8

Source: [41]

Appendix B.4: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2013

Age group	Economically Active Population			Unemployed Population			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female

**ADDIS ABABA CITY ADMINISTRATION**

All Ages	1,695,065	875,424	819,641	409,467	138,635	270,833	24.2	15.8	33.0
10-14	11,682	2,241	9,441	2,616	718	1,898	22.4	32.0	20.1
15-19	117,980	36,769	81,211	36,867	16,887	19,980	31.2	45.9	24.6
20-24	286,056	128,125	157,931	87,838	35,422	52,416	30.7	27.6	33.2
25-29	372,911	191,580	181,331	91,493	31,732	59,762	24.5	16.6	33.0
30-34	264,481	146,180	118,301	58,267	16,441	41,826	22.0	11.2	35.4
35-39	224,704	121,464	103,239	47,727	12,967	34,759	21.2	10.7	33.7
40-44	127,373	75,111	52,263	23,914	6,433	17,481	18.8	8.6	33.4
45-49	99,110	53,028	46,083	18,564	3,628	14,936	18.7	6.8	32.4
50-54	73,532	40,295	33,237	15,176	2,791	12,385	20.6	6.9	37.3
55-59	53,859	34,312	19,547	9,841	3,552	6,289	18.3	10.4	32.2
60-64	32,027	23,001	9,027	8,243	3,512	4,731	25.7	15.3	52.4
65+	31,350	23,319	8,032	8,923	4,552	4,371	28.5	19.5	54.4

Source: [41]

Appendix B.5: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2014

Age Group	Economically Active			Unemployed			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female
All Ages	1,707,471	887,508	819,963	401,758	140,941	260,816	23.5	15.9	31.8
10-14	18,632	5,631	13,001	8,133	4,023	4,110	43.7	71.4	31.6
15-19	132,613	39,162	93,451	41,331	15,942	25,388	31.2	40.7	27.2
20-24	293,324	132,771	160,553	93,600	37,008	56,593	31.9	27.9	35.2
25-29	364,904	185,469	179,435	90,250	32,598	57,652	24.7	17.6	32.1
30-34	246,944	144,947	101,996	51,988	20,027	31,961	21.1	13.8	31.3
35-39	232,674	121,669	111,005	46,587	9,797	36,790	20.0	8.1	33.1
40-44	140,070	81,147	58,923	24,158	6,278	17,880	17.2	7.7	30.3
45-49	87,973	48,568	39,406	14,641	2,184	12,458	16.6	4.5	31.6
50-54	74,879	44,723	30,156	13,441	4,406	9,035	18.0	9.9	30.0
55-59	50,042	32,712	17,330	6,086	2,374	3,712	12.2	7.3	21.4
60-64	29,533	18,586	10,947	5,607	1,533	4,074	19.0	8.2	37.2
65+	35,884	32,124	3,760	5,935	4,771	1,164	16.5	14.9	31.0

Source: [41]

Appendix B.6: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2015

Age Group	Economically Active Population			Unemployed Population			Unemployment Rate		
	Total	Male	Female	Total	Male	Female	Total	Male	Female

**ADDIS ABABA CITY**

All Ages	1,728,296	902,490	825,806	366,227	130,123	236,103	21.2	14.4	28.6
10-14	17,786	7,733	10,053	6,677	3,339	3,338	37.5	43.2	33.2
15-19	111,430	30,002	81,428	37,991	12,287	25,704	34.1	41.0	31.6
20-24	283,945	128,729	155,216	94,289	38,828	55,460	33.2	30.2	35.7
25-29	353,807	181,270	172,537	81,166	33,267	47,900	22.9	18.4	27.8
30-34	280,552	153,982	126,570	45,908	13,786	32,122	16.4	9.0	25.4
35-39	246,248	136,113	110,135	36,758	8,211	28,547	14.9	6.0	25.9
40-44	138,833	80,932	57,901	16,532	4,269	12,263	11.9	5.3	21.2
45-49	94,830	55,954	38,876	17,061	5,629	11,432	18.0	10.1	29.4
50-54	68,221	40,358	27,863	5,526	974	4,552	8.1	2.4	16.3
55-59	59,178	32,299	26,878	13,729	4,338	9,391	23.2	13.4	34.9
60-64	29,680	21,829	7,851	3,394	1,691	1,704	11.4	7.7	21.7
65+	43,785	33,288	10,497	7,195	3,504	3,691	16.4	10.5	35.2

Source: [41]

Appendix B.7: Unemployed Population of Urban Areas Aged Ten Years and Above by Age Group Sex and Unemployment Rate, ADDIS ABABA CITY ADMINISTRATION: 2016

**ADDIS ABABA CITY ADMINISTRATION**

All ages	1,870,105	951,896	918,209	393,144	117,788	275,356	21.0	12.4	30.0
10-14	10,984	1,542	9,442	6,498	781	5,717	59.2	50.7	60.5
15-19	102,063	28,517	73,546	26,230	7,872	18,358	25.7	27.6	25.0
20-24	272,349	112,408	159,941	78,207	28,317	49,890	28.7	25.2	31.2
25-29	421,320	196,140	225,180	89,469	20,920	68,549	21.2	10.7	30.4
30-34	348,065	197,643	150,422	68,592	18,575	50,017	19.7	9.4	33.3
35-39	266,920	142,888	124,032	45,272	12,844	32,428	17.0	9.0	26.1
40-44	148,761	93,529	55,233	20,423	7,264	13,159	13.7	7.8	23.8
45-49	105,456	55,829	49,627	21,696	6,613	15,083	20.6	11.8	30.4
50-54	74,118	37,274	36,844	13,714	4,505	9,209	18.5	12.1	25.0
55-59	51,276	34,322	16,954	9,117	3,553	5,564	17.8	10.4	32.8
60-64	33,918	24,875	9,043	4,931	1,871	3,060	14.5	7.5	33.8
65+	34,876	26,929	7,947	8,995	4,672	4,323	25.8	17.3	54.4

Source: [41]

**APPENDIX C**

Capacity analysis results for East-West route at off-peak hours

Appendix C.1: Theoretical capacity of E-W corridor at off-peak hours (T=12hr) (2023-2027) year

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time ( $t_r$ )=[0.67* column 4] (mm:ss) (5)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (6)	$\Psi=0.6,$ $Lq=1.5$
						P (trains/day) (T=12hr) (7)
EW22-EW21	Up	2	01:42	01:08	00:30	216
	Down	2	01:49	01:13	00:30	204
EW21-EW20	Up	3	01:39	01:06	00:45	206
	Down	2	01:28	00:58	00:30	246
EW20-EW19	Up	1	01:24	00:56	00:15	279
	Down	1	01:23	00:55	00:15	283
EW19-EW18	Up	1	01:41	01:07	00:15	236
	Down	1	01:43	01:09	00:15	231
EW18-EW17	Up	1	01:29	00:59	00:15	265
	Down	1	01:38	01:05	00:15	243
EW17-EW16	Up	1	01:06	00:44	00:15	346
	Down	1	01:14	00:49	00:15	313
EW16-EW15	Up	2	01:34	01:02	00:30	232
	Down	3	01:21	00:54	00:45	240
EW15-EW14	Up	1	01:22	00:54	00:15	286
	Down	1	01:19	00:52	00:15	296
EW14-EW13	Up	1	01:17	00:51	00:15	302
	Down	1	01:25	00:56	00:15	277
EW13-EW12	Up	1	01:49	01:13	00:15	219
	Down	1	01:56	01:17	00:15	208
EW12-EW11	Up	1	01:19	00:52	00:15	296
	Down	1	01:46	01:11	00:15	225
EW11-EW10	Up	1	01:25	00:56	00:15	277
	Down	1	01:32	01:01	00:15	257
EW10-EW9	Up	1	01:37	01:04	00:15	246
	Down	1	01:46	01:11	00:15	225
EW9-EW8	Up	1	01:34	01:02	00:15	253
	Down	1	01:29	00:59	00:15	265
EW8-EW7	Up	2	02:16	01:31	00:30	168
	Down	2	02:05	01:23	00:30	182

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time ( $t_r$ )=[0.67* column 4] (mm:ss) (5)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (6)	$\Psi=0.6,$ $Lq=1.5$
						P (trains/day) (T=12hr) (7)
EW7-EW6	Up	3	02:36	01:44	00:45	142
	Down	3	02:13	01:29	00:45	162
EW6-EW5	Up	1	01:18	00:52	00:15	298
	Down	1	01:24	00:56	00:15	279
EW5-EW4	Up	1	01:54	01:16	00:15	211
	Down	1	02:14	01:29	00:15	182
EW4-EW3	Up	1	01:35	01:03	00:15	250
	Down	1	01:37	01:04	00:15	246
EW3-EW2	Up	3	02:10	01:27	00:45	165
	Down	3	02:22	01:35	00:45	153
EW2-EW1	Up	2	02:19	01:33	00:30	165
	Down	2	03:06	02:04	00:30	127

Appendix C.2: Theoretical capacity of E-W corridor at off-peak hours (T=14hr) (2028-2032) year

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time ( $t_r$ )=[0.67* column 4 ] (mm:ss) (5)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (6)	$\Psi=0.6,$ $Lq=1.5$
						P (T=14hr) (6)
EW22-EW21	Up	2	01:42	01:08	00:30	252
	Down	2	01:49	01:13	00:30	238
EW21-EW20	Up	3	01:39	01:06	00:45	240
	Down	2	01:28	00:58	00:30	287
EW20-EW19	Up	1	01:24	00:56	00:15	325
	Down	1	01:23	00:55	00:15	329
EW19-EW18	Up	1	01:41	01:07	00:15	276
	Down	1	01:43	01:09	00:15	270
EW18-EW17	Up	1	01:29	00:59	00:15	309
	Down	1	01:38	01:05	00:15	283
EW17-EW16	Up	1	01:06	00:44	00:15	403
	Down	1	01:14	00:49	00:15	365
EW16-EW15	Up	2	01:34	01:02	00:30	271
	Down	3	01:21	00:54	00:45	280

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time ( $t_r$ )=[0.67* column 4 ] (mm:ss) (5)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (6)	$\Psi=0.6,$ $Lq=1.5$
						P (T=14hr) (6)
EW15-EW14	Up	1	01:22	00:54	00:15	334
	Down	1	01:19	00:52	00:15	345
EW14-EW13	Up	1	01:17	00:51	00:15	353
	Down	1	01:25	00:56	00:15	323
EW13-EW12	Up	1	01:49	01:13	00:15	256
	Down	1	01:56	01:17	00:15	243
EW12-EW11	Up	1	01:19	00:52	00:15	345
	Down	1	01:46	01:11	00:15	263
EW11-EW10	Up	1	01:25	00:56	00:15	323
	Down	1	01:32	01:01	00:15	300
EW10-EW9	Up	1	01:37	01:04	00:15	287
	Down	1	01:46	01:11	00:15	263
EW9-EW8	Up	1	01:34	01:02	00:15	295
	Down	1	01:29	00:59	00:15	309
EW8-EW7	Up	2	02:16	01:31	00:30	196
	Down	2	02:05	01:23	00:30	212
EW7-EW6	Up	3	02:36	01:44	00:45	165
	Down	3	02:13	01:29	00:45	189
EW6-EW5	Up	1	01:18	00:52	00:15	348
	Down	1	01:24	00:56	00:15	325
EW5-EW4	Up	1	01:54	01:16	00:15	246
	Down	1	02:14	01:29	00:15	212
EW4-EW3	Up	1	01:35	01:03	00:15	293
	Down	1	01:37	01:04	00:15	287
EW3-EW2	Up	3	02:10	01:27	00:45	193
	Down	3	02:22	01:35	00:45	179
EW2-EW1	Up	2	02:19	01:33	00:30	193
	Down	2	03:06	02:04	00:30	148

Appendix C.3: Theoretical capacity of E-W corridor at off-peak hours (T=16hr) (2033-2037) year

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time (mm:ss) ( $t_r$ )=[0.67 * column 4] (5)	Equivalent Buffer time (mm:ss) ( $t_{zu}$ )=[0.25* 'a'] (6)	$\Psi=0.6,$ $L_q=1.5$
						P (T=14hr) (7)
EW22-EW21	Up	2	01:42	01:08	00:30	288
	Down	2	01:49	01:13	00:30	272
EW21-EW20	Up	3	01:39	01:06	00:45	274
	Down	2	01:28	00:58	00:30	327
EW20-EW19	Up	1	01:24	00:56	00:15	372
	Down	1	01:23	00:55	00:15	375
EW19-EW18	Up	1	01:41	01:07	00:15	315
	Down	1	01:43	01:09	00:15	308
EW18-EW17	Up	1	01:29	00:59	00:15	354
	Down	1	01:38	01:05	00:15	324
EW17-EW16	Up	1	01:06	00:44	00:15	461
	Down	1	01:14	00:49	00:15	418
EW16-EW15	Up	2	01:34	01:02	00:30	310
	Down	3	01:21	00:54	00:45	320
EW15-EW14	Up	1	01:22	00:54	00:15	382
	Down	1	01:19	00:52	00:15	395
EW14-EW13	Up	1	01:17	00:51	00:15	403
	Down	1	01:25	00:56	00:15	369
EW13-EW12	Up	1	01:49	01:13	00:15	293
	Down	1	01:56	01:17	00:15	277
EW12-EW11	Up	1	01:19	00:52	00:15	395
	Down	1	01:46	01:11	00:15	300
EW11-EW10	Up	1	01:25	00:56	00:15	369
	Down	1	01:32	01:01	00:15	343
EW10-EW9	Up	1	01:37	01:04	00:15	327
	Down	1	01:46	01:11	00:15	300
EW9-EW8	Up	1	01:34	01:02	00:15	337
	Down	1	01:29	00:59	00:15	354
EW8-EW7	Up	2	02:16	01:31	00:30	224
	Down	2	02:05	01:23	00:30	242
EW7-EW6	Up	3	02:36	01:44	00:45	189
	Down	3	02:13	01:29	00:45	216
EW6-EW5	Up	1	01:18	00:52	00:15	397
	Down	1	01:24	00:56	00:15	372

Stations from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Blocking time from timetable (mm:ss) (4)	Buffer time (mm:ss) ( $t_r$ )=[0.67 * column 4] (5)	Equivalent Buffer time (mm:ss) ( $t_{zu}$ )=[0.25* 'a'] (6)	$\Psi=0.6,$ $Lq=1.5$
						P (T=14hr) (7)
EW5-EW4	Up	1	01:54	01:16	00:15	281
	Down	1	02:14	01:29	00:15	242
EW4-EW3	Up	1	01:35	01:03	00:15	333
	Down	1	01:37	01:04	00:15	327
EW3-EW2	Up	3	02:10	01:27	00:45	220
	Down	3	02:22	01:35	00:45	204
EW2-EW1	Up	2	02:19	01:33	00:30	220
	Down	2	03:06	02:04	00:30	170

Appendix C.4: Theoretical capacity of E-W corridor at off-peak hours (T=18hr) (2038-2047) year

Stations from-to (1)	Track direction (3)	No. intermediate block section 'a' (5)	Blocking time from timetable (mm:ss) (7)	Buffer time (mm:ss) ( $t_r$ )=[0.67 * column (7)] (9)	Equivalent Buffer time (mm:ss) ( $t_{zu}$ )=[0.25* 'a'] (10)	$\Psi=0.6,$ $Lq=1.5$
						P (trains/day) (T=18hr)
EW22-EW21	Up	2	01:42	01:08	00:30	324
	Down	2	01:49	01:13	00:30	306
EW21-EW20	Up	3	01:39	01:06	00:45	309
	Down	2	01:28	00:58	00:30	368
EW20-EW19	Up	1	01:24	00:56	00:15	418
	Down	1	01:23	00:55	00:15	424
EW19-EW18	Up	1	01:41	01:07	00:15	354
	Down	1	01:43	01:09	00:15	347
EW18-EW17	Up	1	01:29	00:59	00:15	398
	Down	1	01:38	01:05	00:15	364
EW17-EW16	Up	1	01:06	00:44	00:15	519
	Down	1	01:14	00:49	00:15	470
EW16-EW15	Up	2	01:34	01:02	00:30	349
	Down	3	01:21	00:54	00:45	360
EW15-EW14	Up	1	01:22	00:54	00:15	429
	Down	1	01:19	00:52	00:15	444
EW14-EW13	Up	1	01:17	00:51	00:15	453
	Down	1	01:25	00:56	00:15	416
EW13-EW12	Up	1	01:49	01:13	00:15	329
	Down	1	01:56	01:17	00:15	312

Stations from-to (1)	Track direction (3)	No. intermediate block section 'a' (5)	Blocking time from timetable (mm:ss) (7)	Buffer time (mm:ss) ( $t_r$ )=[0.67 * column (7)] (9)	Equivalent Buffer time (mm:ss) ( $t_{zu}$ )=[0.25* 'a'] (10)	$\Psi=0.6,$ $Lq=1.5$
						P (trains/day) (T=18hr)
EW12-EW11	Up	1	01:19	00:52	00:15	444
	Down	1	01:46	01:11	00:15	338
EW11-EW10	Up	1	01:25	00:56	00:15	416
	Down	1	01:32	01:01	00:15	386
EW10-EW9	Up	1	01:37	01:04	00:15	368
	Down	1	01:46	01:11	00:15	338
EW9-EW8	Up	1	01:34	01:02	00:15	379
	Down	1	01:29	00:59	00:15	398
EW8-EW7	Up	2	02:16	01:31	00:30	252
	Down	2	02:05	01:23	00:30	272
EW7-EW6	Up	3	02:36	01:44	00:45	213
	Down	3	02:13	01:29	00:45	243
EW6-EW5	Up	1	01:18	00:52	00:15	447
	Down	1	01:24	00:56	00:15	418
EW5-EW4	Up	1	01:54	01:16	00:15	316
	Down	1	02:14	01:29	00:15	272
EW4-EW3	Up	1	01:35	01:03	00:15	375
	Down	1	01:37	01:04	00:15	368
EW3-EW2	Up	3	02:10	01:27	00:45	248
	Down	3	02:22	01:35	00:45	230
EW2-EW1	Up	2	02:19	01:33	00:30	248
	Down	2	03:06	02:04	00:30	191

## APPENDIX D

Capacity analysis results for North-South route at off-peak hours

Appendix D.1: Theoretical capacity of N-S corridor at off-peak hours (T=12hr) (2023-2027) year

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS27-NS26	Up	2	20:00	3:07	2:05	0:30	127
	Down	2	20:00	2:42	1:48	0:30	144
NS26-NS25	Up	1	20:00	1:47	1:11	0:15	224
	Down	1	20:00	1:19	0:52	0:15	296
NS25-NS24	Up	1	20:00	1:28	0:58	0:15	268
	Down	1	20:00	1:25	0:56	0:15	277
NS24-NS23	Up	1	20:00	2:50	1:53	0:15	145
	Down	1	20:00	2:13	1:29	0:15	182
NS23-NS22	Up	1	20:00	1:42	1:08	0:15	234
	Down	1	20:00	1:37	1:04	0:15	246
NS22-NS21	Up	1	20:00	2:28	1:39	0:15	165
	Down	1	20:00	2:16	1:31	0:15	179
NS21-EW20	Up	3	20:00	2:37	1:45	0:45	141
	Down	2	20:00	2:36	1:44	0:30	149
EW20-EW19	Up	1	9:17	1:24	0:56	0:15	279
	Down	1	12:46	1:23	0:55	0:15	283
EW19-EW18	Up	1	9:17	1:41	1:07	0:15	236
	Down	1	12:46	1:43	1:09	0:15	231
EW18-EW17	Up	1	9:17	1:29	0:59	0:15	265
	Down	1	12:46	1:38	1:05	0:15	243
EW17-EW16	Up	1	9:17	1:06	0:44	0:15	346
	Down	1	12:46	1:14	0:49	0:15	313
EW16-NS15	Up	3	20:00	3:16	2:11	0:45	116
	Down	2	20:00	2:52	1:55	0:30	136
NS15-NS14	Up	1	20:00	1:08	0:45	0:15	338
	Down	1	20:00	1:14	0:49	0:15	313
NS14-NS13	Up	1	20:00	1:23	0:55	0:15	283
	Down	1	20:00	1:25	0:56	0:15	277
NS13-NS12	Up	2	20:00	1:25	0:56	0:30	253
	Down	2	20:00	1:31	1:01	0:30	238

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS12-NS11	Up	3	20:00	3:09	2:06	0:45	120
	Down	3	20:00	3:07	2:05	0:45	121
NS11-NS10	Up	1	20:00	1:46	1:11	0:15	225
	Down	1	20:00	1:42	1:08	0:15	236
NS10-NS9	Up	3	20:00	2:53	1:55	0:45	130
	Down	3	20:00	2:06	1:24	0:45	170
NS9-NS8	Up	2	20:00	1:14	0:49	0:30	283
	Down	2	20:00	1:23	0:55	0:30	257
NS8-NS7	Up	2	20:00	2:53	1:55	0:30	136
	Down	2	20:00	2:24	1:36	0:30	160
NS7-NS6	Up	1	20:00	3:04	2:03	0:15	134
	Down	1	20:00	3:12	2:08	0:15	129

Appendix D.2: Theoretical capacity of N-S corridor at off-peak hours (T=14hr) (2028-2032) year

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS27-NS26	Up	2	20:00	3:07	2:05	0:30	148
	Down	2	20:00	2:42	1:48	0:30	168
NS26-NS25	Up	1	20:00	1:47	1:11	0:15	261
	Down	1	20:00	1:19	0:52	0:15	345
NS25-NS24	Up	1	20:00	1:28	0:58	0:15	313
	Down	1	20:00	1:25	0:56	0:15	323
NS24-NS23	Up	1	20:00	2:50	1:53	0:15	169
	Down	1	20:00	2:13	1:29	0:15	212

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.3 3* column 5] (mm:ss) (6)	Equivalent Buffer time (mm:ss) ( $t_{zu}$ ) = [0.25* 'a'] (7)	$\Psi=0.6,$ $Lq=1.5$  P
NS23-NS22	Up	1	20:00	1:42	1:08	0:15	273
	Down	1	20:00	1:37	1:04	0:15	287
NS22-NS21	Up	1	20:00	2:28	1:39	0:15	193
	Down	1	20:00	2:16	1:31	0:15	208
NS21-EW20	Up	3	20:00	2:37	1:45	0:45	164
	Down	2	20:00	2:36	1:44	0:30	174
EW20-EW19	Up	1	9:17	1:24	0:56	0:15	325
	Down	1	12:46	1:23	0:55	0:15	330
EW19-EW18	Up	1	9:17	1:41	1:07	0:15	276
	Down	1	12:46	1:43	1:09	0:15	270
EW18-EW17	Up	1	9:17	1:29	0:59	0:15	309
	Down	1	12:46	1:38	1:05	0:15	283
EW17-EW16	Up	1	9:17	1:06	0:44	0:15	403
	Down	1	12:46	1:14	0:49	0:15	365
EW16-NS15	Up	3	20:00	3:16	2:11	0:45	136
	Down	2	20:00	2:52	1:55	0:30	159
NS15-NS14	Up	1	20:00	1:08	0:45	0:15	394
	Down	1	20:00	1:14	0:49	0:15	365
NS14-NS13	Up	1	20:00	1:23	0:55	0:15	330
	Down	1	20:00	1:25	0:56	0:15	323
NS13-NS12	Up	2	20:00	1:25	0:56	0:30	295
	Down	2	20:00	1:31	1:01	0:30	277
NS12-NS11	Up	3	20:00	3:09	2:06	0:45	140
	Down	3	20:00	3:07	2:05	0:45	141

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ ) =[0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $L_q=1.5$
							P
NS11-NS10	Up	1	20:00	1:46	1:11	0:15	263
	Down	1	20:00	1:42	1:08	0:15	273
NS10-NS9	Up	3	20:00	2:53	1:55	0:45	152
	Down	3	20:00	2:06	1:24	0:45	198
NS9-NS8	Up	2	20:00	1:14	0:49	0:30	330
	Down	2	20:00	1:23	0:55	0:30	300
NS8-NS7	Up	2	20:00	2:53	1:55	0:30	159
	Down	2	20:00	2:24	1:36	0:30	187
NS7-NS6	Up	1	20:00	3:04	2:03	0:15	157
	Down	1	20:00	3:12	2:08	0:15	150

Appendix D.3: Theoretical capacity of N-S corridor at off-peak hours (T=16hr) (2032-2037) year

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ ) =[0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $L_q=1.5$
							P
NS27-NS26	Up	2	20:00	3:07	2:05	0:30	168
	Down	2	20:00	2:42	1:48	0:30	192
NS26-NS25	Up	1	20:00	1:47	1:11	0:15	299
	Down	1	20:00	1:19	0:52	0:15	395
NS25-NS24	Up	1	20:00	1:28	0:58	0:15	358
	Down	1	20:00	1:25	0:56	0:15	369

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section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25*'a'] (mm:ss) (7)	$\Psi=0.6,$ $L_q=1.5$
							P
NS24-NS23	Up	1	20:00	2:50	1:53	0:15	193
	Down	1	20:00	2:13	1:29	0:15	243
NS23-NS22	Up	1	20:00	1:42	1:08	0:15	311
	Down	1	20:00	1:37	1:04	0:15	327
NS22-NS21	Up	1	20:00	2:28	1:39	0:15	220
	Down	1	20:00	2:16	1:31	0:15	238
NS21-EW20	Up	3	20:00	2:37	1:45	0:45	188
	Down	2	20:00	2:36	1:44	0:30	199
EW20-EW19	Up	1	9:17	1:24	0:56	0:15	372
	Down	1	12:46	1:23	0:55	0:15	377
EW19-EW18	Up	1	9:17	1:41	1:07	0:15	315
	Down	1	12:46	1:43	1:09	0:15	308
EW18-EW17	Up	1	9:17	1:29	0:59	0:15	353
	Down	1	12:46	1:38	1:05	0:15	324
EW17-EW16	Up	1	9:17	1:06	0:44	0:15	461
	Down	1	12:46	1:14	0:49	0:15	417
EW16-NS15	Up	3	20:00	3:16	2:11	0:45	155
	Down	2	20:00	2:52	1:55	0:30	182
NS15-NS14	Up	1	20:00	1:08	0:45	0:15	450
	Down	1	20:00	1:14	0:49	0:15	417
NS14-NS13	Up	1	20:00	1:23	0:55	0:15	377
	Down	1	20:00	1:25	0:56	0:15	369
NS13-NS12	Up	2	20:00	1:25	0:56	0:30	337
	Down	2	20:00	1:31	1:01	0:30	317
NS12-NS11	Up	3	20:00	3:09	2:06	0:45	160
	Down	3	20:00	3:07	2:05	0:45	161

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25*'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS11-NS10	Up	1	20:00	1:46	1:11	0:15	300
	Down	1	20:00	1:42	1:08	0:15	311
NS10-NS9	Up	3	20:00	2:53	1:55	0:45	173
	Down	3	20:00	2:06	1:24	0:45	226
NS9-NS8	Up	2	20:00	1:14	0:49	0:30	377
	Down	2	20:00	1:23	0:55	0:30	343
NS8-NS7	Up	2	20:00	2:53	1:55	0:30	181
	Down	2	20:00	2:24	1:36	0:30	213
NS7-NS6	Up	1	20:00	3:04	2:03	0:15	179
	Down	1	20:00	3:12	2:08	0:15	172

Appendix D.4: Theoretical capacity of N-S corridor at off-peak hours (T=18hr) (2038-2047) year

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33*column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ )=[0.25*'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS27-NS26	Up	2	20:00	3:07	2:05	0:30	190
	Down	2	20:00	2:42	1:48	0:30	216
NS26-NS25	Up	1	20:00	1:47	1:11	0:15	336
	Down	1	20:00	1:19	0:52	0:15	444
NS25-NS24	Up	1	20:00	1:28	0:58	0:15	403
	Down	1	20:00	1:25	0:56	0:15	416
NS24-NS23	Up	1	20:00	2:50	1:53	0:15	218
	Down	1	20:00	2:13	1:29	0:15	274
NS23-NS22	Up	1	20:00	1:42	1:08	0:15	350
	Down	1	20:00	1:37	1:04	0:15	368
NS22-NS21	Up	1	20:00	2:28	1:39	0:15	248
	Down	1	20:00	2:16	1:31	0:15	268

section from-to (1)	Track direction (2)	No. intermediate block section 'a' (3)	Inter-arrival time (mm:ss) (4)	Blocking time from timetable (mm:ss) (5)	Buffer time ( $t_r$ )=[0.33* column 5 ] (mm:ss) (6)	Equivalent Buffer time ( $t_{zu}$ ) = [0.25* 'a'] (mm:ss) (7)	$\Psi=0.6,$ $Lq=1.5$
							P
NS21-EW20	Up	3	20:00	2:37	1:45	0:45	211
	Down	2	20:00	2:36	1:44	0:30	224
EW20-EW19	Up	1	9:17	1:24	0:56	0:15	418
	Down	1	12:46	1:23	0:55	0:15	424
EW19-EW18	Up	1	9:17	1:41	1:07	0:15	354
	Down	1	12:46	1:43	1:09	0:15	347
EW18-EW17	Up	1	9:17	1:29	0:59	0:15	398
	Down	1	12:46	1:38	1:05	0:15	364
EW17-EW16	Up	1	9:17	1:06	0:44	0:15	519
	Down	1	12:46	1:14	0:49	0:15	470
EW16-NS15	Up	3	20:00	3:16	2:11	0:45	174
	Down	2	20:00	2:52	1:55	0:30	205
NS15-NS14	Up	1	20:00	1:08	0:45	0:15	506
	Down	1	20:00	1:14	0:49	0:15	470
NS14-NS13	Up	1	20:00	1:23	0:55	0:15	424
	Down	1	20:00	1:25	0:56	0:15	416
NS13-NS12	Up	2	20:00	1:25	0:56	0:30	379
	Down	2	20:00	1:31	1:01	0:30	356
NS12-NS11	Up	3	20:00	3:09	2:06	0:45	180
	Down	3	20:00	3:07	2:05	0:45	182
NS11-NS10	Up	1	20:00	1:46	1:11	0:15	338
	Down	1	20:00	1:42	1:08	0:15	350
NS10-NS9	Up	3	20:00	2:53	1:55	0:45	195
	Down	3	20:00	2:06	1:24	0:45	254
NS9-NS8	Up	2	20:00	1:14	0:49	0:30	424
	Down	2	20:00	1:23	0:55	0:30	386
NS8-NS7	Up	2	20:00	2:53	1:55	0:30	204
	Down	2	20:00	2:24	1:36	0:30	240
NS7-NS6	Up	1	20:00	3:04	2:03	0:15	201
	Down	1	20:00	3:12	2:08	0:15	194

## APPENDIX E

Population and Unemployment rate forecasted results

Year	Population	Year	Population	Year	Unemployment rate (%)	Year	Unemployment rate (%)
2014	3194969	2033	5040864	2010	27.113	2029	19.0395
2015	3272576	2034	5163308	2011	24.9837	2030	18.9302
2016	3352068	2035	5288727	2012	23.8165	2031	18.8266
2017	3433491	2036	5417192	2013	23.0215	2032	18.7281
2018	3516892	2037	5548777	2014	22.4233	2033	18.6343
2019	3602318	2038	5683558	2015	21.946	2034	18.5447
2020	3689819	2039	5821614	2016	21.5504	2035	18.4591
2021	3779446	2040	5963023	2017	21.2135	2036	18.3771
2022	3871250	2041	6107866	2018	20.9207	2037	18.2984
2023	3965284	2042	6256228	2019	20.6622	2038	18.2228
2024	4061602	2043	6408194	2020	20.4312	2039	18.15
2025	4160260	2044	6563851	2021	20.2225	2040	18.0799
2026	4261314	2045	6723289	2022	20.0324	2041	18.0123
2027	4364822	2046	6886600	2023	19.858	2042	17.947
2028	4470845	2047	7053878	2024	19.6969	2043	17.8839
2029	4579444			2025	19.5475	2044	17.8229
2030	4690680			2026	19.4082	2045	17.7637
2031	4804618			2027	19.2777	2046	17.7064
2032	4921324			2028	19.1551	2047	17.6507