

Addis Ababa University
Addis Ababa Institute Of Technology
School Of Civil And Environmental Engineering



**Assessment of Improvement Areas for Increasing the
Capacity of Ethio-Djibouti Railway Line**

**A Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Railway Civil Engineering**

By

YOHANNES MELKAMU

Advisor

BINIYAM AYALEW (MSc)

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Addis Ababa

The undersigned have examined the thesis entitled ‘**Assessment of improvement areas for increasing the capacity of Ethio-Djibouti railway line**’ presented by **YOHANNES MELKAMU**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

Biniyam Ayalew	_____	_____
Advisor	Signature	Date
Mequanent Mulugeta	_____	_____
Internal Examiner	Signature	Date
Dr. Bikila Teklu	_____	_____
External Examiner	Signature	Date
Dr. Daniel	_____	_____
Chair person	Signature	Date

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I hereby declare that the work which is being presented in this thesis entitled “Assessment of improvement areas for increasing the capacity of Ethio-Djibouti railway line” is original work of my own, it has not been presented for a degree of any other university and all the resource of materials used for this thesis have been duly acknowledged.

Yohannes Melkamu

Researcher

Signature

Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Biniyam Ayalew (MSc)

Adviser

Signature

Date

ABSTRACT

Ethio-Djibouti railway line can support the economic growth of the country by allowing transportation of more goods than now, reduce greenhouse gas emission (environmental friendly), reduce road congestion, allows the country to increase the variety of export goods. This research aims to analyze the capacity issues of Ethio-Djibouti railway line and identify and assess possible capacity improvement areas to satisfy the railway transport demand of Ethiopia for the coming 50years time period.

To attain the objective of the research firstly practical capacity of the existing Ethio-Djibouti railway line is done by UIC405 analytical method; secondly railway transportation demand for both freight and passenger is assessed along the corridor; it's obvious that the capacity of the existing railway will saturate in the future, the saturation year is identified by comparing the practical capacity of Ethio-Djibouti railway line with railway transportation demand analysis done along the corridor. Finally possible capacity expansion plan mainly infrastructure improvement is identified in this research.

The single track section of Ethio-Djibouti railway practically can accommodate 33 trains/day. The section from Dire Dawa to Negad starting from 2030GC; the section from Awash to DireDawa starting from 2036GC and the section from Adama to Awash starting from 2037GC will become saturated and needed capacity improvement.

To satisfy the increasing railway transportation demand along Ethio-Djibouti railway line increasing the number of trains operating on the line can be the solution; but the sections infrastructure capacity wouldn't allow to add more trains in the saturation years.

Therefore, in 2030GC the single track railway from DireDawa to Djibouti; in the year of 2036GC the section from Awash to Dire Dawa and in the year of 2037 GC the railway line section from Adama to Awash should have to be changed to double track in order to fulfill the demand. The double track section from Sebeta to Adama can practically accommodate 64 trains/day but the demand analysis shows that starting from 2059GC the line will become saturated in this case infrastructure expansion is not necessary because it can satisfy the demand on the specified time window.

Key words: capacity, Ethio-Djibouti railway, capacity improvement, UIC405, capacity analysis, railway demand analysis

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CHAPTER 1 INTRODUCTION

1.1 General

The Addis Ababa-Djibouti Railway is a standard gauge railway that links Addis Ababa with the port of Djibouti, providing landlocked Ethiopia with improved railroad access to the sea. The port of Djibouti is critical for Ethiopia's economy, accounting for 90% of Ethiopia's trade in 2016. Ethiopia is focusing on highway construction but it is not keeping up with the growth in demand either, therefore, it is important to see alternative modes to handle the traffic. Ethiopian government increasingly observes railway as an alternative transport mode needed to handle the increasing freight traffic that will accompany sustained economic growth. By virtue of this, railway becomes more desirable mode of transportation and hence, roads and other modes will be relied less and will not be congest.

Railways are important, as they allow transporting passengers and freight across vast distances. Rail lines carry 21 billion passengers and 10 billion tons of freight worldwide annually [1]. Building efficient transportation systems such as railways, can improve both local and global economies by allowing transportation of more goods, reduce greenhouse gas emissions, make highways safer and reduce road congestion.

The railway industry faces four main challenges, which are capacity and congestion, operational efficiency and reliability, structural and competition issues and safety and security.

Ethiopia is the world's fast growing country that has increased its import and export quantity. Due to the reason that, Ethio-Djibouti railway line is the only and economical way to connect with the rest of the world, this railway line may face capacity constraint in a little while.

Nowadays, given the growing pressure from the transportation, improving railway capacity is significant to meet requirements of different customers. Therefore, an approach for maximizing railway capacity while minimizing the operating cost sought to, enable a better use of the existing infrastructure. Development of viable and

successful railways calls for proper planning that involves making the best possible forecast of future transport needs or demand of the corridor.

Therefore, numerous capacity studies must be performed in order to work out what part of extra traffic can be absorbed by the existing infrastructure and how much investment will be required for new infrastructure.

Infrastructure management and train operation are therefore fields of interesting optimization problems; optimization methods from infrastructure side and from train operation side are inevitably integrated. Railways are challenging subject of planning and forecasting worldwide due to a big project size and the uncertainties of future. The optimal capacity usually depends on the condition of the fixed equipment as well as the organization of the train operation.

The aim of this study is to increase the capacity of Ethio-Djibouti railway line to fulfill the railway demand along Ethio-Djibouti corridor.

1.2 Statement of the Problem

The Ethio-Djibouti corridor is the major import and export corridor of the country handling more than 90% of the foreign trade [17]. In Ethiopia, freight growth is expected to continue to be strong and this will continue to exert pressure on the accommodation of freight paths see figure 1. The demand for freight transportation in Ethiopia has been rising reflecting growth in the economy. Such growth will place an increasing pressure on a network seeking to provide capability for growth in both passenger and freight traffic.

The pre-feasibility study conducted by ERC consultants on Ethio-Djibouti railway estimated that with the required number of rolling stock, more efficient services, and an aggressive marketing policy, railway demand could increase dramatically: as a result upon the commencement of the new railway, demand could increase from its present share 5% (between Dire Dawa and Djibouti) per year to 60% share between Addis-Djibouti per year or more.

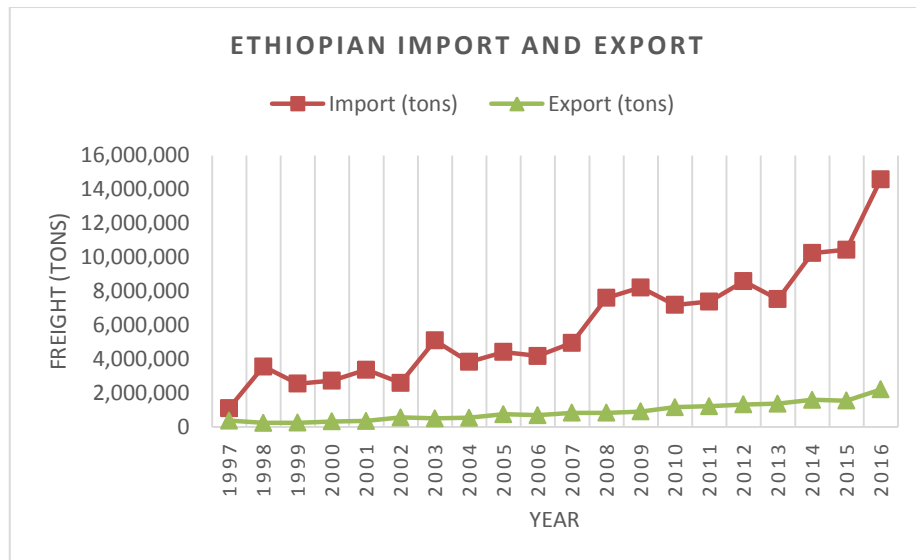


Figure 1 Ethiopian import and export chart 1997-2016 [26]

There are approaches (such as building new lines, installing new signaling system, optimizing the length of block sections and so on) that could bring increased capacity. This research sought for an approach for maximizing railway capacity that can accommodate the increasing freight volume and number of passenger because Ethio-Djibouti railway line is the economical way out to import and export goods.

1.3 Objective of the Research

The study encompasses the following general and specific objectives.

1.3.1. General Objective

The general objective of the research is to identify possible improvement areas to increase the capacity of Ethio-Djibouti railway line to satisfy the country transport demand.

1.3.2. Specific Objective

The specific objective of the research is listed as follows:

- To assess the maximum practical capacity of the Ethio-Djibouti railway line,
- To forecast the freight and passenger transport demand, along Ethio-Djibouti corridor for the coming 50 years,
- To identify the gaps and appraising options to bridge capacity constraints of Ethio-Djibouti railway.

1.4 Methodology

In order to achieve the main aim of the study there are various procedural tasks done in this research and these procedures are discussed as follows;

- First, reviewing of related literatures which focus on railway capacity.
- Developing an appropriate method for achieving the general and specific objective of the research.
- Collecting relevant data about Ethio-Djibouti railway line and import and export data of Ethiopia as well as OD (origin destination) data of passengers.
- Transportation demand of Ethiopia increases year to year therefore, Ethio-Djibouti railway line will face capacity constraint at some year in the future. Identifying the capacity saturation year of Ethio-Djibouti railway line and device economic improvement areas for enhancing the capacity of Ethio-Djibouti railway line to satisfy the country transport demand along the corridor.

1.5 Limitation of the study

Railway capacity is extremely dependent on how it is used it varies with particular mix of trains, changes in infrastructure and operating conditions. Each of these fundamental parameters affects the railway capacity differently. In this research only the infrastructure parameter is considered for increasing the capacity levels of the corridor although train mix, signaling system and operating parameters can enhance the capacity levels of the line. It is suggested that improving existing rail networks through operational means is better; in addition, exploiting existing infrastructure with new technology is even better. This thesis considers analytical capacity analysis method it's a good start to estimate the line capacity however if it is supported by software simulation the results will become more realistic. The reason for this limitation is the immensity and complexity of the research area as well as simulation software is not available.

1.6 Significance of the Study and expected output

As we know, Ethiopia is a landlocked and poor country this Ethio-Djibouti railway line is the critical path for country's import and export. Over 90% of Ethiopian external trades

are conducted through port of Djibouti; to be economical and to attain sustainable development the country must utilize this railway line to its full capacity.

Railways face enormous growth of demand but without enough increase in capacity making railway networks more and more saturated. Therefore, this research aims to identify capacity improvement areas to increase the capacity of Ethio-Djibouti railway line.

1.7 Thesis layout

This thesis consists of six chapters; each chapter presents a section of the work that has been completed and details of these chapters have been summarized below:

Chapter 1: represents background of research followed by problem statement, research objective, methodology applied, significance and expected output, and thesis outline.

Chapter 2: review of related literatures which focused on railway capacity concept and definitions, main parameters of capacity, methods to measure railway capacity and railway capacity optimization presented in this chapter.

Chapter 3: describes research design and methodology which is conducted in this thesis.

Chapter 4: This chapter is the core of the thesis which analyses the theoretical and practical capacity of Ethio-Djibouti railway line and railway demand analysis along Ethio-Djibouti railway line is covered. Saturation year of the line with capacity optimization areas are discussed.

Chapter 5: conclusions, recommendations and recommended future research are stated.

CHAPTER 2 LITERATURE REVIEW

2.1 Railway Capacity Concepts and Definitions

Railway capacity is not deterministic. It is difficult or even impossible to define railway capacity in a consistent way. The capacity of a railway system is not easily determined or even denied. This is a consequence of the interdependencies in railway systems as capacity depends not only on the infrastructure, but also on operational constraints and the rolling stock used [2].

The reason that it is difficult to define railway capacity is that there are several parameters that can be measured; it varies with changes in infrastructure, particular mix of trains and operating conditions. Although railway capacity is complex to understand, it is essential for determining the amount of traffic that can be moved over a rail system and the degree of service and reliability that can be expected. Railway capacity has been defined by many scholars differently over time as follows.

In 1979 Kahan defined railway capacity as the ability of the carrier to supply required the necessary services within acceptable service levels and costs so as to meet the present and projected demand for such services [19]. In 1993 Skarstaeterhagen defined, the capacity of a railway line is the ability to operate trains with an acceptable punctuality [20]. In 1999, Krueger defined railway capacity as 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 [21]. In 2002 Wood, Robertson defines capacity as the only true measure of capacity therefore is the range of timetables that the network could support, tested against future demand scenarios and expected operational performance [22].

Hansen in 2004 defined capacity as the capability of the infrastructure to handle one or several timetables [18]. Longo, Stok in 2007 defined capacity as the maximum number of trains which can pass a given point on a railway line in a given time interval [23]. Oetting in 2007 defines capacity as the ratio between the chosen time window and the sum of average minimum headway time and required average buffer time [24]. In 2008, Barter defines capacity as the number of trains that can be incorporated into a timetable that is conflict-free, commercially attractive, compliant with regulatory requirements, and can be operated in the face of anticipated levels of primary delay whilst meeting agreed performance targets.

According to International Union of Railways (UIC) code 406 Railway Capacity is: "the total number of possible train paths in a defined time window, considering the actual path mix or known developments, respectively", UIC also emphasizes that the capacity is affected by interdependencies and the interrelationship between the four major elements of railroad as shown in Figure 2 [2].

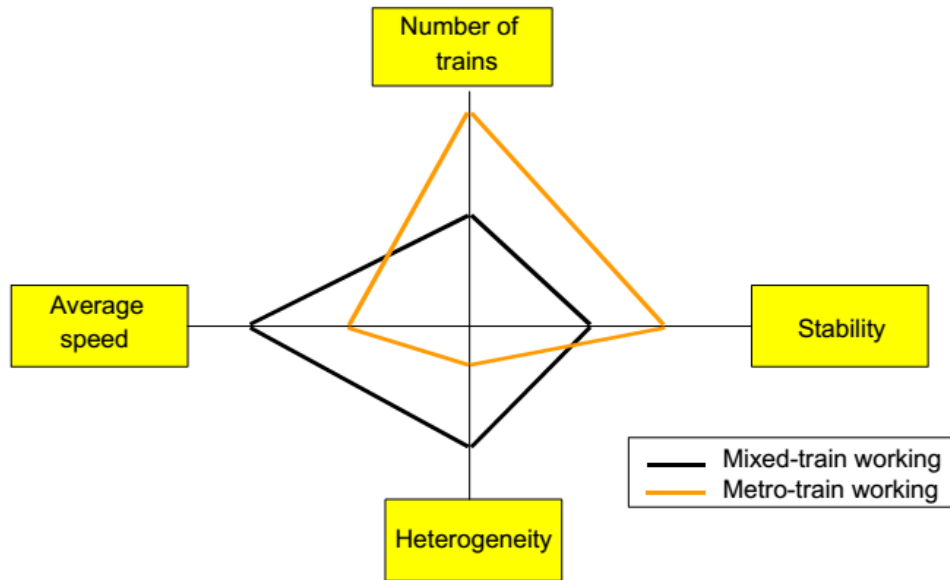


Figure 2 Capacity balance according to UIC code 406 definition

The above definitions of railway capacity show (although many definitions are alike) that there is great variation in how railway capacity can be defined. There is no solid definition of capacity and the rail infrastructure capacity concerns and expectations vary between different points of view by railroad customers, infrastructure planner, timetable planner, and railroad operators.

2.2 Types of Railway Capacity

Different types of railway capacity are usually used in the railway environment such as;

2.2.1 Theoretical Capacity

It is 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. Theoretical Capacity is calculated using an empirical formula. This number is relatively easy to generate (it depends on the longest distance between crossing stations

for single-track lines or the minimum headway for double-track lines). It is not possible to actually run the number of trains that can be worked out mathematically [1].

According to UIC, the "Theoretical Capacity" is the absolute maximum capacity which can be achieved subject to: Absolute train-path harmony (the same parameters for majority of trains); Minimum headway (shortest possible spacing for all trains); providing best quality of service [13]. UIC also recognizes that it is almost impossible to achieve theoretical capacity in practice.

2.2.2 Practical Capacity:

It is the practical limit of "representative" traffic volume that can be moved on a line at a reasonable level of reliability. The "representative" traffic reflects the actual train mix, priorities, traffic bunching, etc. It is the capacity that can permanently be provided under normal operating conditions. It is usually around 60%-75% of the theoretical capacity, which has already been concluded by Kraft (1982). Theoretical capacity is the maximum capacity that can be utilized under perfect circumstances and practical capacity is the capacity that can be utilized in daily operation [2].

Generally, railway managers know that scheduling as many trains as theoretical capacity is not viable. However, they must make the best use of the expensive railway infrastructures. For this purpose, the application of simulation methods seems to be a convenient way to evaluate the trade-off between capacity and reliability. However, an in-depth analysis using simulation methods must be done to obtain practical capacity measures. A clear distinction should be made between theoretical and practical capacity (see Fig. 3). Practical capacity is a more realistic measure of railway capacity, which takes into account reliability and operational aspects.

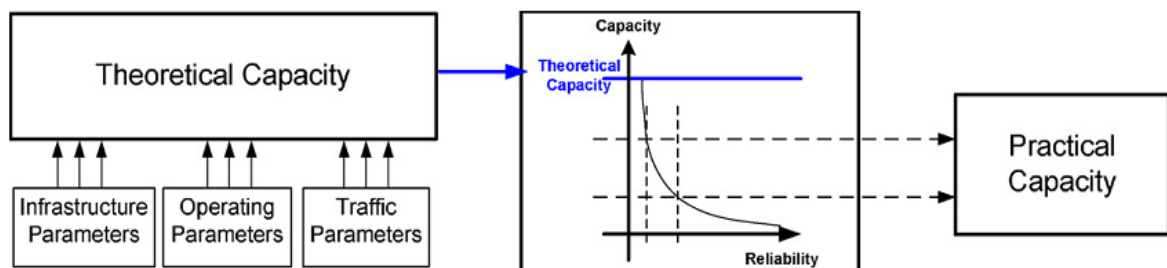


Figure 3 Reliability is the most influential parameter between theoretical capacity and practical capacity [1]

2.3 Main Parameters of Railway Capacity

Railway capacity is extremely dependent on how it is used. Railway capacity varies with particular mix of trains, changes in infrastructure and operating conditions. These are some of the fundamental factors that affect it. Parameters of railway capacity is illustrated graphically, see figure 2.

2.3.1 Infrastructure Parameters

A) BLOCK AND SIGNALING SYSTEM:

The signals help extends the train driver's visibility, so it allows greater speeds. Its role is to keep trains at a safe distance. Two types of systems: fixed-block signaling + moving-block signaling.

Fixed-block-signaling system: The position of each train is known only by the block section(s) that it occupies. The separation between trains is maintained by imposing restriction that at most one train occupies each block section at a time.

Moving-block signaling system: The position of each train is known continuously, thus permitting better regulation of the relative distances. This requires an efficient communication system between line signals, cabs and control centers.

B) SINGLE/DOUBLE TRACKS:

It is not as simple as multiplying the number of tracks. A double-track line usually has a capacity of more than two times rather than a single track; however, a four-track line rarely increases capacity by more than 50% over a double line. Adding a second track may not eliminate the problem because the station is the real bottleneck.

C) TRACK STRUCTURE AND SPEED LIMITS:

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

D) LENGTH OF THE SUBDIVISION:

If the length of the subdivision increases, so does the transit time of trains. "Bottleneck" (or the most constrained line section) traditionally introduced as the bounding factor to

the overall capacity. Capacity can potentially increase as the line sections between the stations become shorter, and more auxiliary tracks are available at the station to allow crossing and overtaking operations.

2.3.2 Traffic Parameters:

A) NEW OR EXISTING LINES:

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

B) TRAIN MIX:

Railway capacity is very much dependent on traffic mix. The ideal case is when all trains are the same or have the same speed. As the mixture of different trains' increases, more interference is generated. Besides maximum speed, other rolling stock characteristics such as acceleration and deceleration are also important.

C) PRIORITY:

Train priorities decrease capacity because priority trains are given preferential treatment over lower priority trains, which results in increased delays. As a rule, the greater the number of priority classes, the less capacity is available.

2.3.3 Operating Parameters:

A) TRACK INTERRUPTIONS:

Track interruptions can be planned events (maintenance times, commercial stops, etc.) and unplanned events (train failures, broken rails, etc.) that take a track out of service. These interruptions directly reduce the number of hours available to move trains.

B) QUALITY OF SERVICE, RELIABILITY, OR ROBUSTNESS:

Random minor disturbances and failures occur in the real management reducing the theoretical capacity. So, some buffer times must be added to design a robust timetable. A balance between service reliability and physical capacity is needed to find the economically optimal level of capacity. The average delays increase exponentially when

the number of trains exceeds the saturation level and then network reliability is lost. Increasing the number of trains over the saturation level is not profitable.

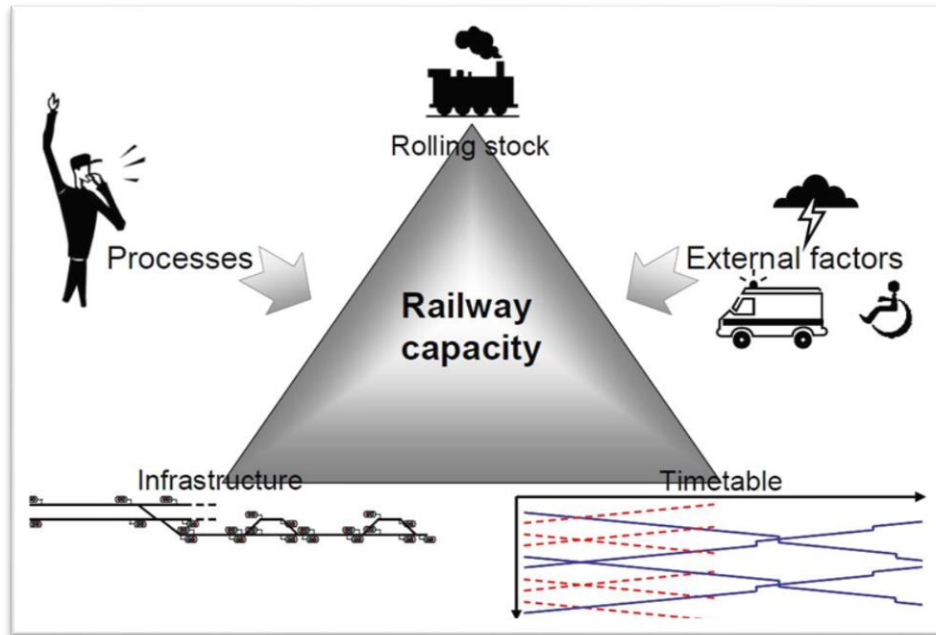


Figure 4 Parameters of railway capacity [7]

2.4 Measuring Railway Capacity Utilization

Railway infrastructure is a scarce and expensive resource, which should be allocated and utilized as efficiently as possible. Capacity utilization should be quantified to analyze how well it is utilized. There are two perspectives to quantify railway capacity these are differences in requirements (qualitative) and capacity metrics (quantitative).

2.4.1 Metrics of capacity utilization

Different metrics can be used for measuring capacity utilization. Here, metrics of capacity utilization classified in three main categories of throughput (such as number of trains, tons, train-miles), level of service (LOS) (terminal/station dwell, punctuality/reliability factor, and delay), and asset utilization (velocity, infrastructure occupation time or percentage) [8]. Strengths and weaknesses of each type of metric are briefly summarized in Table 1.

A. THROUGHPUT

Throughput is a measure of how much material can be transported over a route in a specific period of time. Throughput can be measured in trains, tons or cars. The number

of trains per day is often used when discussing capacity on a route and has the advantage of being intuitive, easily measured and understandable by the general public.

The key weakness of using throughput as a capacity metric is its variability depending on the specific traffic and operations. Different train types use different amounts of capacity, carry different amounts of cargo and have different numbers of cars [15].

B. LEVEL OF SERVICE

Level of service is a measure of the reliability and timeliness of transportation. Long travel times or unreliable deliveries are unacceptable to shippers. The units of level of service are terminal dwell, punctuality, reliability and train delay. Level of service is an indirect measure of capacity since it only measures the effect of insufficient or excess capacity and not capacity itself. To shippers, level of service is the most important metric of capacity [15].

C. ASSET UTILIZATION

Asset utilization measures the usage of the railroad's assets. A railroad's assets include the infrastructure, rolling stock, motive power and personnel. Railcars and locomotives are costly to purchase and maintain and railroads want to make efficient use of them. A railroad can move sufficient cargo at a high level of service but still be underutilizing its assets. Asset utilization, like level of service, is an indirect measure of capacity.

Occupation time of infrastructure can be a measure of asset utilization but is mainly used for passenger focused railroads that run through timetable as previously discussed. Velocity is useful for measuring asset utilization; it is a weak measure when it comes to capacity [15].

Table 1 Analyzing metrics of capacity utilization [16]

Category	Examples		Description	Strengths	Weaknesses
Throughput	Macro	Number of trains, train-km	How many passengers can be transported over a period of time	Easily measurable and understandable	Does not reflect quality of service
	Micro	Number of passengers, Passenger km, seat-km			
Level of service (LOS)	Average delay, percentage of cancelled or late trains		Measures reliability and timeliness	Important for general public	Indirect measure heavily depends on how saturated the network is. Does not take scheduled waiting time and timetable supplements into account which are a waste of time for passengers
Asset utilization	Macro	Capacity Utilization Index (CUI), Total time utilization of infrastructure (UIC 406 method), Number of trains per km of infrastructure in a given time period	Estimating how saturated the network is	Important to estimate how efficiently the infrastructure is utilized	A measure of macro capacity utilization, does not reflect the actual value of trains, load factor and how close the passengers are standing (micro capacity utilization)
	Micro	Load factor	Estimating how crowded the passenger trains are	Important to estimate how efficiently the rolling stock is utilized and the level of comfort for passengers	A measure of micro capacity utilization, does not reflect how saturated the network is (macro capacity utilization)

2.4.2 Different Views of Railway Capacity

Due to differences in requirements, capacity is viewed differently from the position of the market, infrastructure planning, timetabling and operations. These are summarized in table. 2.

Table 2- Different views of capacity [2]

Market (customer needs)	Infrastructure planning	Timetable planning	Operations
<ul style="list-style-type: none"> • expected number of train paths (peak) • expected mix of traffic and speed (peak) • infrastructure quality need • journey times as short as possible • translation of all short and long-term market induced demands to reach optimized load 	<ul style="list-style-type: none"> • expected number of train paths (average) • expected mix of traffic and speed(average) • expected conditions of infrastructure • time supplements for expected disruptions • maintenance strategies 	<ul style="list-style-type: none"> • requested number of train paths • requested mix of traffic and speed • existing conditions of infrastructure • time supplements for expected disruptions • time supplements for maintenance • connecting services in stations • requests out of regular interval timetables (system times, train stops, ...) 	<ul style="list-style-type: none"> • actual number of trains • actual mix of traffic and speed • actual conditions of infrastructure • delays caused by operational disruptions • delays caused by track works • delays caused by missed connections • additional capacity by time supplements not needed

While capacity demands from the market standpoint are oriented towards satisfying peak values, infrastructure planning by contrast must be oriented towards a definition of capacity that, on average, guarantees profitable utilization of the infrastructure.

From a timetable point of view, capacity considerations bring together a given infrastructure and existing demands for train paths. From an operational point of view, on the other hand, the capacity situation is always in flux and depends on current infrastructure availability, progress with building measures, delays, diversions and the number of additional trains.

Each of these different situations is correct in terms of its own specific background. The parameters mean, however, that each viewpoint leads to a different capacity-requirement result.

2.5 Methods to Evaluate Railway Capacity

Numerous approaches and tools have been developed to determine rail line capacity; however, unlike the highway capacity analysis domain, there is no commonly accepted standard for railway capacity measurement.

The literature classifies capacity analysis approaches and methodologies in several different ways. Although the approaches differ, the input typically includes infrastructure and rolling stock data, operating rules and signaling features.

Abril, et al. [1] classified the capacity methodologies as analytical methods, optimization methods, and simulation methods. Joern Pachl divided the capacity methodologies into two major classes: analytic and simulation. Overall, the analytical and simulation methods are the most common methods found in many literatures.

For our review, the most relevant methods can be classified as: Analytical Methods, Optimization Methods, Simulation Methods and combination of Analytical and Simulation methods.

Although the term "combined methodology" was not used commonly in the reviewed literature, it was added as a new class to address the fact that many reviewed studies took advantage of both analytical and simulation methods.

In some cases, analytical models are called optimization methods or parametric models, taking advantage of different modeling features, such as probabilistic distribution or timetable optimization. The latter method, timetable optimization, is typically achieved by using specialized software or simulation tools.

2.5.1 Analytical Methods:

The analytical approach typically uses several steps of data processing through mathematical equations or algebraic expressions. These are very simple models aimed at determining a preliminary solution. They usually obtain theoretical capacities and determine practical capacities either as a percentage of the theoretical capacity or by including regularity margins when they calculate the theoretical capacity [1]. Analytical methods can be conducted with or without specific software [13]. From several analytical methods the most common one is UIC 405 methods. Analytical methods can also be used for reference or comparison. Analytical methods for computing railway line capacity may be a good start for identifying bottlenecks and major constraints; however, analytical results vary from one method to another depending on what type of parameters they model. Furthermore, analytical models are very sensitive to parameter input and train mix variations.

2.5.1.1 UIC Leaflet 405

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); 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 405 OR, 1996) that establish a link between railway capacity and railway quality [1].

$$C = \frac{T}{t_{fm} + t_{zu} + t_r} \dots\dots\dots \text{(UIC Leaflet 405)}$$

Where C is the capacity of a section in number of trains in period T; t_{fm} is the average time span at minimal sequence of trains; t_r is the running time margin; and t_{zu} is the added time.

2.5.1.2 UIC Leaflet 406

They are designed to provide more strategic methods for solving the railway capacity problem and provide much better solutions than purely analytical formulae. Optimization methods for evaluating railway capacity are based on obtaining optimal saturated timetables. This method obtains line capacity by scheduling a maximum number of additional train services in a timetable (starting with either an empty timetable or with an initial base timetable).

The International Union of Railways proposes a new method that is included in the framework of the optimization methods (UIC Leaflet 406, 2004), which is based on a timetable compaction method. Capacity consumption on railway lines depends on both the infrastructure and the timetable. Therefore, the capacity calculation according to the UIC 406 method is based on an actual timetable. To evaluate the capacity utilization, it is necessary to know both the infrastructure and the timetable. Therefore, the first steps of evaluating the railway capacity are to build up the infrastructure and create/reproduce the timetable (see all the work procedure in fig 5).

To evaluate the railway capacity according to the UIC 406 method, the railway network has to be divided into line sections. For each line section the timetable has to be compressed so that the minimum headway time between the trains is achieved [4].

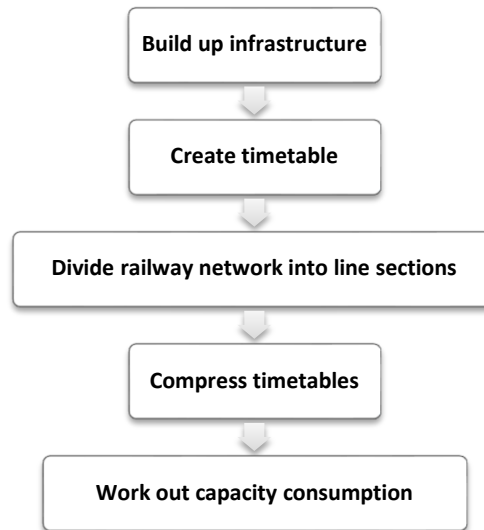


Figure 5 Workflow of the UIC 406 method [2]

When the timetable has been compressed it is possible to work out the capacity consumption of the timetable by comparing the cycle times.

2.5.2 Simulation Methods

Simulation is an imitation of a system's operation which should be as close as possible to its real-world equivalent [13]. Common software used in this category are: Multi-Rail (U.S), RAILSIM (U.S), Open-Track (Switzerland), SIMONE (Netherland), Rail-Sys (Germany), DEMIURGE (France), RAILCAP (Belgium), and CMS (UK)

Multi-Rail (Multimodal Applied Systems) has a full train simulation capability, which shows train conflicts in detailed graphical and tabular formats. The user can define the conflict rules within the track manager, when defining the various characteristics of the track arcs and switches [1].

SIMONE (In control Enterprise Dynamics) is a simulation model for rail- way networks. It can support determination of the robustness of a timetable, trace and quantification of bottlenecks in a network, and analysis of cause and effect relations when delays emerge [1].

Open Track (Open Track Railway Technology) is a simulation tool to answer questions about railway operations. It calculates train movements under the constraints of the signaling system and timetable. It also handles simulation where random generators produce different initial delays and station delays. It was developed at the Swiss Federal Institute of Technology Zurich [18].

2.5.3 Combined Analytical-Simulation Approach

In the combined approach, simulation tools are used to evaluate and understand the capacity bottlenecks through the corridor, and analytical methods are developed to improve the capacity utilization levels. The process of applying simulation-analytical practices may be repeated by the research team until an acceptable set of outputs and alternatives is found [13].

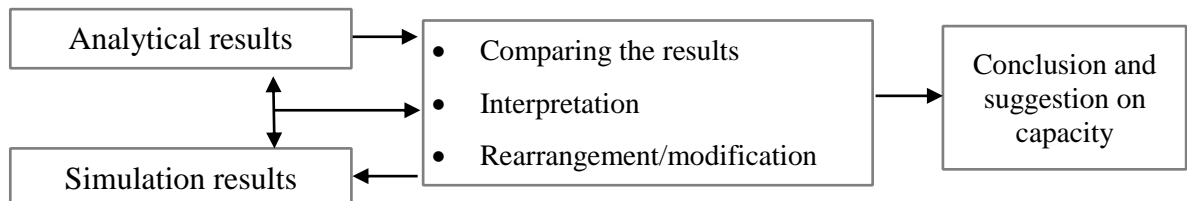


Figure 6 - Basic diagram of combined analytical-simulation approach to evaluate capacity

In conclusion, analytical methods may be a good start for optimization methods. Combined analytical-simulation approach is best practice to get more accurate results.

2.6 Railway Capacity Optimization

Railway capacity is a scarce resource that has to be utilized in the best way possible to satisfy demand and provide the best service for passengers and freight customers [2]. Optimizing the use of railway infrastructure is a complex and difficult task. Therefore, numerous capacity studies must be performed in order to work out what part of extra traffic can be absorbed by the existing infrastructure and how much investment will be required for new infrastructure.

Many railroad lines are approaching the limits of practical capacity, and the estimated future demand is projected to increase 88% by 2035 [6]. Therefore, identifying a good multiyear capacity expansion plan has become a particularly timely and important objective for railroads. Line capacity is, in essence, what the infrastructure managers have to sell as their final product [1].

Before going to describe railway optimization methods firstly we have to see capacity challenge throughout the world. Since the research concentrates on the optimization of Ethio-Djibouti railway line we have to analyze the import and export trade of Ethiopia because this is the main corridor for this trade. Finally, different optimization methods are elaborated.

2.6.1 Worldwide Railway Capacity Challenge

Expansion of railroad infrastructure has not kept up with the growth in passenger and freight demand in recent years leaving many railroads around the world with the “capacity challenge”. In the European Union, since 1995, many railroads have had considerable growth in passenger-km and freight ton-km.

The fastest growth in passenger-km since 1995 belongs to Great Britain (42%), Ireland (41%), Belgium (40%), France (34%) and Spain (28%) and the fastest growth in freight ton-km belongs to Great Britain (61%), Switzerland (57%), Austria (43%), Hungary (33%) and Germany (30%) [15].

These trends have caused saturated railroad networks in many European railroads and continuous growth trends would exacerbate the situation in coming years. The same trends can be seen in North American railroads. The US Department for Transport estimates that total railroad freight tonnage will increase 88% by 2035 requiring an investment of \$148 billion for infrastructure expansions. Without any improvements, 25% of primary corridors would operate at or near capacity and 30% above capacity [15].

One consequence of the globalization of the economy and the increasing integration of the international economies is a considerable growth in the entire transport sector. During the 1990's, many countries began to suffer from congestion in certain areas and on certain routes. Nowadays, there is no doubt about the congestion of the transport situation in some countries. The problem is now beginning to threaten economic competitiveness. Greater economic development cannot take place in the current transport scenario unless ambitious measures are taken. Revitalizing the railways is one of the principal measures [1].

Railways all over the world are increasingly experiencing capacity constraints. In North America, railway freight traffic has increased nearly 30% over the past 10 years, and this demand is projected to increase another 88% by 2035 [6].

2.6.2 The Growth of Freight and passenger Transportation in Ethiopia

According to the plan of relevant state institutions in Ethiopia, under the premise of considering the Ethiopia country's sustained economic growth in the future, the lowest GDP growth is 7%, with an annual growth target of 10%. The forecast for the next five

years is based on the growth rate of 10.4% for the minimum and 13.4% for the maximum as specified in the Growth and Transition Program. These two values are considered as extreme values, the middle value will be taken considering the elasticity of trade to GDP growth, and the future import and export forecast are shown in the table below.

Table 3 the forecasted value of Ethiopia’s future import & export growth rate

Predicted level	Annual growth rate	Practical growth rate					
		2009-2020		2021-2030		2031-2040	
		Export	Import	Export	Import	Export	Import
High	13.4	16	14	14	12	12	12
Medium	12.0	14	12	12	10	10	10
Low	10.4	12	10	10	8	8	8

Source feasibility study of Eth-Djibouti railway

Based on the above forecast on the growth rate of Ethiopia economic development and foreign trade, it can be inferred that the foreign trade volume through Djibouti Port is shown in the following table.

Table 4 foreign trade volume through Djibouti port source feasibility study of Eth-Djibouti railway

Import/Export	Item	2015	2020	2025	2030	2035
Import	Petroleum	173	316	576	681	806
	Dry goods	69	229	400	511	653
	Container	296	336	382	742	1441
	others	104	251	603	1001	1662
	Subtotal	642	1132	1994	2935	4320
Export	Coffee	11	20	36	51	72
	Rapeseed	12	22	41	58	82
	Dry peas	19	35	64	91	128
	others	38	77	155	279	500
	Subtotal	80	154	296	478	772
Import & Export total		722	1286	2290	3413	5092

Passenger transport volume: Travelling scale of passenger traffic transport can be estimated on the basis of population number and travel rate per capital. Service of the newly constructed railway covers 7 regions, 2 main administrative areas in the city, 11 districts, with a population of 20 million, which is 28% of the total population in Ethiopia, as well as major cities including Addis Ababa, Dire Dawa, Adama, Bishoftu, Metehara, Awash, Chiro, Harar and the industrial and commercial center of Haromaya.

2.6.3 Railway capacity Optimization Methods

Optimizing the use of railway infrastructure is a complex and difficult task. Therefore, numerous capacity studies must be performed in order to work out what part of extra traffic can be absorbed by the existing infrastructure and how much investment will be required for new infrastructure.

Capital expansion is a very costly means of increasing railway capacity in spite of this fact that capacity consumption can be measured by compressing the timetable graphs as much as possible for the line section and then using the compression ratio as a measurement of the capacity consumption. UIC406 uses the following steps to optimize the railway capacity.

- Compacting a previous timetable and studying the available capacity
- Obtaining alternative saturated and consistent timetables
- Saturating a previous timetable with new trains

Other improvement areas are somehow a costly method of capacity optimization as compared to UIC406 timetable saturation method. These improvement areas focus on optimizing the railway parameters such as infrastructure, train capacity and train traffic that will be presented can be divided into three different groups. Capital expansion is a very costly means of increasing capacity. A more cost-effective solution is to manage the existing capacity more effectively using computer-based decision support systems.

2.6.3.1 Optimization of the Infrastructure:

Infrastructure optimization is a very costly means of increasing capacity. Number of tracks in a section is a basic parameter affecting capacity. One way to improve capacity is to increase the number of tracks in a section. The distance between two crossing stations or two passing stations is a critical parameter with impact on capacity. In single track sections, trains can only cross or overtake other trains in stations and in double track sections fast trains can only overtake slower trains in stations [5]. Maximum speed determines the journey time and the block occupation time.

To increase the capacity of our railway network by optimizing the infrastructure we have to improve or upgrade on one or more of the infrastructure parameters such as; Length of the sub division, Track structure and speed limits, Network effects, Definition of lines, routes, Number of tracks, Block and signaling system.

2.6.3.2 Optimization of Train Capacity:

This improvement area is related to the optimization of train capacity. In order to analyze this concept, it is necessary to consider several aspects. The rolling stock features such as traction power, braking capability, length and weight of the trains, among others, which determine the running time. The maximum allowed load per train is constrained by train length and weight, both of them limited by legislation. In addition, maximum weight is also dependent on geographical and infrastructural conditions as well as engine power.

2.6.3.3 Peak Reduction of the Train Traffic:

It must be noted that the reference time used to determine railway capacity has an impact on railway capacity. At present most cargo trains of the world operated in nightly timetables what is associated to increased expenses if compared with daily transport.

2.7 Conclusion

In this literature review the term capacity, its different types, the methods to evaluate it, the main parameters affecting it, measuring railway capacity utilization, and railway capacity optimizations as well as its importance in the railway sector have been covered.

A variety of techniques have been used for capacity analysis such as analytical, optimization, simulation and combined (analytical and simulation) methods. Analytical methods for computing railway line capacity may be a good start for identifying bottlenecks and major constraints; however, analytical results vary from one method to another depending on what type of parameters they model. Furthermore, analytical models are very sensitive to parameter input and train mix variations.

The UIC 406 capacity method can be used in an analytical way determining the capacity consumption as the sum of the occupation time, buffer time, and time supplements. This sum is then divided by the time window observed. In addition to the analytical way of determining the capacity consumption, capacity consumption can be measured by compressing the timetable graphs as much as possible for the line section and then using the compression ratio as a measurement of the capacity consumption.

Although the UIC 406 capacity method is a straightforward and fast method to evaluate railway capacity, the method has paradoxes. The less capacity utilization by dividing the line section into smaller line sections due to the overtaking is a paradox of the UIC 406 method. Another paradox of the UIC 406 method is that an extra train can result in less capacity consumption [4].

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1 General

Research methodology provides means and ways of breaking through problems to create a better understanding and to achieve a comprehensive solution that meet the aims and objectives laid in place as the goal of a study. It provides researchers means of tackling problems. It provides means of locating solution to any defined problem or offset situation.

In recent years, most railway network of the world faces enormous growth but without enough increase in capacity making railway networks more and more saturated. In order to utilize Ethio-Djibouti railway line to its full capacity firstly capacity analysis must be done.

Generally speaking, there are two main approaches to improve the capacity levels; either by applying new capital investment toward upgraded or expanded infrastructure, or by improving operational characteristics and parameters of the rail services. In either approach, it is necessary to assess and analyze the benefits, limitations and challenges of the approach, often done through capacity analysis.

Railway capacity analysis is an important approach to determine whether the network can handle an intended traffic flow or not. It's practically impossible to use the full absolute capacity of any railway line. Therefore, we have to determine its practical capacity as a percentage of theoretical capacity by referring the standard, which are specified by UIC.

It is obvious that many railways face capacity constraint if the existing infrastructure does not hold the increasing demand of transportation, therefore identifying a good multiyear capacity expansion plan has become timely and important. This is the main objective of this research.

The following flowchart illustrates a step- by- step procedures, which are followed while conducting this research.

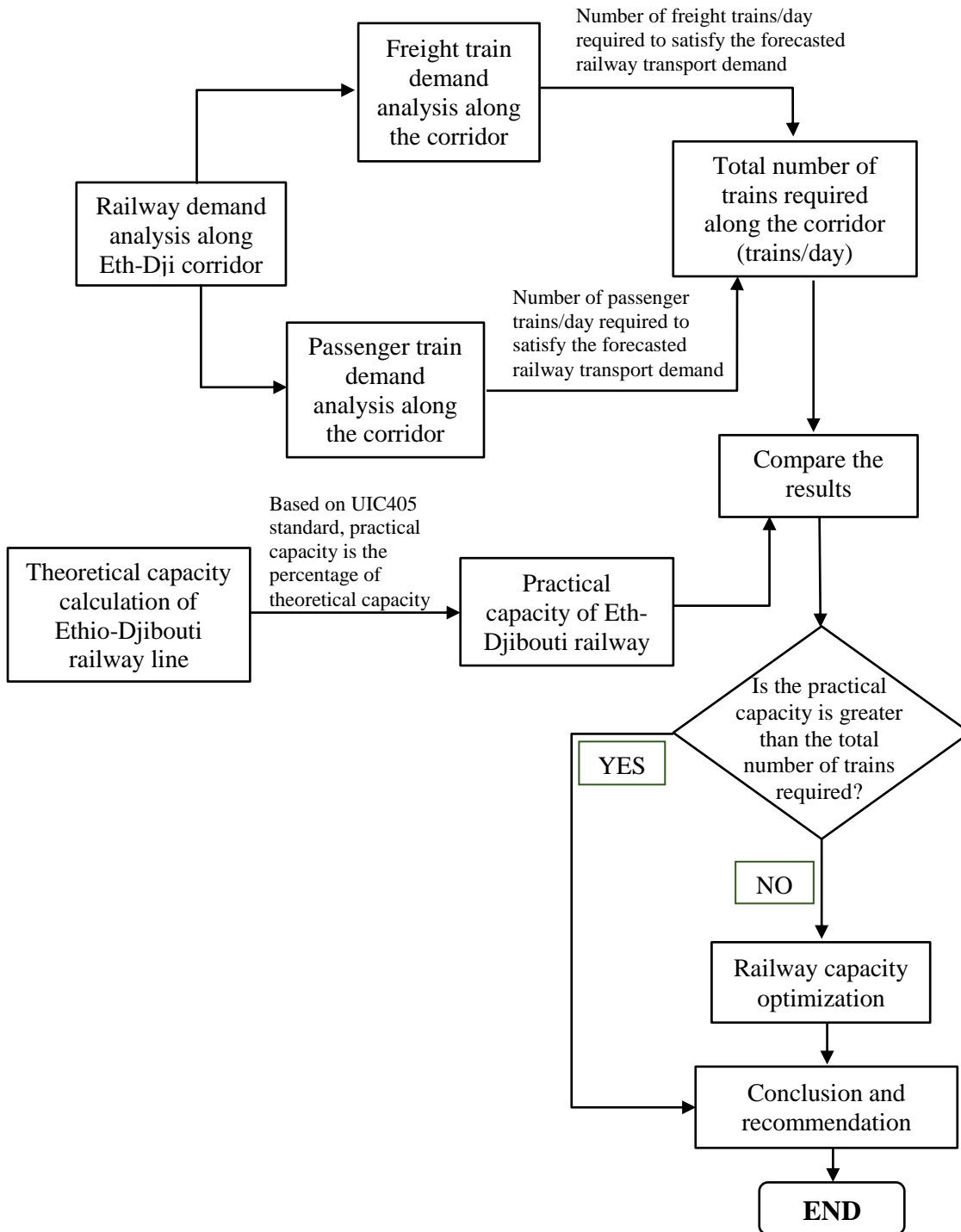


Figure 7 Flow chart showing the methods used in this study

3.2 Method of Analysis

Numerous approaches and tools have been developed to determine railway capacity; however, unlike the highway capacity analysis domain, there is no commonly accepted standard for railway capacity measurement. The most relevant approaches to evaluate railway capacity can be classified according to their methodology, the required data and

the detail level of estimating results. Analytical methods describe the problem by means of mathematical formulae and may represent a good start for identifying major capacity constraints; they are mostly applied for determining a preliminary solution.

The most relevant methods, which are used in this thesis, are described below.

3.2.1. Theoretical capacity of Railway line [UIC 405]

Analytical capacity analysis method (UIC 405 method) this approach typically uses several steps of data processing through mathematical equations or algebraic expressions and is often used to determine a solution for the problem (theoretical capacity).

According to UIC, the "Theoretical Capacity" is the absolute maximum capacity which can be achieved subject to.

- Absolute train-path harmony (the same parameters for majority of trains)
- Minimum headway (shortest possible spacing for all trains)
- Providing best quality of service

UIC proposed an analytical method [UIC, 1983], known as the UIC formula:

$$C = \frac{T}{t_{fm} + t_{zu} + t_r} \quad (1)$$

Where:

- C = capacity (number of trains operated in the time T)
- T = 1440 minutes (for one day)
- t_{zu} = additional time, it is added to take in account the fact that the capacity decreases when the number of sections increases.
- t_{zu} is an extra time based on the number a of the intermediate block sections on the line and calculated by means of the formula $t_{zu} = 0.25 * a$. where 'a' is the number of block sections along the railway line (a block section can be defined as a section within/protected by signals, i.e., each track, in a fixed-block train control & signaling system, is divided in block sections of fixed length (e.g. 2 km) in case of long distances between consecutive stations (more than 3-4 km) and evaluating the occupation time of the resulting block intervals; for safety reason, can be occupied only by a train per time and are thus protected by

signals); this parameter takes into account that the increase of capacity on the determinant section, following its division into more block sections, is less than proportional to the reduction of the travel time.

- t_r = running time margin is a breathing space added to train headways to reduce knock on delays and to achieve an acceptable quality of service. The UIC proposed two expressions for this extra time margin:

$t_r = 0.67 \times t_{fm}$, when the desired utilization of railway infrastructure is 60%

$t_r = 0.33 \times t_{fm}$, when the desired utilization of railway infrastructure is 75%

- t_{fm} = average of minimum train headways.

$$t_{fm} = \frac{\sum n_i * n_j * t_{fij}}{\sum n_i * n_j} (\text{min/train}) \quad (2)$$

Where:

- t_{fij} is the minimum headway between a trains of type j following a train of type i. (min/train)
- n_i number of trains of type i,
- n_j number of trains of type j, The time table is required to know the sequence case where one train of type j follows one train of type i.

The exact calculation of t_{fm} takes into account the order of dispatch of trains belonging to different speed classes considering, for example, to have only two type of trains (slow and fast) with different allowed speed on the line, the minimum headway on the line will be different considering the four possible successions of trains: fast-fast, slow-slow, fast-slow and slow-fast. The time table is required to know the sequence case where one train of type j follows one train of type i.

This method lets an efficient estimation of the capacity of a line and it can be used as a reference measure and for identifying bottlenecks too.

This method lets an efficient estimation of the capacity of a line and it can be used as a reference measure and for identifying bottlenecks too. To work on analytical capacity analysis the line must be divided in to line sections according to number of tracks and position of each station.

3.2.2. Practical capacity calculation methods

Practical Capacity represents the practical limit of the number of trains (usually considering the current train mix, priorities, traffic bunching, etc.) that can be moved on a line in order to guarantee a reasonable level of reliability. It is a more realistic measurement than theoretical capacity. It is calculated based on the standard set by UIC. The ratio which proportionate practical and theoretical capacity according to UIC405 is illustrated in table 6.

Table 5 Standard values of capacity utilization UIC 405 [2]

Type of line	Peak hour	Daily period	Comment
Dedicated suburban passenger traffic	85%	70%	The possibility to cancel some services allows for high levels of capacity utilization.
Dedicated high speed line	75%	60%	Can be higher when number of trains is low (smaller than 5 per hour) with strong homogeneity.
Mixed-traffic lines	75%	60%	Can be higher when number of trains is low (smaller than 5 per hour) with strong heterogeneity.

3.2.3. Demand Forecasting

The purpose of demand forecasting is to use the best available information to guide future activities toward organizational goals. Forecasting methods can be classified as qualitative or quantitative. Qualitative methods generally involve the use of expert judgment to develop forecasts. Such methods are appropriate when historical data on the variable being forecast are either not applicable or unavailable. Quantitative forecast methods can be used when the following conditions are satisfied such as past information about the variable being forecast is available; if the information is quantified; it's reasonable to assume that the pattern of the past will continue into the future.

Majority of quantitative approaches fall in the category of time series analysis. Analysis of the time series identifies patterns. Once the patterns are identified, they can be used to develop a forecast. One of the best known quantitative demand forecasting approaches is simple linear regression method. The Strength of time series model is listed below.

- Needs available historical data, once the data is there they provide quick answer.
- The models can handle more than simple trends (growth & decline) as they can also consider cycles in the data (annual, weekly, daily).

- Can make relation too many variables like traffic Vs time, economic growth Vs time, commodity flow Vs time and others.
- The decision to employ a time series model usually occurs if little is known about the determinants of the dependent variable.
- The forecasting equation is dependent so that one can forecast the response over time of the dependent variable to the forecast values of the independent variable.

3.2.3.1. Simple linear regression method

Simple linear regression analysis establishes a relationship between a dependent variable (passenger or freight) and one independent variables (year).

$$Y = a + b X \quad (3)$$

Where:

Y = dependent variable which is passenger or freight

X = independent variable represents the time window in years

a = y-axis intercept

b = slope of regression line

Constants a and b are computed using the following equations:

$$a = \frac{\sum y \sum x^2 - \sum x \sum x y}{n \sum x^2 - (\sum x)^2}, \quad b = \frac{n \sum x y - \sum x \sum y}{n \sum x^2 - \sum x \sum y} \quad (4)$$

Once the constants a and b are computed, a future value of X can be entered into the regression equation and a corresponding value of Y (the forecast) can be calculated. Factors considered for accuracy of regression model is the coefficient of correlation “ r ” and the one with the best fit will be selected ($r^2 > 95\%$). If correlation coefficient r^2 is less the accuracy of forecast is less and we can't use regression model.

3.2.3.2. The coefficient of correlation (r)

The coefficient of correlation r , explains the relative importance of the relationship between x and y . r is computed by:

$$r = \frac{n \sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2] * [n \sum y^2 - (\sum y)^2]}} \quad (5)$$

The sign of r shows the direction of the relationship. The absolute value of r shows the strength of the relationship. The sign of r is always the same as the sign of b . r can take on any value between -1 and $+1$.

3.2.4. Modal split between different transport modes

The objective of modal split is to carry out the ratio for different modes of transport. The selection of one mode or another is a complex process that depends on factors such as travel time, cost, and interval between departures. The procedures for modal split of freight and passenger transport are different in many aspects like data availability, the complexity and nature of mode, the content and background of the models used and the details of practical application.

Proper modal split analysis involves the assessment of the capacity, cost and performance of existing and proposed alternative transport systems along the corridor. In spite of increased role of non-price factors in the modern transport marketing process, price still remains a critical element.

Binary logit model is used to split the modes where the travel choice between different modes is made. The traveler will associate some value for the utility of each mode if the utility of one mode is higher than the other, then that mode is chosen. But in transportation, we have disutility also. The disutility here is the travel cost. This can be represented as

$$c_{ij} = a_1 t_{ij}^v + a_2 t_{ij}^w + a_3 t_{ij}^t + a_4 f_{ij} + a_5 \emptyset_j \quad (6)$$

Where:

- t_{ij}^v is the in-vehicle travel time between i and j,
- t_{ij}^w is the walking time to and from stops,
- t_{ij}^t is the waiting time at stops,
- f_{ij} is the fare charged to travel between i and j, and
- \emptyset_j is the parking cost.

If the travel cost is low, then that mode has more probability of being chosen. Then the choice of a mode is expressed as a probability distribution. This functional form is called logit, where c_{ij} is called the generalized cost and is the parameter for calibration. Then the modal choice is expressed by probability equation:

$$P_{ij}^1 = \frac{e^{-c_{ij}^1}}{\sum e^{-c_{ij}^m}} \quad (7)$$

Where:

P_{ij} is the percentage mode choice

c_{ij} the generalized cost.

3.3 Data collection and analysis

In this thesis there are three basic types of data required following describes how these data are collected and analyzed accordingly. The collected data for Ethio-Djibouti railroad track structure, type of stations, locomotive type and number is gathered from Ethiopian Railway Corporation (ERC).

To make Ethio-Djibouti railway viable and successful there is a need of proper planning that involves making the best possible forecast of future transport demand of the corridor. For demand analysis the gross import and export quantity of freight is found from Ethiopian Revenue and customs authority (ERCA) starting from the year 1997G.C up to 2016G.C. To forecast the amount of passenger which will use Ethio-Djibouti railway origin destination data of current traffic flow is needed. Passenger information is gathered from critical bus stations which are found along Ethio-Djibouti corridor like Addis Ababa, Adama, Awash, Dire Dawa, Harar and Djibouti. However, analyzing these data to obtain meaningful information requires great concentration and devotion.

Different websites also searched to extract some supportive ideas and data. Relevant scientific papers and articles were extracted from online databases. Some of the articles were searched from the references of other relevant articles.

Data analysis in this thesis, for the freight and passenger the amount is forecasted for the coming 50 years' time period and modal split is done to differentiate how much passenger or freight is going to use railway so this is converted to number of trains per day required to satisfy the demand. Consequently the maximum practical capacity of the line is determined in terms of trains per day. After that by comparing the maximum practical capacity of the line with the number of trains required to satisfy the required transportation demand conclusion will be drawn.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Theoretical and practical capacity of Ethio-Djibouti railway line

4.1.1. Theoretical capacity of Ethio-Djibouti railway line

Theoretical capacity is the number of trains that could run over a route during specific time interval. It is calculated mathematically using an empirical formula and represents an upper limit for line capacity. Theoretical capacity can be determined by using analytical capacity analysis method (UIC 405 method). This method lets an efficient estimation of the capacity of a line and it can be used as a reference measure and for identifying bottlenecks too. The analytical approach typically uses several steps of data processing through mathematical equations or algebraic expressions and is often used to determine a solution for the problem.

Input data required for analytical capacity analysis are obtained from Ethiopian railway corporation and current status of the project are listed as follows; Length of trains 200 m long passenger trains & 850 m long freight trains; Average speed of the train 70km/hr for freight, 100km/hr for passenger; signaling system for the Ethio-Djibouti is a semi-automatic system. Every platform inside the stations should be able to serve a 200m long passenger trains. Moreover, each freight station should be able to accommodate also the 850m long freight trains in order to permit crossing and overtaking.

Based on UIC405 method there are assumptions such as, the freight services are point to point service without intermediate stops; The passenger services stop in all the station along the itinerary; Block sections of fixed length 3 km.

4.1.1.1 Timetable of Ethio-Djibouti railway line

The input data which is required to calculate theoretical capacity by using UIC405 leaflet is operational train schedule of the line which is used for taking headway time of the consecutive trains. For both passenger and freight trains the time table is done on the operational plan of Ethio-Djibouti railway but it is not detail and the headways are not specified. By taking this data as benchmark and from ERC feasibility study the speed of the trains for freight 70 Km/hr, for passenger 100km/hr for calculating the travel time

that will take to travel from one station to the next station for the double as well as the single track section as shown by the timetable in table 7 and 8 respectively. According to ERC the freight trains on the line mainly comprises non-stop trains pick-up and drop trains shall be organized to digest local freight transportation along the line.

Table 6 Timetable for the double track section

Station	Freight	Passenger	Freight	Freight	Passenger	Freight	Passenger	Passenger (Night)
SEBETA	12:50	1:12	2:11	3:58	4:19	6:30	7:34	1:48
LABU	1:02	1:20	2:23	4:10	4:27	6:42	7:42	2:00
INDODE	1:17	1:31	2:38	4:25	4:36	6:57	7:51	2:15
BISOFTU	1:49	1:54	3:10	4:57	4:59	7:29	8:14	2:47
MODJO	2:07	2:06	3:28	5:15	5:11	7:47	8:26	3:05
ADAMA	2:27	2:20	3:48	5:35	5:25	8:07	8:40	3:25
	Dawn	up	Dawn	Dawn	up	Dawn	up	Dawn

Table 7 Timetable for single-track section

Direction	station														Direction
	Adama	Feto	Methara	Awash	Sirba Kunkur	Mieso	Erer	Dire Dawa	Arawa	Adigala	Aysha	Dawanle	Frontier Station	Djibouti	
up	2:00	2:36	3:30	3:56	4:33	5:15	5:36	6:32	7:18	8:11	8:55	9:30	9:30	10:48	down
up	2:20	2:45	3:23	3:41	4:07	4:36	4:57	5:36	6:08	6:45	7:16	7:40	7:40	8:35	down
down	8:47	8:11	7:17	6:52	6:15	5:43	5:12	4:16	3:30	2:37	1:53	1:18	1:18	12:00	up
down	7:15	6:50	6:12	5:54	5:28	4:59	4:38	3:59	3:27	2:50	2:19	1:55	1:55	1:00	up
down	11:47	11:11	10:17	9:52	9:15	8:43	8:12	7:16	6:30	5:37	4:53	4:18	4:18	3:00	up
up	7:05	7:30	8:08	8:26	8:52	9:21	9:42	10:21	10:53	11:30	12:01	12:25	12:25	13:20	down

**4.1.1.2 Theoretical Capacity of Double Track Railway Section
{From Sebeta/Addis Ababa up to Adama}**

This line consists of 5 different types of stations SEBETA, LABU, INDODE, BISHOFTU, MODJO, and ADAMA (included) which is constructed and ready for operation. The stations and their intended purpose are specified on table 6

Table 8 Double track line with stations from Addis Ababa – Adama

STATION	TYPE	CHAINAGE
SEBETA	Both freight and passenger	0
LABU	passenger	13,322
INDODE	freight	31,631
BISHOFTU	passenger	69,241
MODJO	Both freight and passenger	89,894
ADAMA	Both freight and passenger	113,255

The theoretical capacity “C” of the double track railway line from Addis Ababa–Adama is calculated by equation (1) (UIC405). The parameters t_{fm} , t_{zu} , t_r in equation (1) can again have respective formulas and $T=1440$ minutes. To calculate t_{zu} & t_r firstly t_{fm} must be determined by equation (2). For calculating t_{fm} the variables n_i , n_j and t_{fij} is extracted from the timetable developed in table 7.

t_r is calculated by using the formula $t_r = 0.33 \times t_{fm}$, by taking the desired utilization of Ethio-Djibouti railway infrastructure as 75% (UIC405).

t_{zu} can be calculated by the formula $t_{zu} = 0.25*a$, where “a” is the number of block sections along the railway line and calculated by dividing length between each consecutive stations by block section (section within/protected by signals). Length between each consecutive station is determined from chain-age specified in table 6; and UIC405 specifies a block section must between 3km - 4km taking the minimum 3km as a block section to increase efficiency of the railway line.

The above description of capacity calculation is presented in a tabular form for easy reference, identifying the bottleneck, and understanding the capacity of each section of the line as shown in the tables; table 10 (double track section from Addis Ababa – Adama) and table 12 (single track section from Adama/Ethiopia-Negad/Djibouti) and Sample calculations are illustrated in appendix B. For the double track section as it is illustrated in table 10 the bottleneck section is from Sebeta to Labu which accommodates the minimum number of trains/day and its theoretical capacity is **86trains/day**.

Table 9 Theoretical capacity calculation of double track section from Sebeta to Adama

Section		Length [km]	ni	nj	ni*nj	tfij	ni*nj*tfij	tfm	tr	tzu	C [trains/day]
From	To										
SEBETA	LABU	13.322	1	1	1	17	17	17	5.61	1.67	86
			1	2	2	17	34				
			2	1	2	17	34				
			1	1	1	17	17				
			1	2	2	17	34				
			Σ	8		136					
LABU	INDODE	18.309	1	1	1	11	11	11	3.63	1.5	89
			1	2	2	11	22				
			2	1	2	11	22				
			1	1	1	11	11				
			1	2	2	11	22				
			Σ	8		88					
INDODE	BISHOFTU	37.61	1	1	1	5	5	5	1.65	3	149
			1	2	2	5	10				
			2	1	2	5	10				
			1	1	1	5	5				
			1	2	2	5	10				
			Σ	8		40					
BISHOFTU	MOJO	20.653	1	1	1	6	6	6	1.32	1.75	148
			1	2	2	6	12				
			2	1	2	6	12				
			1	1	1	6	6				
			1	2	2	6	12				
			Σ	8		48					
MOJO	ADAMA	23.361	1	1	1	7	7	7	2.31	2	127
			1	2	2	7	14				
			2	1	2	7	14				
			1	1	1	7	7				
			1	2	2	7	14				
			Σ	8		56					

4.1.1.3 Theoretical capacity of Single track railway section

{From Adama/Ethiopia to Negad/Djibouti}

This railway section consists of 14 different type of stations ADAMA (excluded), Feto, Metehara, Awash, Sirba Kunkur, Mieso, Bike, Dire Dawa, Arawa, Adigala, Aysha, Dawanle, Alisabeh, Holhol & Negad which is constructed and ready for operation.

Table 10 Single track line with stations from Adama/Ethiopia-Negad/Djibouti

STATION	TYPE	CHAINAGE
Feto	Both freight and passenger	154,426
Methara	Both freight and passenger	217,548
Awash	Both freight and passenger	247,044
Sirba Kunkur	passenger	290,444
Mieso	Both freight and passenger	338,724
Bike	passenger	374,284
Dire Dawa	Both freight and passenger	438,844
Arawa	Passing station	491,912
Adigala	Passing station	553,690
Aysha	Passing station	604,640
Dawanle	Both freight and passenger	645,440
Alisabeh	Both freight and passenger	665,214
Holhol	passenger	711,214
Negad	Both freight and passenger	743,214

Sample calculations for analytical capacity analysis are illustrated in appendix B.

Table 11 Analytical capacity analysis for single track section from Adama/Ethiopia-Negad/Djibouti

Section		Length [km]	ni	nj	ni*nj	tfij	ni*nj*tfij	tfm	tr	tzu	C [trains/day]
From	To										
ADAMA	FETO	41.171	1	1	1	9	9	9	2.97	3.5	93
			1	1	1	9	9				
			1	1	1	9	9				
			1	1	1	9	9				
			1	1	1	9	9				
			Σ	5		45					
FETO	METHARA	63.122	1	1	1	7	7	7	2.31	5.25	99
			1	1	1	7	7				
			1	1	1	7	7				
			1	1	1	7	7				
			1	1	1	7	7				
			Σ	5		35					
METHARA	AWASH	29.496	1	1	1	7	7	7	2.31	2.5	122
			1	1	1	7	7				
			1	1	1	7	7				
			1	1	1	7	7				
			1	1	1	7	7				
			Σ	5		35					
AWASH	SIRBA KUNKUR	43.400	1	1	1	15	15	15	4.95	3.75	61
			1	1	1	15	15				
			1	1	1	15	15				
			1	1	1	15	15				
			1	1	1	15	15				
			Σ	5		75					
SIRBA KUNKUR	MIESO	48.28	1	1	1	16	16	16	5.28	4	57
			1	1	1	16	16				
			1	1	1	16	16				
			1	1	1	16	16				
			1	1	1	16	16				
			Σ	5		80					
MIESO	BIKE	35.56	1	1	1	16	16	16	5.28	3	59

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			1	1	1	16	16				
			1	1	1	16	16				
			1	1	1	16	16				
			1	1	1	16	16				
			Σ		5		80				
BIKE	DIRE DAWA	64.56	1	1	1	17	17	17	5.61	5.5	51
			1	1	1	17	17				
			1	1	1	17	17				
			1	1	1	17	17				
			1	1	1	17	17				
			Σ		5		85				
DIRE DAWA	ARAWA	53.068	1	1	1	10	10	10	3.3	4.5	81
			1	1	1	10	10				
			1	1	1	10	10				
			1	1	1	10	10				
			1	1	1	10	10				
			Σ		5		50				
ARAWA	ADIGALA	61.778	1	1	1	13	13	13	4.29	5.25	64
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			Σ		5		65				
ADIGALA	AYSHA	50.95	1	1	1	13	13	13	4.29	4.25	67
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			Σ		5		65				
AYSHA	DAWANLE	40.8	1	1	1	21	21	21	7	3.5	45
			1	1	1	21	21				
			1	1	1	21	21				
			1	1	1	21	21				
			1	1	1	21	21				
			Σ		5		105				
DAWANLE	ALISABEH	20	1	1	1	20	20	20	6.6	1.75	50
			1	1	1	20	20				
			1	1	1	20	20				
			1	1	1	20	20				
			1	1	1	20	20				
			Σ		5		100				
ALISABEH	HOLHOL	46	1	1	1	13	13	13	4.29	3.75	68
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			1	1	1	13	13				
			Σ		5		65				
HOLHOL	NEGAD	32	1	1	1	15	15	15	4.95	2.75	63
			1	1	1	15	15				
			1	1	1	15	15				
			1	1	1	15	15				
			1	1	1	15	15				
			Σ		5		75				

For the single track railway line from Adama/Ethiopia-Negad Djibouti the bottleneck section is as calculated in table 12 the minimum number of trains are accommodated on the section from Aysha-Dawanle its theoretical capacity is **45trains/day**.

4.1.2. Practical capacity of Ethio-Djibouti railway line

Practical capacity represents the practical limit of the number of trains (usually considering the current train mix, priorities, traffic bunching, etc.) that can be moved on a line in order to guarantee a reasonable level of reliability. It is a more realistic measurement than theoretical capacity, usually around 60%-75% of theoretical capacity (UIC405). Practical capacity is a more realistic measure of railway capacity, which takes into account reliability and operational aspects. The calculation of the practical capacity requires the definition of ratio between theoretical and practical capacity, in our case since the Ethio-Djibouti railway holds mixed traffic UIC405 proposes 75% capacity utilization see table 6. It is worth noticing that it is not possible to give a unique value to the whole railway network because of complexity and diversification of components (lines, stations or their subparts), which require different estimation of capacity itself. Anyway, at network's level it will be possible to estimate a global capacity value by referring to the lower local value.

The capacity of the railway line is determined by the minimum number of trains per day which is entertained by section which have less capacity or the bottleneck section.

For the double track section, as it's calculated in table 10 the bottleneck section is from Sebeta to Labu and its theoretical capacity is 86trains/day. Therefore, the practical capacity can be calculated as follows;

- $86 \text{ trains/day} * 75\% / 100 = \underline{\mathbf{64trains/day}}$ for double track section (Sebeta – Adama);

For the single track section the bottleneck section is from Aysha - Dawanle its theoretical capacity is 45trains/day. Therefore, the practical capacity will become

- $45 \text{ trains/day} * 75\% / 100 = \underline{\mathbf{33trains/day}}$ for single track section (Adama/Ethiopia– Negad/Djibouti).

4.2 Freight Railway Demand Analysis along Ethio-Djibouti Corridor

The step by step approach used for determining the number of pairs of freight train required to satisfy the forecasted demand on each year are illustrated below;

- Forecasting of the total volume of import and export of goods of Ethiopia by using Regression method by taking previous import export data which is found from Ethiopian Revenue and customs authority (ERCA).
- Calculation of total import/export freight volume which passes through port of Djibouti from the total amount of Ethiopian import/export trade. Port share is done based on the data found from ministry of transport of Ethiopia (MOT).
- Modal split of freight between railway and road. Percentage of choosing to transport the freight by railway is calculated.
- Number of trains per day required to transport the forecasted freight is calculated. This is done by taking into consideration the type and capacity of different train arrangements and taking the best alternative. The type of trains and their capacity is found from ERC.

4.2.1. Freight Traffic Forecasting

The forecasting of freight traffic starts from the study of economic development status of the country, the current situation of foreign trade and its plan, and by making an objective judgment for the future economic development it's possible to forecast the future flow of import and export of goods. Forecasting of freight transportation in Ethiopia mainly depend on the import and export volume which was gathered on the past years.

In this thesis the freight forecast is done by using least square regression method which relates time and import and export data. Import export data is collected from the Ethiopian Revenues and Customs Authority (ERCA). To forecast the future import/export freight volume of Ethiopia for the coming 50 years the previous 20 years import and export data of Ethiopia (table 13) from 1997 G.C. up to 2016G.C, found from ERCA is used.

Table 12 import and export of Ethiopian trade [26]

Year	Import (tons)	Export (tons)
1997	1,106,794	373,818
1998	3,556,019	241,484
1999	2,553,123	247,883
2000	2,727,216	323,432
2001	3,369,679	350,832
2002	2,595,131	561,291
2003	5,092,941	506,009
2004	3,832,543	539,496
2005	4,413,599	748,154
2006	4,184,892	690,610
2007	4,955,151	831,931
2008	7,603,417	834,480
2009	8,218,723	909,833
2010	7,192,247	1,163,535
2011	7,391,318	1,215,005
2012	8,593,864	1,318,950
2013	7,533,856	1,373,225
2014	10,246,626	1,594,061
2015	10,444,944	1,551,748
2016	14,595,826	2,205,872

In order to use regression as a forecasting model factors must be considered for accuracy of regression model like the coefficient of correlation “r” which explains the relative importance of the relationship between x (year) and y (import/export) and the one with $r^2 > 95\%$ will be selected. If correlation coefficient r^2 is less than 95% the accuracy of forecast is less and we can't use regression model. Coefficient of correlation is calculated by using the following equation and the data depicted in table 14.

$$r = \frac{n * \sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2] * [n \sum y^2 - (\sum y)^2]}}$$

Table 13 coefficient of correlation values

Import	$r = 0.975048921$	$r^2 = 0.950720399$	$r^2 = 95.10 \%$
Export	$r = 0.98230249$	$r^2 = 0.968800032$	$r^2 = 96.88 \%$

The value of coefficient of correlation “r” shows that there is a strong relationship between the variables x and y as year increase import and export increases simultaneously. The result r^2 indicates that it is possible to use linear regression to forecast the future freight demand.

By using the following regression formula we can forecast the future transport demand:

$$y = a + bx$$

Where: - a is the y intercept, b is the slope of the line, y is the tons and x is the year the coefficients a and b are calculated based on the following formula. The regression equation will become as shown in table 12.

$$a = \frac{\sum y * \sum x^2 - \sum x \sum x * y}{n \sum x^2 - (\sum x)^2} \text{ and } b = \frac{n * \sum x * y - \sum x \sum y}{n \sum x^2 - \sum x \sum y}$$

Table 14 regression coefficients and equations of import and export

		Import	Export
coefficients	a	-1,048,367,144	-171,575,595
	b	525,481	85,948
Regression equation		$y = -1,048,367,144 + 525,481 * x$	$y = -171,575,595 + 85,948 * x$

Therefore, the forecasted import and export value starting from 2017 GC up to 50 years is presented in table 17 of column 2 and 3 accordingly. The regression calculation for imports and exports is tabulated and presented in appendix A.

Today's Ethiopia's international trade almost entirely depends on Djibouti's harbor, occasionally aided by Berbera and Sudan port. Basically, the factors affecting the allocation of ports include available port capacity, the relative cost of fees and the cost of inland transportation. The current and the proposed share of ports mainly based on the above factors. Based on Ministry of Transportation (MOT) future plan and the feasibility study of Ethio-Djibouti railway done by ERC estimates the following port distribution.

Table 15 port distribution based on ministry of transport

Harbor	2010 GC.	Five Years Later 2015 GC.
Djibouti port	93%	75%
Berbera port	5%	15%
Sudan port	2%	10%

Since port of Djibouti is better option from other ports because of economic, political, and safety reasons, 75% of Ethiopian import and export trade is conducted by Djibouti port the rest 15% of import and export is covered by the remaining Berbera port and Port Sudan.

It is known that Ethiopia and Djibouti have strong political, economic and social relationship as a result Djibouti port is serving as the main import/export gate for the country without any competitor port for longer time. The study time period of this thesis is

50year as a result the percentage of port share fluctuation is expected throughout this years. This thesis is done by assuming port share fluctuation will be insignificant and port of Djibouti share remains 75% throughout the study period. Djibouti port share from the total amount of import export trade is calculated for the next 50 years' time period and listed on table 17 of column 3 and 4.

Table 16 the forested import and export freight volume of Ethiopia {1} and Djibouti port share on the total amount of import and export volume of the country {2}

Year	The forecasted freight volume of Ethiopia (ton) {1}		Djibouti port share from the total volume [75%] {2}	
	Import (tons)	Export (tons)	Import (tons)	Export (tons)
2017	11,527,952	1,781,542	8,645,964	1,336,156
2018	12,053,433	1,867,490	9,040,075	1,400,617
2019	12,578,914	1,953,438	9,434,186	1,465,078
2020	13,104,395	2,039,386	9,828,296	1,529,539
2021	13,629,876	2,125,334	10,222,407	1,594,000
2022	14,155,357	2,211,282	10,616,518	1,658,461
2023	14,680,838	2,297,230	11,010,628	1,722,922
2024	15,206,319	2,383,178	11,404,739	1,787,383
2025	15,731,800	2,469,126	11,798,850	1,851,844
2026	16,257,281	2,555,074	12,192,961	1,916,305
2027	16,782,762	2,641,022	12,587,071	1,980,766
2028	17,308,243	2,726,970	12,981,182	2,045,227
2029	17,833,724	2,812,918	13,375,293	2,109,688
2030	18,359,205	2,898,866	13,769,404	2,174,149
2031	18,884,686	2,984,814	14,163,514	2,238,610
2032	19,410,167	3,070,762	14,557,625	2,303,071
2033	19,935,648	3,156,710	14,951,736	2,367,532
2034	20,461,129	3,242,658	15,345,846	2,431,993
2035	20,986,610	3,328,606	15,739,957	2,496,454
2036	21,512,090	3,414,554	16,134,068	2,560,915
2037	22,037,571	3,500,502	16,528,179	2,625,376
2038	22,563,052	3,586,450	16,922,289	2,689,837
2039	23,088,533	3,672,398	17,316,400	2,754,298
2040	23,614,014	3,758,346	17,710,511	2,818,759
2041	24,139,495	3,844,294	18,104,621	2,883,220
2042	24,664,976	3,930,242	18,498,732	2,947,681
2043	25,190,457	4,016,190	18,892,843	3,012,142
2044	25,715,938	4,102,138	19,286,954	3,076,603

2045	26,241,419	4,188,086	19,681,064	3,141,064
2046	26,766,900	4,274,034	20,075,175	3,205,525
2047	27,292,381	4,359,982	20,469,286	3,269,986
2048	27,817,862	4,445,930	20,863,396	3,334,447
2049	28,343,343	4,531,878	21,257,507	3,398,908
2050	28,868,824	4,617,826	21,651,618	3,463,369
2051	29,394,305	4,703,774	22,045,729	3,527,830
2052	29,919,786	4,789,722	22,439,839	3,592,291
2053	30,445,267	4,875,670	22,833,950	3,656,752
2054	30,970,748	4,961,618	23,228,061	3,721,214
2055	31,496,229	5,047,566	23,622,172	3,785,675
2056	32,021,710	5,133,514	24,016,282	3,850,136
2057	32,547,191	5,219,462	24,410,393	3,914,597
2058	33,072,672	5,305,410	24,804,504	3,979,058
2059	33,598,153	5,391,358	25,198,614	4,043,519
2060	34,123,634	5,477,306	25,592,725	4,107,980
2061	34,649,114	5,563,254	25,986,836	4,172,441
2062	35,174,595	5,649,202	26,380,947	4,236,902
2063	35,700,076	5,735,150	26,775,057	4,301,363
2064	36,225,557	5,821,098	27,169,168	4,365,824
2065	36,751,038	5,907,046	27,563,279	4,430,285
2066	37,276,519	5,992,994	27,957,389	4,494,746

4.2.2. Modal split of freight

From Ethiopia to Djibouti both road and railway transports are available for transporting freight. People chooses between this two modes of transportation by considering cost and travel time as a basic criteria to transport freight safely, economically and timely. Freight transport market is essentially a service market that is particularly sensitive to changes in price charged by different carriers. The cost is not limited to moving products but also of other aspects of freight distribution and logistics system including cargo handling, inventory and safety. Trader's main purpose is to maximize profit to assure this choosing the best freight transport mode is mandatory depending on time, cost and availability. Ethio-Djibouti corridor is accommodating different transportation system selection by the user, at some sections railway is preferable than road and for other sections vice versa as a result it's better to divide and study the corridor in to different sections reasonably. Therefore in this thesis the analysis is done by dividing the corridor into three reasonable sections.

The sections with their respective reasons are presented as follows.

Section 1: the route from Addis Ababa to Adama the railway line is double track in this section which allows accommodating more trains. The section has two road alternatives the old road and the newly built express road.

Section 2: the route from Adama to Awash the railway line is single track. The road condition is asphalt.

Section 3: the route from Awash to Port of Djibouti the railway is single track and common route for both Ethio-Djibouti and Awash-Woldia railway lines. The two railway lines are connected at Awash station. The road connecting this section is of good quality asphalt.

For analyzing a modal split of freight binary logit model is used based on cost to split the modes where the travel choice between train and truck is made. Then the choice of a mode is expressed as a probability distribution. This functional form is called logit,

$$P_{ij} = \frac{e^{-c_{ij}}}{\sum e^{-c_{ij}^m}}$$

Where C_{ij} is called the generalized cost and is the parameter for calibration. The equation for this can be written as:

$$C_{ij} = a_1 t_{ij}^v + a_2 t_{ij}^w + a_3 t_{ij}^t + a_4 f_{ij} + a_5 \emptyset_j$$

If the travel cost is low, then that mode has more probability of being chosen. Due to the lack of market investigation for freight price of Ethiopian roads and railways, the evaluation follows the condition of Ethiopian Railway cooperation and the local fact the freight price is 0.046 USD/ton-km. The length of the whole international railway line from Sebeta to Nagad is 743.245km. According to ERC the freight train will operate with an average speed of 80km/hr.

According to ERA data the total length of the road is 903Km with the average speed of 60km/hr tariff of 0.047USD/ton/km.

The coefficients a_i are all standard constants and by assuming some logical values for t_{ij}^w, t_{ij}^t and \emptyset_j we can calculate C_{ij} . assumption has been taken there is no walking time in between Addis Ababa to Djibouti, the waiting time at the stops be waiting time at the port and dry ports which is 15 days and an assumption is also made the stay at port, the fair charged between origin and destination, the parking cost become almost half in relation with each other (vehicle and train). The probability of choosing each mode types

P_{ij} are calculated and tabulated in the appendix as well as sample calculations are illustrated in appendix B.

Table 17 Modal share of freight between train and truck

mode	Addis Ababa to Adama	Adama to Awash	Awash to Djibouti
truck	58%	20%	15%
train	42%	80%	85%

The volume of import/export freight which will be transported by railway based on the percentage share calculated in table 18 on each three sections such as (Addis Ababa to Adama; Adama to Awash; Awash to of Djibouti) along the corridor is presented in tabular form in table 19.

Table 18 Freight transport share of different sections along the line

Year	(Section 1) A/A- Adama [42% railway share]		(Section 2) Adama-Awash [80% railway share]		(Section 3) Awash -Djibouti [85% railway share]	
	Import (tons)	Export (tons)	Import (tons)	Export (tons)	Import (tons)	Export (tons)
2017	3,614,013	558,513	6,949,626	1,074,002	7,387,976	1,141,745
2018	3,778,751	585,458	7,266,412	1,125,816	7,724,744	1,196,827
2019	3,943,490	612,403	7,583,198	1,177,630	8,061,512	1,251,909
2020	4,108,228	639,347	7,899,985	1,229,444	8,398,279	1,306,991
2021	4,272,966	666,292	8,216,771	1,281,257	8,735,047	1,362,073
2022	4,437,704	693,237	8,533,557	1,333,071	9,071,814	1,417,155
2023	4,602,443	720,182	8,850,343	1,384,885	9,408,582	1,472,237
2024	4,767,181	747,126	9,167,129	1,436,699	9,745,350	1,527,319
2025	4,931,919	774,071	9,483,916	1,488,512	10,082,117	1,582,401
2026	5,096,658	801,016	9,800,702	1,540,326	10,418,885	1,637,483
2027	5,261,396	827,960	10,117,488	1,592,140	10,755,652	1,692,565
2028	5,426,134	854,905	10,434,274	1,643,954	11,092,420	1,747,647
2029	5,590,872	881,850	10,751,060	1,695,767	11,429,188	1,802,729
2030	5,755,611	908,794	11,067,847	1,747,581	11,765,955	1,857,811
2031	5,920,349	935,739	11,384,633	1,799,395	12,102,723	1,912,893
2032	6,085,087	962,684	11,701,419	1,851,209	12,439,491	1,967,974
2033	6,249,826	989,629	12,018,205	1,903,022	12,776,258	2,023,056
2034	6,414,564	1,016,573	12,334,991	1,954,836	13,113,026	2,078,138
2035	6,579,302	1,043,518	12,651,778	2,006,650	13,449,793	2,133,220
2036	6,744,040	1,070,463	12,968,564	2,058,464	13,786,561	2,188,302

2037	6,908,779	1,097,407	13,285,350	2,110,278	14,123,329	2,243,384
2038	7,073,517	1,124,352	13,602,136	2,162,091	14,460,096	2,298,466
2039	7,238,255	1,151,297	13,918,922	2,213,905	14,796,864	2,353,548
2040	7,402,993	1,178,241	14,235,709	2,265,719	15,133,631	2,408,630
2041	7,567,732	1,205,186	14,552,495	2,317,533	15,470,399	2,463,712
2042	7,732,470	1,232,131	14,869,281	2,369,346	15,807,167	2,518,794
2043	7,897,208	1,259,076	15,186,067	2,421,160	16,143,934	2,573,876
2044	8,061,947	1,286,020	15,502,853	2,472,974	16,480,702	2,628,958
2045	8,226,685	1,312,965	15,819,640	2,524,788	16,817,469	2,684,040
2046	8,391,423	1,339,910	16,136,426	2,576,601	17,154,237	2,739,121
2047	8,556,161	1,366,854	16,453,212	2,628,415	17,491,005	2,794,203
2048	8,720,900	1,393,799	16,769,998	2,680,229	17,827,772	2,849,285
2049	8,885,638	1,420,744	17,086,784	2,732,043	18,164,540	2,904,367
2050	9,050,376	1,447,688	17,403,571	2,783,856	18,501,308	2,959,449
2051	9,215,115	1,474,633	17,720,357	2,835,670	18,838,075	3,014,531
2052	9,379,853	1,501,578	18,037,143	2,887,484	19,174,843	3,069,613
2053	9,544,591	1,528,523	18,353,929	2,939,298	19,511,610	3,124,695
2054	9,709,329	1,555,467	18,670,715	2,991,111	19,848,378	3,179,777
2055	9,874,068	1,582,412	18,987,501	3,042,925	20,185,146	3,234,859
2056	10,038,806	1,609,357	19,304,288	3,094,739	20,521,913	3,289,941
2057	10,203,544	1,636,301	19,621,074	3,146,553	20,858,681	3,345,023
2058	10,368,283	1,663,246	19,937,860	3,198,366	21,195,448	3,400,105
2059	10,533,021	1,690,191	20,254,646	3,250,180	21,532,216	3,455,187
2060	10,697,759	1,717,135	20,571,432	3,301,994	21,868,984	3,510,269
2061	10,862,497	1,744,080	20,888,219	3,353,808	22,205,751	3,565,350
2062	11,027,236	1,771,025	21,205,005	3,405,621	22,542,519	3,620,432
2063	11,191,974	1,797,970	21,521,791	3,457,435	22,879,286	3,675,514
2064	11,356,712	1,824,914	21,838,577	3,509,249	23,216,054	3,730,596
2065	11,521,451	1,851,859	22,155,363	3,561,063	23,552,822	3,785,678
2066	11,686,189	1,878,804	22,472,150	3,612,877	23,889,589	3,840,760

4.2.3. The pairs of freight trains

The pairs of trains which will operate per day to satisfy the forecasted demand is calculated by dividing the volume of import/export freight in table 19 by the maximum possible hauling capacity of one set of train. According to ERC the freight trains on the line mainly comprises non-stop trains pick-up and drop trains shall be organized to digest local freight transportation along the line.

The actual situation of Ethiopia shows that the export volume is much less than the import volume and hence from the current and forecasted freight volume it's possible to determine

the proportion of import and export freight.

- Average import of Ethiopia 87%
- Average export of Ethiopia 13%

Freight trains adopts electric-power dual-locomotive traction system which have best hauling capacity, environmental friendly with a traction mass of 3500t. The Ethio-Djibouti Railway line uses DC locomotive (SS4) or AC locomotives (HXD3C, HXD3B) for the freight.

Length of freight train is governed by the maximum length of platform the freight station. The constructed freight station platform is 850m length therefore the maximum length of freight train is 850m this length includes locomotives and wagons. (See fig. 8)

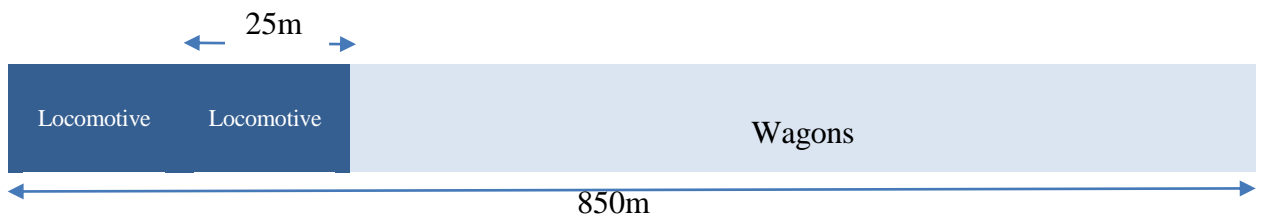


Figure 8 one set of freight train

For freight train two locomotives with a total length of 50m is used to pull all the attached wagons efficiently, see fig 8; the rest 800m wagon arrangement is calculated by weighted average by taking the number, capacity and length of each wagons which are ready for operation see table 20. According to ERC currently there are 1100 different types of freight wagons which are ready for operation.

Table 19 Wagons which are ready for operation

type	Box Wagon	Uncovered Gondola wagon	Covered Gondola Wagon	Hoper Uncovered wagon	Hoper Covered wagon	Flat Wagon	Refrigerated wagon	Tank wagon	Center Beam wagon	Bi-level wagon
number	220	20	110	20	20	550	10	110	20	20
Capacity (ton)	70	70	70	70	69	70	38	70	70	22
Length (m)	16	23	23	23	23	23	16	18	23	25

Each wagons have different capacity and length as shown in table 20 to take this difference into consideration it is better to calculate the maximum possible hauling capacity of one set train by weighted average. The wagons of freight trains along the line will have the following composition:

Considering 800m total length of wagons, the number of wagons for this length is

calculated by weighted average by taking the parameters from table 20 weighted average length of one wagon becomes **21.07m**; and the weighted average of weight which can be carried by one wagon becomes **68.82ton**.

Therefore, total length of wagons is 800m the number of wagon will become $800m/21.07m = 37$ **wagons** can be coupled at a time.

Total amount of average freight volume which can be transported by one set of train becomes; $37\text{wagon} \times 68.82\text{ton} = 2546.34\text{ton}$.

The number of daily trains is based on the hypothesis that all the freight plants (in particular the Port of Djibouti) are able to serve all the forecasted freight trains.

Therefore dividing the forecasted freight volume in table 19 by the average hauled weight and considering the line is working thought the year 365days.

The number of daily freight trains operated on each section of the line is illustrated on the following table.

Table 20 Number of freight train required per day at each year

Year	Section1 A/A-Adama		Section 2 Adama-Awash		Section 3 Awash-Djibouti	
	Import	Export	Import	Export	Import	Export
2017	4	1	8	2	8	2
2018	5	1	8	2	9	2
2019	5	1	9	2	9	2
2020	5	1	9	2	10	2
2021	5	1	9	2	10	2
2022	5	1	10	2	10	2
2023	5	1	10	2	11	2
2024	6	1	10	2	11	2
2025	6	1	11	2	11	2
2026	6	1	11	2	12	2
2027	6	1	11	2	12	2
2028	6	1	12	2	12	2
2029	7	1	12	2	13	2
2030	7	1	12	2	13	2
2031	7	2	13	2	14	3
2032	7	2	13	2	14	3
2033	7	2	13	3	14	3
2034	7	2	14	3	15	3
2035	8	2	14	3	15	3
2036	8	2	14	3	15	3

2037	8	2	15	3	16	3
2038	8	2	15	3	16	3
2039	8	2	15	3	16	3
2040	8	2	16	3	17	3
2041	9	2	16	3	17	3
2042	9	2	16	3	18	3
2043	9	2	17	3	18	3
2044	9	2	17	3	18	3
2045	9	2	18	3	19	3
2046	10	2	18	3	19	3
2047	10	2	18	3	19	4
2048	10	2	19	3	20	4
2049	10	2	19	3	20	4
2050	10	2	19	3	20	4
2051	10	2	20	4	21	4
2052	11	2	20	4	21	4
2053	11	2	20	4	21	4
2054	11	2	21	4	22	4
2055	11	2	21	4	22	4
2056	11	2	21	4	23	4
2057	11	2	22	4	23	4
2058	12	2	22	4	23	4
2059	12	2	22	4	24	4
2060	12	2	23	4	24	4
2061	12	2	23	4	24	4
2062	12	2	23	4	25	4
2063	13	2	24	4	25	4
2064	13	2	24	4	25	5
2065	13	2	24	4	26	5
2066	13	3	25	4	26	5

4.3 Passenger railway demand analysis along Ethio-Djibouti corridor

The step by step approach used for determining the number of pairs of passenger train required to satisfy the forecasted demand on each year are illustrated below;

- By taking the origin destination data forecasting of the total number of passengers along the corridor by using growth rate of the population.
- Calculation of the percentage of Modal choice of passengers between railway, bus and private car. The percentage of railway selection used for the calculation of the total passengers which use railway.

- Number of trains per day required to transport the forecasted passenger is calculated. This is done by taking into consideration the type and capacity of different train arrangements and taking the best alternative.

4.3.1 Passenger Traffic Forecasting

The forecasting of passenger traffic starts from the study of the growth rate of the people and economic development status of the country. The passenger forecast is done using growth rate model of the population since trip flow is directly proportional to population growth rate. The passenger forecast is done by taking the origin-destination data of current passenger traffic between towns along Ethio-Djibouti corridor. Origin destination data is collected from the bus stations found in major cities along the corridor because in Ethio-Djibouti corridor other transport modes other than bus are insignificant most passengers uses bus as a first choice.

The feasibility study done by ERC indicates that the newly constructed railway covers 7 regions, 2 main administrative areas in the city, 11 districts, with a population of over 20 million, which is 28% of the total population of Ethiopia.

Table 21 origin destination results of current passenger traffic between towns along corridor {Unit: person/year} [27]

Origin Destination	A.A	Adama	Awash	D/Dawa	Harar	Djibouti	Total
A.A	-	1,112,958	5,402	132,568	87,746	-	1,338,674
Adama	1,503,115	-	146	11,826	16,936	-	1,532,023
Awash	12,611	31,244	-	-	146	-	44,001
D/Dawa	138,846	8,030	1,460	-	-	88,001	236,337
Harar	179,142	37,960	1,022	-	-	-	218,124
Djibouti	-	-	-	8,435	-	-	8,435
Total	1,833,714	1,190,192	8,030	152,839	104,828	88,001	-

Table 22 population growth rate of Ethiopia [28]

2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2.76	2.7	2.64	1.96	1.89	2.36	2.31	2.27	3.21	3.21	3.2	3.19	3.18	2.9	2.89

Taking the population growth rate of Ethiopia found from Ethiopian statistical agency “table 23” and using regression equation for predicting the future growth rate of the

population at each year. The growth rates at each year are used to forecast the number of passengers illustrated in origin destination data in table 22. The forecasted total number of passengers along Ethio-Djibouti corridor is presented in a tabular form in the appendix A.

4.3.2 Modal Split of Passenger

Passengers choose between different modes of transportation by considering cost, travel time, comfort, availability and safety as a basic criteria. Modal split of passenger is complex task because of the variety of the user's needs have to be taken into consideration.

From actual condition of the corridor and the origin destination record in table 22 shows that more passengers originates and departs from Addis Ababa, Adama and Dire Dawa bus stations. Hence at some sections railway is preferable than road and for other sections vice versa to take this condition into consideration it's better to divide and analyze the corridor between this major cities. The Addis Ababa - Adama railway is a double track and also the Addis/Adama express way is available so passengers do have plenty of options in this section. Therefore in this thesis the analysis is done by dividing the corridor into three sections such as; Section 1: from Addis Ababa to Adama; Section 2: from Adama to Dire Dawa; Section 3 from Dire Dawa to Djibouti.

Based on the logit equation the modal split between passenger train, car and bus is presented in table 24 and sample calculations for modal split are illustrated in appendix B.

For analyzing a modal split of passenger binary logit model is used based on cost to split the modes where the travel choice between train, bus and car is made. Then the choice of a mode is expressed as a probability distribution. This functional form is called logit,

$$P_{ij}^1 = \frac{e^{-c_{ij}^1}}{\sum e^{-c_{ij}^m}}$$

Where C_{ij} is called the generalized cost and is the parameter for calibration. The equation for this can be written as:

$$C_{ij} = a_1 t_{ij}^v + a_2 t_{ij}^w + a_3 t_{ij}^t + a_4 f_{ij} + a_5 \emptyset_j$$

If the travel cost is low, then that mode has more probability of being chosen.

according to the condition of Ethiopian Railway cooperation and the local fact, the financial evaluation is calculated at basic passenger price of 0.023USD/km. The length

of the whole international railway line from Sebeta to Nagad is 743.245km. According to ERC the passenger train will operate with an average speed of 120km/hr. According to ERA data the total length of the road is 903Km with the average speed of 80km/hr for bus with a price of 0.5 birr/km tariff and 100 km/hr for private cars. The probability of choosing each mode types P_{ij} are calculated and tabulated in the appendix as well as sample calculations are illustrated in appendix B.

Table 23: Modal choice of passengers between bus, train and car

mode	Addis Ababa to Adama	Adama to Dire Dawa	Dire Dawa to Djibouti
bus	33%	18%	16%
train	42%	81%	83%
car	25%	1%	1%

The total number of passengers at each year which will choose to be transported by railway based on the percentage share calculated in table 24 on each three sections such as (Section 1: Addis Ababa to Adama; Section 2: Adama to Dire Dawa; Section 3: Dire Dawa to Djibouti) along the corridor is presented in tabular form in table 25 by considering the journey from Ethiopia to Djibouti as up direction and from Djibouti to Ethiopia as down direction.

Table 24 the forecasted passenger number per year using railway

year	AA-ADAMA [42% railway share]		ADAMA-DIRE-DAWA [81% railway share]		DIRE-DAWA-DJIBOUTI [83% railway share]	
	UP	DOWN	UP	DOWN	UP	DOWN
2017	744852	551514	38035	48215	189501	297253
2018	767525	568302	39192	49683	195269	306302
2019	791334	585931	40408	51224	201326	315803
2020	816340	604446	41685	52843	207688	325782
2021	842610	623897	43027	54543	214372	336266
2022	870214	644336	44436	56330	221394	347282
2023	899227	665818	45918	58208	228776	358861
2024	929729	688403	47475	60182	236536	371033
2025	961804	712153	49113	62259	244696	383834
2026	995544	737135	50836	64443	253280	397299
2027	1031046	763422	52649	66741	262312	411466
2028	1068411	791088	54557	69159	271818	426378
2029	1107749	820216	56566	71706	281827	442077

2030	1149179	850892	58681	74388	292367	458611
2031	1192825	883209	60910	77213	303471	476029
2032	1238820	917265	63258	80190	315173	494384
2033	1287308	953167	65734	83329	327509	513735
2034	1338440	991027	68345	86639	340518	534140
2035	1392379	1030965	71100	90130	354240	555666
2036	1449299	1073111	74006	93815	368722	578382
2037	1509387	1117602	77075	97704	384009	602361
2038	1572842	1164586	80315	101812	400153	627685
2039	1639876	1214221	83738	106151	417207	654437
2040	1710719	1266675	87355	110737	435231	682708
2041	1785614	1322130	91180	115585	454285	712597
2042	1864824	1380780	95224	120712	474437	744208
2043	1948630	1442832	99504	126137	495758	777653
2044	2037331	1508510	104033	131878	518325	813052
2045	2131252	1578052	108829	137958	542220	850533
2046	2230739	1651716	113909	144398	567531	890236
2047	2336164	1729776	119293	151222	594352	932309
2048	2447926	1812528	125000	158457	622786	976910
2049	2566454	1900291	131052	166129	652942	1024212
2050	2692211	1993405	137474	174269	684936	1074399
2051	2825690	2092238	144289	182910	718895	1127667
2052	2967427	2197185	151527	192084	754955	1184231
2053	3117994	2308670	159216	201831	793261	1244319
2054	3278010	2427151	167386	212189	833971	1308178
2055	3448138	2553120	176074	223201	877254	1376072
2056	3629097	2687108	185314	234915	923292	1448288
2057	3821657	2829686	195147	247380	972282	1525134
2058	4026650	2981470	205615	260649	1024436	1606943
2059	4244975	3143126	216763	274781	1079981	1694071
2060	4477600	3315369	228642	289839	1139163	1786906
2061	4725569	3498974	241304	305891	1202250	1885865
2062	4990012	3694776	254807	323008	1269528	1991398
2063	5272147	3903679	269214	341271	1341307	2103992
2064	5573293	4126657	284592	360765	1417923	2224172
2065	5894871	4364765	301012	381581	1499737	2352506
2066	6238425	4619144	318555	403819	1587142	2489610

4.3.3 Pairs of Passenger trains

For passenger trains, according to the minimum length of the platforms found in passenger station it has the maximum length of 200m this length includes locomotive and coaches in one set. See figure 9:

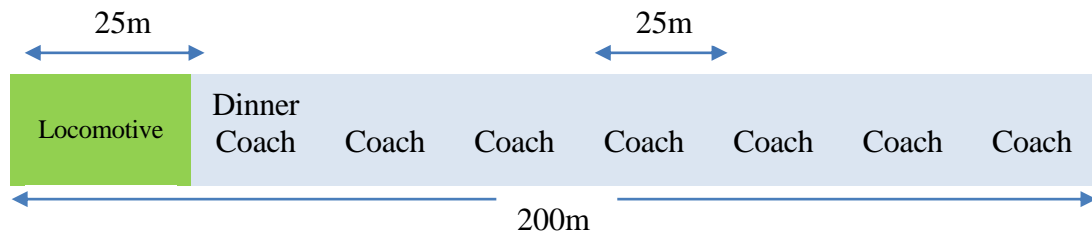


Figure 9 one set of passenger train

For Addis-Djibouti railway ERC have purchased 30 different types of passenger coaches, which are specified on the table below.

Table 25 Type of passenger coaches

Type	hard seat coaches	Hard Sleeper coach	Soft Berth coach	Dinner Coaches
number	20	4	4	2
Capacity(passenger)	118	66	36	50
Length (m)	25	25	25	25

The dinner coach will not be used for passenger transport but only for cater purpose therefore for calculating total number of passengers transported by one set of train; considering 200m total length will occupy 8 set of trains including one locomotive and one dinner coach and the rest 6 coaches is used for passenger seat.

Weighted average number of passenger transported by each coaches is calculated as follows.

$$(20*118+4*66+4*36)/28 = \mathbf{98 \text{ passengers per coach,}}$$

Total number of passengers transported by one trip is

$$98 \text{ passengers} * 6 \text{ coaches} = \mathbf{588 \text{ passengers,}}$$

The number of trains per day is presented table 27, which is calculated as dividing the total number of passengers on each direction by total number of passenger which can be transported by one set of train.

Table 26 pairs of passenger trains/day required to satisfy the forecasted demand

Year	AA-ADAMA		ADAMA-DIRE-DAWA		DIRE-DAWA-DJIBOUTI	
	UP	DOWN	UP	DOWN	UP	DOWN
2017	4	3	1	1	1	2
2018	4	3	1	1	1	2
2019	4	4	1	1	1	2
2020	4	4	1	1	1	2
2021	4	4	1	1	1	2
2022	5	4	1	1	2	2
2023	5	4	1	1	2	2
2024	5	4	1	1	2	2
2025	5	4	1	1	2	2
2026	5	4	1	1	2	2
2027	5	4	1	1	2	2
2028	5	5	1	1	2	2
2029	6	5	1	1	2	3
2030	6	5	1	1	2	3
2031	6	5	1	1	2	3
2032	6	5	1	1	2	3
2033	6	5	1	1	2	3
2034	7	6	1	1	2	3
2035	7	6	1	1	2	3
2036	7	6	1	1	2	3
2037	8	6	1	1	2	3
2038	8	7	1	1	2	3
2039	8	7	1	1	2	4
2040	8	7	1	1	3	4
2041	9	7	1	1	3	4
2042	9	8	1	1	3	4
2043	10	8	1	1	3	4
2044	10	8	1	1	3	4
2045	10	9	1	1	3	4
2046	11	9	1	1	3	5
2047	11	9	1	1	3	5
2048	12	10	1	1	3	5
2049	12	10	1	1	4	5
2050	13	11	1	1	4	6
2051	14	11	1	1	4	6

2052	14	12	1	1	4	6
2053	15	12	1	1	4	6
2054	16	13	1	1	4	7
2055	17	14	1	2	5	7
2056	17	14	1	2	5	7
2057	18	15	1	2	5	8
2058	19	16	1	2	5	8
2059	20	17	2	2	6	8
2060	21	18	2	2	6	9
2061	23	19	2	2	6	9
2062	24	20	2	2	6	10
2063	25	21	2	2	7	10
2064	26	22	2	2	7	11
2065	28	23	2	2	7	11
2066	30	24	2	2	8	12

4.4 Total number of passenger and freight trains/day required

In the future the capacity of Ethio-Djibouti railway will become saturated and cannot be able to add more trains to satisfy the forecasted railway demand. to identify the year that Ethio-Djibouti railway capacity become saturated; the total number of both passenger and freight trains which will occupy the track have to be determined and compared with the practical capacity of the line. The total number of passenger and freight trains required each day thought the year which will occupy Ethio-Djibouti railway track are presented in table 28.

Based on the data from Ethiopian Revenue and Customs Authority and the current situation of the country shows that volume of import freight is much greater than export freight, with 87% (import) to 13% (export) ratio so there is an empty return of freight trains from Ethiopia to Djibouti. Hence these empty return freight trains will occupy the track also and have to be considered to determine the total number of freight trains. The total number of freight trains occupying the track each day to satisfy the forecasted demand can be determined by multiplying the number trains used to transport the imported freight by two the result is presented in table 28 of column {1}.

The number of passenger trains at each section travelling in the up or down direction is different. Therefore the total number of passenger trains at the three sections (Addis Ababa

to Adama; Adama to Dire Dawa; Dire Dawa to Djibouti) occupying the track each day to satisfy the forecasted demand is calculated by taking the maximum number of trains in one direction and multiply by two the result is presented in table 28 of column {2}.

Table 27 pair of trains per day that will occupy Ethio-Djibouti railway track to satisfy the forecasted demand

Year	FREIGHT TRAIN {1}			PASSENGER TRAIN {2}		
	A/A – ADAMA	ADAMA- AWASH	AWASH - DJIBOUTI	A/A – ADAMA	ADAMA- DIRE-DAWA	DIREDAWA- DJIBOUTI
2017	8	16	16	8	2	4
2018	10	16	18	8	2	4
2019	10	18	18	8	2	4
2020	10	18	20	8	2	4
2021	10	18	20	8	2	4
2022	10	20	20	10	2	4
2023	10	20	22	10	2	4
2024	12	20	22	10	2	4
2025	12	22	22	10	2	4
2026	12	22	24	10	2	4
2027	12	22	24	10	2	4
2028	12	24	24	10	2	4
2029	14	24	26	12	2	6
2030	14	24	26	12	2	6
2031	14	26	28	12	2	6
2032	14	26	28	12	2	6
2033	14	26	28	12	2	6
2034	14	28	30	14	2	6
2035	16	28	30	14	2	6
2036	16	28	30	14	2	6
2037	16	30	32	16	2	6
2038	16	30	32	16	2	6
2039	16	30	32	16	2	8
2040	16	32	34	16	2	8
2041	18	32	34	18	2	8
2042	18	32	36	18	2	8
2043	18	34	36	20	2	8
2044	18	34	36	20	2	8
2045	18	36	38	20	2	8
2046	20	36	38	22	2	10

2047	20	36	38	22	2	10
2048	20	38	40	24	2	10
2049	20	38	40	24	2	10
2050	20	38	40	26	2	12
2051	20	40	42	28	2	12
2052	22	40	42	28	2	12
2053	22	40	42	30	2	12
2054	22	42	44	32	2	14
2055	22	42	44	34	4	14
2056	22	42	46	34	4	14
2057	22	44	46	36	4	16
2058	24	44	46	38	4	16
2059	24	44	48	40	4	16
2060	24	46	48	42	4	18
2061	24	46	48	46	4	18
2062	24	46	50	48	4	20
2063	26	48	50	50	4	20
2064	26	48	50	52	4	22
2065	26	48	52	56	4	22
2066	26	50	52	60	4	24

4.5 Capacity improvement areas

The objective of the thesis is to identify the main capacity problems of Ethio-Djibouti railway line and suggest possible and timely capacity improvements.

According to the freight forecasting done within the study period the freight volumes in 2066 GC are expected to increase more than 3 times the current 2017 GC freight volume (see table in appendix A). The number of passengers using railway are increasing rapidly in 2066 GC becomes about 8 times the current 2017 GC passenger number (see table in appendix A). This considerable rise in number of passengers and volume of freight creates the increase in the demand of railway transport as a result capacity constraint will be caused at some time.

The railway capacity analysis done using UIC405 method shows the practical capacity of Ethio-Djibouti railway double track section (Addis Ababa to Adama) is 64 trains/day and that of single track section (Adama/Ethiopia-Negad/Djibouti) are 33 trains/day.

The railway transportation demand analysis done for passenger and freight within the study period indicates the number of trains required each day to satisfy the forecasted demand of railway is illustrated in a tabular form in table 28.

In the single track section from Adama to Djibouti from table 22 we can extract the saturation years and presented in the following table.

Table 28 single track section of Ethio-Djibouti railway line saturation years

year	Railway line	Trains required per day	Total number of trains operating
2030 GC	Adama to Awash	24 freight trains	26 trains per day
		2 passenger trains	
	Awash to Dire Dawa	26 freight trains	28 trains per day
		2 passenger trains	
	Dire Dawa to Djibouti	30 freight trains	32 trains per day
		2 passenger trains	
2036 GC	Adama to Awash	28 freight trains	30 trains per day
		2 passenger trains	
	Awash to Dire Dawa	30 freight trains	32 trains per day
		2 passenger trains	
	Dire Dawa to Djibouti	30 freight trains	36 trains per day
		6 passenger trains	
2037 GC	Adama to Awash	30 freight trains	32 trains per day
		2 passenger trains	
	Awash to Dire Dawa	32 freight trains	34 trains per day
		2 passenger trains	
	Dire Dawa to Djibouti	32 freight trains	38 trains per day
		6 passenger trains	

The analysis done shows the single line section of Ethio-Djibouti railway practically can accommodate 33 trains per day as shown in table 33 the section from Dire Dawa/Ethiopia to Negad/Djibouti will become saturated in the year of 2030 GC and needed capacity improvement.

Second phase improvement in the year of 2036 GC the section from Awash to Diredawa and in the year of 2037 GC the railway section from Adama to Awash need capacity improvement.

To satisfy the increasing railway transportation demand on the single track section is by increasing the number of trains operating on the line; but the capacity analysis done indicates that this section wouldn't allow adding more trains in the saturation years 2030

GC, 2036GC and 2037GC because of infrastructure constraint. Therefore at the first phase in 2030GC the single track railway from DireDawa to Djibouti should have to be changed to double track in order to fulfill the demand. Second phase in the year of 2036GC the section from Awash to Dire Dawa and in the year of 2037 GC the railway line section from Adama to Awash has to be changed to double track railway in order to satisfy the forecasted railway transportation demand.

Double track railway line section; comparing the railway demand number of trains required calculated in table 28 and practical capacity (64 trains/day) it can be concluded that the double track section from SEBETA-ADAMA didn't have the ability to add more train and become saturated at the year of 2059GC.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Railway transportation is predominantly used to transport passengers and freight. The demand for passenger and freight transportation is rapidly increasing in many countries for a variety of reasons. In order to optimize the financial and economic prosperity of a nation, efficient railways are required. Building and optimizing railway networks, however, is a difficult topic due to the inherent structural complexity of railways and various operational factors. In this thesis, the focus is upon capacity determination and expansion planning.

This research shows the demand of railway transport through Ethio-Djibouti corridor for the coming 50 years starting from 2017 GC. It also analyzed the capacity of the newly constructed railway line and estimated whether this line can accommodate the forecasted transportation demand or not.

Based on the analysis, it can be concluded that, for the double track section proper maintenance and increasing its efficiency by improving its operation is enough because it can satisfy all the traffic demand thought the study year and upgrading the infrastructure is not that much necessary.

When the analytical models were applied to analyze the capacity of the Ethio-Djibouti Railway, it was found that the single track section from Dire Dawa to Djibouti of the line starting from 2030 GC and the section from Awash to Dire Dawa, Adama to Awash starting from 2036 GC and 2037 GC respectively cannot meet the anticipated traffic demand. Therefore, infrastructure upgrade by constructing additional track needed at each section in each respective years of capacity saturation.

5.2 Recommendations

The freight transportation of Ethiopia until now is mainly depends on road but now the government constructed this railway line to facilitate the import and export. Therefore this railway line must satisfy the countries full demand; however the single track section of the railway will face capacity constraint starting from 2030GC. Therefore capacity improvement is a timely solution for this railway line. Some of recommendations are elaborated below.

- The timetable developed by ERC for Ethio-Djibouti railway freight trains are in a day time but developing night timetables for freight trains is necessary; to reduce traffic congestion and to get enough power supply freight trains should operate in nightly timetables.
- Since the infrastructure for the single line railway is constructed changing the railway line to double truck will cost around forty percent of the original cost; consequently upgrading the infrastructure will double the current capacity.

5.3 Future Research

This thesis has focused upon utilizing the capacity of existing railway network, and determining saturation point, and when the line saturates what are mechanisms to increase the capacity level to satisfy the demand of transportation. Analytical models were used for capacity determination of the line. There are many avenues that still need to be investigated in future studies. The most significant areas for further research are as below:

- Software based capacity analysis and expansion model for optimizing the capacity of Ethio-Djibouti railway line.
- Investigation of other mechanisms (other than track duplication) for capacity expansion should be performed.
- New capacity expansion approaches should be compared in order to identify the best and the most cost effective way of performing capacity expansion in railway networks.
- Influence of the newly constructed railway Awash Woldia Hara Gebeya railway in the capacity of Ethio-Djibouti railway line.

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APPENDIX A

n	Year (x)	Import(tons) [y]	Export(tons) [y]	(Import) [x*y]	(Export) [x*y]	(Import/Ex port) [x2]	(Import) [y2]	(Export) [y2]
1	1997	1,106,794	373,818	2,210,267,742	746,514,894	3,988,009	1,224,993,095,678	139,740,027,362
2	1998	3,556,019	241,484	7,104,925,419	482,485,707	3,992,004	12,645,269,193,887	58,314,685,499
3	1999	2,553,123	247,883	5,103,693,443	495,518,109	3,996,001	6,518,438,498,197	61,445,979,706
4	2000	2,727,216	323,432	5,454,431,226	646,864,098	4,000,000	7,437,704,999,791	104,608,290,320
5	2001	3,369,679	350,832	6,742,728,587	702,015,616	4,004,001	11,354,739,622,710	123,083,367,276
6	2002	2,595,131	561,291	5,195,453,009	1,123,705,327	4,008,004	6,734,706,843,129	315,048,004,282
7	2003	5,092,941	506,009	10,201,159,932	1,013,536,319	4,012,009	25,938,043,496,764	256,045,255,836
8	2004	3,832,543	539,496	7,680,416,605	1,081,149,368	4,016,016	14,688,387,503,581	291,055,602,356
9	2005	4,413,599	748,154	8,849,266,403	1,500,048,566	4,020,025	19,479,857,929,489	559,734,255,691
10	2006	4,184,892	690,610	8,394,892,911	1,385,363,935	4,024,036	17,513,319,210,312	476,942,361,341
11	2007	4,955,151	831,931	9,944,988,387	1,669,685,707	4,028,049	24,553,523,063,244	692,109,346,678
12	2008	7,603,417	834,480	15,267,660,679	1,675,635,730	4,032,064	57,811,945,098,388	696,356,779,024
13	2009	8,218,723	909,833	16,511,415,419	1,827,854,055	4,036,081	67,547,415,211,357	827,795,687,563
14	2010	7,192,247	1,163,535	14,456,415,721	2,338,705,460	4,040,100	51,728,411,545,318	1,353,813,823,958
15	2011	7,391,318	1,215,005	14,863,940,955	2,443,375,055	4,044,121	54,631,585,136,329	1,476,237,150,584
16	2012	8,593,864	1,318,950	17,290,854,789	2,653,726,877	4,048,144	73,854,502,046,344	1,739,628,416,646
17	2013	7,533,856	1,373,225	15,165,653,076	2,764,302,181	4,052,169	56,758,993,325,329	1,885,747,249,507
18	2014	10,246,626	1,594,061	20,636,704,784	3,210,438,232	4,056,196	104,993,344,588,809	2,541,029,486,655
19	2015	10,444,944	1,551,748	21,046,561,495	3,126,771,211	4,060,225	109,096,848,269,473	2,407,920,302,142
20	2016	14,595,826	2,205,872	29,425,185,216	4,447,037,812	4,064,256	213,038,136,622,276	4,865,870,974,297
Σ	40,130.0 0	120,207,910	17,581,649	241,546,615,796	35,334,734,261	80,521,510	937,550,165,300,401	20,872,527,046,724
	Import	Export		Import	Export			
a	-1,048,367,144.08	-171,575,594.54	b	525,480.96	85,948.01			

The forecasted growth rate of Ethiopian population

Year	Popn growth rate	Year	Popn growth rate	Year	Popn growth rate	Year	Popn growth rate	Year	Popn growth rate
2015	2.87	2026	3.508	2037	4.146	2048	4.784	2059	5.422
2016	2.928	2027	3.566	2038	4.204	2049	4.842	2060	5.48
2017	2.986	2028	3.624	2039	4.262	2050	4.9	2061	5.538
2018	3.044	2029	3.682	2040	4.32	2051	4.958	2062	5.596
2019	3.102	2030	3.74	2041	4.378	2052	5.016	2063	5.654
2020	3.16	2031	3.798	2042	4.436	2053	5.074	2064	5.712
2021	3.218	2032	3.856	2043	4.494	2054	5.132	2065	5.77

Assessment of improvement areas for increasing the capacity of Ethio-Djibouti railway line

2022	3.276	2033	3.914	2044	4.552	2055	5.19	2066	5.828
2023	3.334	2034	3.972	2045	4.61	2056	5.248		
2024	3.392	2035	4.03	2046	4.668	2057	5.306		
2025	3.45	2036	4.088	2047	4.726	2058	5.364		

The forecasted total number of passengers

year	popn growth rate	AA-ADAMA		ADAMA-DIRE-DAWA		DIRE-DAWA-DJIBOUTI	
		UP	DOWN	UP	DOWN	UP	DOWN
2017	2.986	1790510	1325755	46783	59305	229698	360307
2018	3.044	1845013	1366111	48207	61110	236690	371275
2019	3.102	1902245	1408488	49703	63006	244032	382792
2020	3.16	1962356	1452996	51273	64997	251743	394888
2021	3.218	2025505	1499753	52923	67089	259844	407595
2022	3.276	2091861	1548885	54657	69286	268357	420948
2023	3.334	2161603	1600525	56479	71596	277304	434983
2024	3.392	2234925	1654815	58395	74025	286710	449737
2025	3.45	2312030	1711906	60410	76579	296602	465253
2026	3.508	2393136	1771960	62529	79265	307006	481574
2027	3.566	2478475	1835148	64759	82092	317954	498747
2028	3.624	2568295	1901654	67105	85067	329477	516822
2029	3.682	2662859	1971673	69576	88199	341608	535851
2030	3.74	2762450	2045413	72178	91498	354384	555892
2031	3.798	2867368	2123098	74920	94973	367844	577005
2032	3.856	2977934	2204965	77809	98635	382028	599254
2033	3.914	3094490	2291267	80854	102495	396981	622709
2034	3.972	3217403	2382276	84066	106566	412749	647443
2035	4.03	3347065	2478282	87453	110861	429382	673535
2036	4.088	3483893	2579594	91029	115393	446936	701069
2037	4.146	3628335	2686544	94803	120177	465466	730135
2038	4.204	3780870	2799486	98788	125230	485034	760830
2039	4.262	3942011	2918800	102998	130567	505706	793257
2040	4.32	4112306	3044892	107448	136207	527552	827525
2041	4.378	4292342	3178198	112152	142170	550649	863754
2042	4.436	4482751	3319183	117127	148477	575075	902070
2043	4.494	4684206	3468347	122391	155150	600919	942609
2044	4.552	4897431	3626226	127962	162212	628273	985517
2045	4.61	5123202	3793395	133861	169690	657236	1030949
2046	4.668	5362353	3970471	140110	177611	687916	1079074
2047	4.726	5615778	4158115	146731	186005	720427	1130071

Assessment of improvement areas for increasing the capacity of Ethio-Djibouti railway line

2048	4.784	5884437	4357039	153751	194904	754892	1184134
2049	4.842	6169361	4568007	161196	204341	791444	1241469
2050	4.9	6471660	4791839	169094	214354	830225	1302301
2051	4.958	6792525	5029419	177478	224981	871388	1366870
2052	5.016	7133238	5281694	186380	236266	915096	1435432
2053	5.074	7495178	5549688	195837	248254	961528	1508266
2054	5.132	7879831	5834498	205887	260995	1010874	1585670
2055	5.19	8288794	6137308	216573	274540	1063338	1667966
2056	5.248	8723790	6459394	227939	288948	1119142	1755501
2057	5.306	9186674	6802129	240033	304280	1178524	1848648
2058	5.364	9679448	7166996	252909	320602	1241740	1947809
2059	5.422	10204267	7555590	266621	337985	1309067	2053419
2060	5.48	10763461	7969637	281232	356506	1380804	2165947
2061	5.538	11359542	8410995	296807	376249	1457273	2285897
2062	5.596	11995222	8881674	313416	397304	1538822	2413816
2063	5.654	12673431	9383844	331137	419768	1625827	2550293
2064	5.712	13397338	9919849	350051	443745	1718694	2695966
2065	5.77	14170364	10492225	370249	469349	1817863	2851523
2066	5.828	14996213	11103711	391827	496703	1923808	3017710

APPENDIX B

Sample calculations

Modal split of freight from Addis/Ababa-Adama

Table: Modal share for freight between train and truck

		Trip distance(km)	Speed (km/hr)	t_{ij}^v	t_{ij}^w	t_{ij}^t	f_{ij}	\emptyset_j	c_{ij}	p_{ij}
	a_i			0.03	0.04	0.06	0.1	0.1		
A/A-Adama	truck	98	60	98	5	3	0.047	4	3.725	58%
	train	113	80	84.75	15	2	0.046	0	3.672	42%
Adama - Awash	truck	193	60	193	5	3	0.047	4	1.743	20%
	train	134	80	100.5	15	2	0.046	0	4.170	80%
Awash - Djibouti	truck	612	60	612	5	3	0.047	4	9.145	15%
	train	490	80	367.5	15	2	0.046	0	11.75	85%

Table: modal split of passengers between train, bus and car

		Trip distance (km)	Speed (km/hr)	t_{ij}^v	t_{ij}^w	t_{ij}^t	f_{ij}	\emptyset_j	c_{ij}	p_{ij}
	a_i			0.03	0.04	0.06	0.1	0.1		
A/A-Adama	train	113	120	56.5	10	2	0.35	-	2.85	42%
	Car	98	100	58.8	-	-	1.75	4	2.34	25%
	bus	98	80	73.5	5	3	0.50	-	2.63	33%
Adama-Dire Dawa	train	326	120	163	10	2	0.35	-	9.70	81%
	car	412	100	247.2	-	-	1.75	4	5.445	1%
	bus	412	80	309	5	3	0.50	-	8.166	18%
Dire Dawa - Djibouti	train	299	120	149.5	10	2	0.35	-	9.27	83%
	car	393	100	235.8	-	-	1.75	4	5.04	1%
	bus	393	80	294.75	5	3	0.50	-	7.65	16%

The modal split is done according to generalized cost parameter C_{ij} ,

$$c_{ij} = a_1 t_{ij}^v + a_2 t_{ij}^w + a_3 t_{ij}^t + a_4 f_{ij} + a_5 \emptyset_j$$

The constants are $a_1=0.03$, $a_2=0.04$, $a_3=0.06$, $a_4=0.1$, $a_5=0.1$

Where t_{ij}^v the in-vehicle travel time between i and j

t_{ij}^w is the walking time to and from stops,

t_{ij}^t is the waiting time at stops,

f_{ij} is the fare charged to travel between i and j and,

\emptyset_j is the parking cost.

Input data; distance from Addis/Ababa to Adama by train 113km, by truck 98km

Average speed of train 80km/hr, for truck 60km/hr.

$$t_{ij}^v = (113\text{km}) / (80\text{km/h}) = 1.4125\text{hr} = 84.75\text{min};$$

$$t_{ij}^v = (98\text{km}) / (60\text{km/h}) = 1.633\text{hr} = 98\text{min};$$

$$t_{ij}^w = 15 \text{ min, for train; } t_{ij}^w = 5 \text{ min};$$

$$t_{ij}^t = 2 \text{ hr, for train; } t_{ij}^t = 3 \text{ hr, for train}$$

$$f_{ij} = 0.046\text{USD/km for train; } f_{ij} = 0.047\text{USD/km for truck}$$

$$C_{ij(\text{train})} = 0.03 * 84.75 + 0.04 * 15 + 0.06 * 2 + 0.1 * 0.046 + 0.1 * 0 = 3.672$$

$$C_{ij(\text{truck})} = 0.03 * 98 + 0.04 * 5 + 0.06 * 3 + 0.1 * 0.047 + 0.1 * 4 = 3.725$$

The probability of choosing on mode is calculated by the following formula;

$$P_{ij}^1 = \frac{e^{-c_{ij}^1}}{\sum e^{-c_{ij}^m}}$$

$$P_{ij}^{\text{train}} = \frac{e^{-3.672}}{e^{-3.672} + e^{-3.725}} = 42\%$$

$$P_{ij}^{\text{truck}} = \frac{e^{-3.725}}{e^{-3.672} + e^{-3.725}} = 58\%$$

Modal split of passenger from Addis Ababa-Adama

$$t_{ij(\text{train})}^v = (113\text{km}) / (120\text{km/h}) = 0.941\text{hr} = 56.50\text{min};$$

$$t_{ij(\text{bus})}^v = (98\text{km}) / (80\text{km/h}) = 1.225\text{hr} = 73.5\text{min};$$

$$t_{ij(\text{car})}^v = (98\text{km}) / (100\text{km/h}) = 0.98\text{hr} = 58.8\text{min};$$

$$t_{ij(\text{train})}^w = 10 \text{ min, } t_{ij(\text{bus})}^w = 5 \text{ min, } t_{ij(\text{car})}^w = 0 \text{ min,}$$

$$t_{ij(\text{train})}^t = 2 \text{ h; } t_{ij(\text{bus})}^t = 3 \text{ h, } t_{ij(\text{car})}^t = 0,$$

$$f_{ij(\text{train})} = 0.35\text{birr/km; } f_{ij(\text{bus})} = 0.50\text{birr/km; } f_{ij(\text{car})} = 1.75\text{birr/km;}$$

$$\emptyset_{j(\text{train})} = 0; \emptyset_{j(\text{bus})} = 0; \emptyset_{j(\text{car})} = 4\text{birr}$$

$$C_{ij(\text{train})} = 0.03 * 56.5 + 0.04 * 10 + 0.06 * 2 + 0.1 * 0.35 + 0.1 * 0 = 2.85$$

$$C_{ij(\text{bus})} = 0.03*73.5+0.04*5+0.06*3+0.1*0.50+0.1*0=2.34$$

$$C_{ij(\text{car})} = 0.03*58.8+0.04*0+0.06*0+0.1*1.75+0.1*4=2.63$$

The probability of choosing on mode is calculated as follows;

$$P_{ij}^{\text{train}} = \frac{e^{-2.85}}{e^{-2.85}+e^{-2.34}+e^{-2.63}} = \underline{42\%}$$

$$P_{ij}^{\text{bus}} = \frac{e^{-2.34}}{e^{-2.85}+e^{-2.34}+e^{-2.63}} = \underline{25\%}$$

$$P_{ij}^{\text{car}} = \frac{e^{-2.63}}{e^{-2.85}+e^{-2.34}+e^{-2.63}} = \underline{33\%}$$

Theoretical capacity calculation

$$C = \frac{T}{t_{fm} + t_{zu} + t_r}$$

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

T = 1440 minutes (for one day)

$$t_{zu} = 0.25*a$$

Where “a” is block section within/protected by signals, i.e., each track, in a fixed-block train control & signaling system. Take block sections of fixed length 3 km in case of long distances between consecutive stations.

tr= running time margin, $t_r = 0.33 \times t_{fm}$, the desired utilization is 75%

t_{fm} = average of minimum train headways

$$t_{fm} = \frac{\sum n_i * n_j * t_{fij}}{\sum n_i * n_j}$$

Where t_{fij} is the minimum headway between a train of type j following a train of type i.

Double track section from Labu to Indode length 18.309km

From the timetable we can determine minimum train headway as $t_{fij}=11$ min

Therefore

$$t_{fm} = \frac{1 * 1 * 11 + 1 * 2 * 11 + 2 * 1 * 11 + 1 * 1 * 11 + 1 * 2 * 11}{1 * 1 + 1 * 2 + 2 * 1 + 1 * 1 + 1 * 2} = \underline{11 \text{ min/train}}$$

$$t_r = 0.33 \times 11 = \underline{3.63}$$

$$t_{zu} = 0.25 * a$$

But $a = 18.309 \text{ km} / 3 \text{ km} = \mathbf{6 \text{ block sections}}$

$$t_{zu} = 0.25 * 6 = 1.5$$

$$C = \frac{1440}{11 + 1.5 + 3.63} = \mathbf{89 \text{ trains/day}}$$

Theoretical capacity for single track SIRBA KUNKUR to MIESO distance 48.28km

From the timetable we can determine minimum train headway as $t_{fij} = 16 \text{ min}$

Therefore

$$t_{fm} = \frac{1 * 1 * 16 + 1 * 1 * 16 + 1 * 1 * 16 + 1 * 1 * 16 + 1 * 1 * 16}{1 * 1 + 1 * 1 + 1 * 1 + 1 * 1 + 1 * 1} = \mathbf{16 \text{ min/train}}$$

$$tr = 0.33 \times 16 = \mathbf{5.28}$$

$$t_{zu} = 0.25 * a$$

But $a = 48.28 \text{ km} / 3 \text{ km} = \mathbf{16 \text{ block sections}}$

$$t_{zu} = 0.25 * 16 = 4$$

$$C = \frac{1440}{16 + 5.28 + 4} = \mathbf{57 \text{ trains/day}}$$