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Analyzing Addis Ababa Light Rail Transit Railway Operation Reliability

By

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Advisor

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The undersigned have examined the thesis entitled **Analyzing Addis Ababa Light Rail Transit Railway Operation Reliability** presented by **Abdourahman Omar Hassan**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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I certify that research work titled "**Analyzing Addis Ababa Light Rail Transit Railway Operation Reliability**" is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Abstract

Delays in railway networks cause problems in the daily operation and result in reduced reliability of the railway operation. Since the delay is not caused only by the overcrowded train schedules but also the congestion at railway stations during the peak hours. In fact the determination of train dwell time is an essential step in planning railway timetable with taking the passengers' experience into account.

In view of that, this research focuses on describing how it is possible to use passenger flow to estimate the actual delays on Addis Ababa LRT. The combination of the passenger flow on dwell time and the headway of a train is described, the research methodology adopt a strategy to estimate these paramaters to consider various kinds of improvement and demonstrating the possibility of predicting an eventual decreasing the delay of the trip and by the same time satisfy the customers.

The result demonstrated that using together between dwell time and headway time to analyse the reliability of AALRT have given a benefit return concerning about the delay caused but the daily operation..

Finally, as the proposed investigated method is relatively easy to implement based on collection passengers flow data, the contributions from the outcomes of these models are briefly addressed.

Keywords: reliability, dwell time, headway, delay, passengers flow

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Terms and definition

Dwell time: is the length of time any train stops at any station.

Train capacity: is the capacity of a train which can carry at rated load or over load.

End of route: is the last point/destination of any train route.

End time: is the time on which any train stops operation.

Route: is the direction/way of train runs through on the specified network.

Route length: is distance travel from a point of origin to a point of destination along a specified route.

Route name: is the name given for routes along specified railway network.

Start of route: is the beginning/origin of a route.

Start time: is the time on which any train starts operation.

Start time interval/head on time: is the time difference between successive trains on the same route.

Station: is the place where passengers alight and board or place where trains stop along the train route in my case.

AA-LRT: Addis Ababa Light Rail Transit

APC: Automatic passenger counting

AFC: Automatic fare collection

CREC: China Railway Engineering Corporation

Chapter 1

1.1 Introduction

Ethiopia has launched the construction of a 5,000 km railway network which aims to link the capital, Addis Ababa, to various regions of the country which is part of the country's five-year transformation plan (China Railway Engineering Corporation, 2011).Therefore studying about and preparing for the operation is indispensable to make the city transportation system modern and efficient.

Delays in a railway network are one of the biggest problems in the daily operations of a railway company. Therefore, attention to transit quality and efficiency in general and reliability in particular is increasing. For railway services, reliability can be defined as the continuity of correct service. Seen from the passengers' point of view, the reliability can be contain the closely related concept punctuality, punctuality relates to the deviation from the scheduled arrival and departure times. Trains are not allowed to depart before time since from a passenger perspective; the next departure is late by the frequency. Therefore, the trains will always depart "on time"/punctual or delayed. If the time is divided in small time intervals (e.g. seconds), it is very difficult for the trains to depart exactly on time. Since the trains are not allowed to depart before time, the risk of (very) small delays is high. In high-frequency systems, more focus on headway deviation is common because travelers tend to arrive at random. However, in case the vehicles operate slower than planned, the headway deviation method may not be sufficient to describe the reliability of the railway operation. To achieve a method with low complexity, the headway deviation can be combined with the running time deviation of the vehicles to guesstimate the impact on the reliability of the railway operation in case of altered timetables or modified infrastructure, it is necessary to conduct a simulation of the railway operation. Therefore, this research first presents the traditional method of simulating train delays. This is next section followed by an approach that takes passenger delays into account when measuring the reliability of the railway operation.

1.2 Background

1.2.1 History

The project is located in Addis Ababa, the capital of Ethiopia, which was the location of the head office of African Union. The altitude of the plateau is 2400m. With an urban population of over 3.400.000, it takes 25% of the total population of Ethiopia. The urban area is 530.14 km2, and the density reached 5.607.96/km2. (Golini, 2000)

To effectively solve the problem of urban transportation, especially that of the downtown area, the government of Ethiopia decides to build a light rail in the city of Addis Ababa. Currently this project has planned to construct two lines, the east-west line and the south-north line. About 3 km is the shared section; wich has the greatest passenger flow. Addis Ababa's transport problems are diverse:

- Chaotic movement of mini-bus taxi
- Environmentally unacceptable emission
- Unsafe, hazardous to life and property

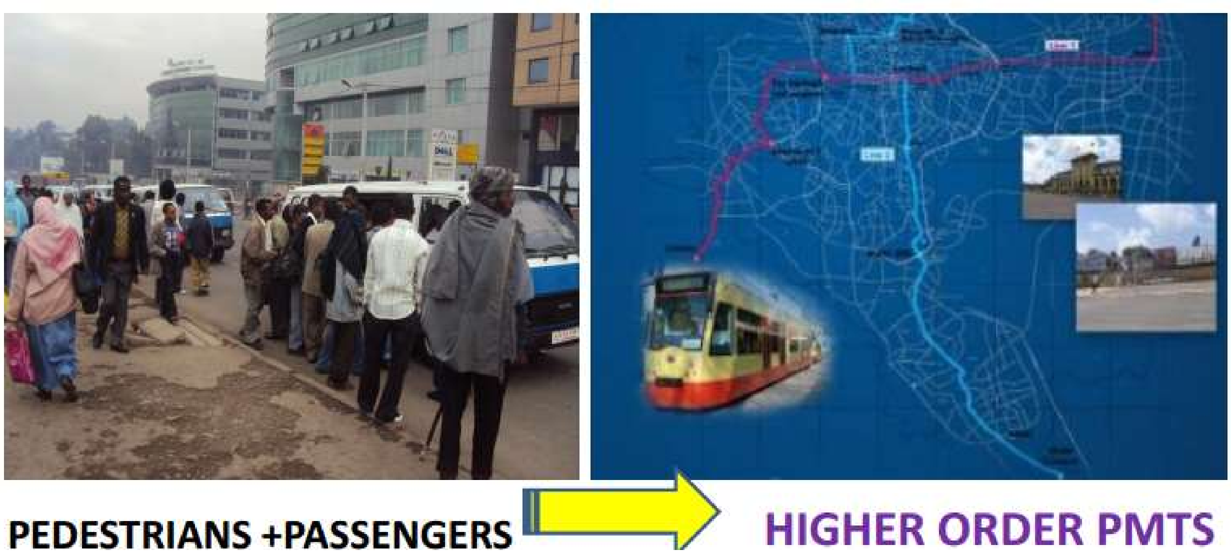


Figure 1.1: chaotic movement to better traffic

According to CREC the system carried on average 113,500 daily passengers in January 2016 with 153,000 passengers as highest passenger load during a single day. Service frequency was 10 minutes during peak hours on both lines and 20 minutes during off-peak hours. On average there were 94 train rotations on the Blue line (3,177.2 vehicle-kilometers) and 93 rotations on the Green line (3,236.4 vehicle-kilometers). (China railway group, 2017)

1.2.2 Future expansion

There are future plans for extensions in all four directions. According to Getachew Betru, CEO of Ethiopian Railways Corporation, the Ethiopian government indicated that any new line built should be completely grade-separated. Apart from extending the existing lines, two new lines are under consideration by the Ethiopian government. The first one will start at St. George's Cathedral, pass along Mexico Square to the African Union Headquarters and will terminate at Lebu, connecting to the new national rail network. The second line will start at Megenagna Roundabout and passes via Bole Airport, Wello Sefer area, Saris market area and Jommo area and terminates at Lebu. (China railway group, 2017).

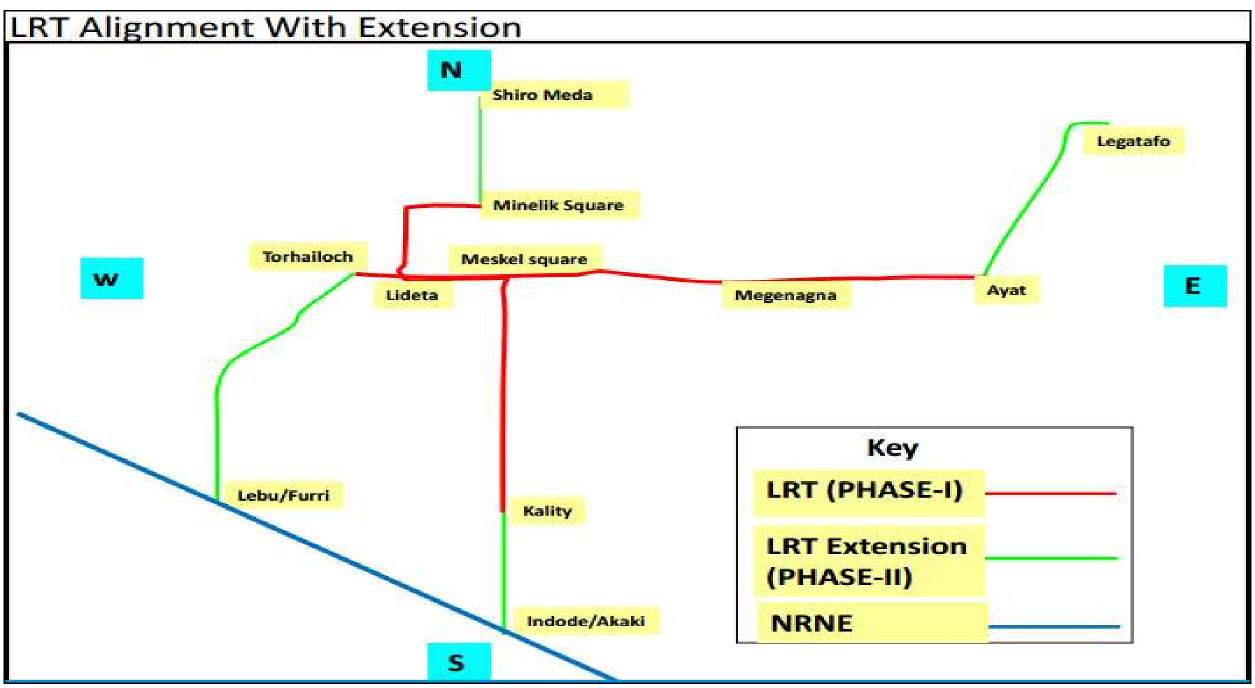


Figure 1.2: Addis Ababa network (From Kality depot)

1.3 Statement of Problem

For railway operation, reliability can be defined as the continuity of correct services. As it seems in Addis Ababa LRT demand it becomes more used gradually because of the fact that population growth faster than the transport facility. Thus, long queues for long time especially at peak hours are becoming more prevalent problem in Addis Ababa LRT that affects operation time, hence reliability of railway operation system.

Figure1.3: Peak hour passenger volume problem

Deploying train transportation system with more reliable and efficient time table, may not be recovered the existing problem. So, there are a lot of paramaters that the reliability of the train depends and which might be solved the actual issue, dwell time and headway time are some of these measure points that involved the inefficiency of Addis Ababa LRT based vehicle capacity, on passengers demand volumes and passengers service times.

In fact delays in railway networks causes' problem in daily operation and result for reduced reliability of the railway operation system. Then a model with an aim of minimizing average passenger travel time, waiting time and providing number of trains required in that line (EW). Therefore, the purpose of this study is to minimize actual train delay.

The reliability improvement of the Addis Ababa LRT can contribute a better result by including more supplements to the timetable increasing headway time according to dwell time. However, there is a trade-off between reliability and headway time of Addis Ababa LRT.

1.4 Objectives

1.4.1 General Objective

The general objective of this research is to analyse reliability of Addis Ababa LRT through passenger flow at stations and the headway time of the train trip of consecutives trains.

1.4.2 Specific Objective

The specific objectives of this study are:

- To investigate passenger flow (i.e. boarding and alighting)
- To study influence of the dwell time regarding the headway parameter
- To identify the factors that cause customers satisfaction
- To minimize the average waiting of passenger(s)

1.5 Research questions

In this work an in-depth investigation will be made on how the railway transport industry can take advantage form the improvement of the headway through dwell time reliability about Addis Ababa LRT. Particularly major cause of lowering about reliability of railway operations is 'Delay' to remedy this defect this paper will work on some method based of two closely related parameters like dwell time and the headway time on train. These and other questions are going to be addressed by this research.

- What is the relation between dwell time and headway time?
- How the headway time can minimize the delay of the AALRT railway operation reliability?
- How the improvement of the headway time can satisfy customers?

1.6 Methodology

The following methodology have been employed in this thesis as listed below and carried out orderly:

- Literature review
- Passenger flow model, followed by the headway time delay

Dwell time is a key parameter of system performance, service reliability and quality in any mode of public transportation. The following highlights the importance of dwell time studies:

i) Dwell time studies gives insight into the travel time and headway variations and can produce effective timetables;
ii) With known parameters affecting dwell time, efforts can be made at critical stations to reduce dwell time.

So the approach adopted during this study is the analyzing of this parameters of Addis Ababa LRT to get better and reliable timetable for trains trips during the day and the work started collecting data about passenger flow for each station in order to test and compare if the new design will give us a good result comparing with the existing one. Therefore the approach consists to make an analytical computation to see the difference about the headway time, the dwell time, and speed average. A quick explanation is given of how and why the analytical method is attractive way to analyze a statistical data.

1.6.1 Analytical method

When using an analytical method a mathematical model is developed using some or all available data for the system. Analytical methods are often used to find optimal or near-optimal solutions to given problems. Depending on the input data, analytical methods are used for different measures like delay or cost analysis. Analytical methods are often mathematically demanding, but do not require much input because the input data is sparse the methods often make a lot of assumptions, which may result in less reliable results. The computational time for analytical methods is usually rather small, hence these methods are good for quick evaluations and many different solutions can be evaluated within a short range of time. For this reason analytical methods are of good use when planning future investments, where uncertainty and lack of realistic input, knowledge is dominating the situation. Analytical methods are used for strategic decisions in the early planning process and are usually only practical for very simple structured systems. An analytical solution method will be the solution of a periodic event scheduling problem which is used to solve problems of the effect speed restriction on actual travel time between two stations of a train to reduce or measure delay in our case.

Then the coming chapter will see how it proceed using these model concerned about the estimation model dwelling time. First it will try to see the existing design to make some adjustment on level of the headway time in proportion to decrease the dwell time, this will be the way it will be followed. This research is based on the design of the existed Addis Ababa LRT design system and observations of constructions held on East-West line. Data gathered from field and existing preliminary design controlled and synthesized based on variables such as safety, operational efficiency, cost, energy efficient system and soon in order to come up with different and more suitable signaling design for Addis Ababa LRT system. And this research will try to prove the hypothesis through getting enough facts about the headway time and the consequences by improving the average speed of the operation such as operational efficiency and energy consumption. Customers' satisfaction issues are also the main parameter that has to be respected and improved on the study new design.

Some technical documents/parameters that can be used for mathematical analysis are being received from Ethiopian Railway Corporation.

- **Data Collection:**
- **Primary data**:
  . Field observation of station at all most 80% AALRT station and recording each individual parameter; like head on time, dwell time, operation, and demand of passenger
- **Secondary data**:
  . Design data and facility concerning the study from Addis Ababa light rail transit office.
  . Reviewing different standards and manual for light rail transit.

- Research journal articles - industry related journals such as Journal of Air Transport Management, Journal of Transportation Planning and Technology and Review of Network Economics,

1.7 Limitations of the study

This thesis thematic area is limited to looking in to the relationships on dwelling time station increasing and the headway delay concerning AALRT operation. Furthermore due to lack of delay in the daily operation, the analysis is done on the line segment of EW concentrating on some the section of this line of AALRT; the issue is to maximize the efficiency of the travel time and customers satisfaction.

The project is mainly focused on qualitative assessment of the reliability on AALRT operation based on time (dwell time, headway time) and comfort approach rather than design by using quantitative data.

1.9 Layout of the thesis

Chapter 1 is about the introduction, statement problem, objectives and about methodology in brief way.

Chapter 2 introduces the Literature review to the reader; it then describes a little related work concerned on punctuality, delays, headway speed restrictions etc.

Therefore it describes also about the passenger flow, the different estimation model for dwell times and a final conclusion.

The third chapter will present the collected data for analysis conducted. The analysis is utilized for one method of attack. The approach is “investigates the dwell time on passenger flow and the headway there by punctuality”.

Chapter 4, are the results and discussing from the earlier chapters. Then we relate these results to the research questions, which are described in previous section.

Chapter 5 is the concluding part followed by some recommendations for further research is given.

Chapter 2

2. Literature Review

Over the last twenty years, a range of researchers has studied railway punctuality and delays and passengers flow issues. Literature reports on different types of railway timetabling research. The overview in this section starts with selected literature that gives an overview of railway practice and research. The main part of this review focuses on timetable construction and evaluation. This part starts with timetable construction.

2.1 Punctuality

In the transportation sector service planning goes further beyond determining optimal travel cost and duration. It extends further in to meeting customer requirements and expectations. Studies have shown that these days in the transport sector punctuality takes of critical significance (Hariss 1992, Bates 2001). In rail way service in addition to smoothening operations punctuality is contributing a lot towards insuring delivery of quality service. Train stations currently, being crowded with busy multi-platform sets, it is becoming critical to have a clear understanding of the punctuality of individual travels coming in and going out (Carvile 2003). Punctuality is a critical issue in railways as the provision of reliable arrival time most often out ways the provision of faster journey with less certain arrival times (Harris 1992).

It have been noticed that in Norway the railway system doesn't only show variation but also there is a declining trend[1] When it comes to punctuality from the year 2005 to 2010 (see figure 2 below). With this context in mind efforts had been employed to provide a holistic explanation regarding factors influencing punctuality (Olsson & Haugland, 2004).

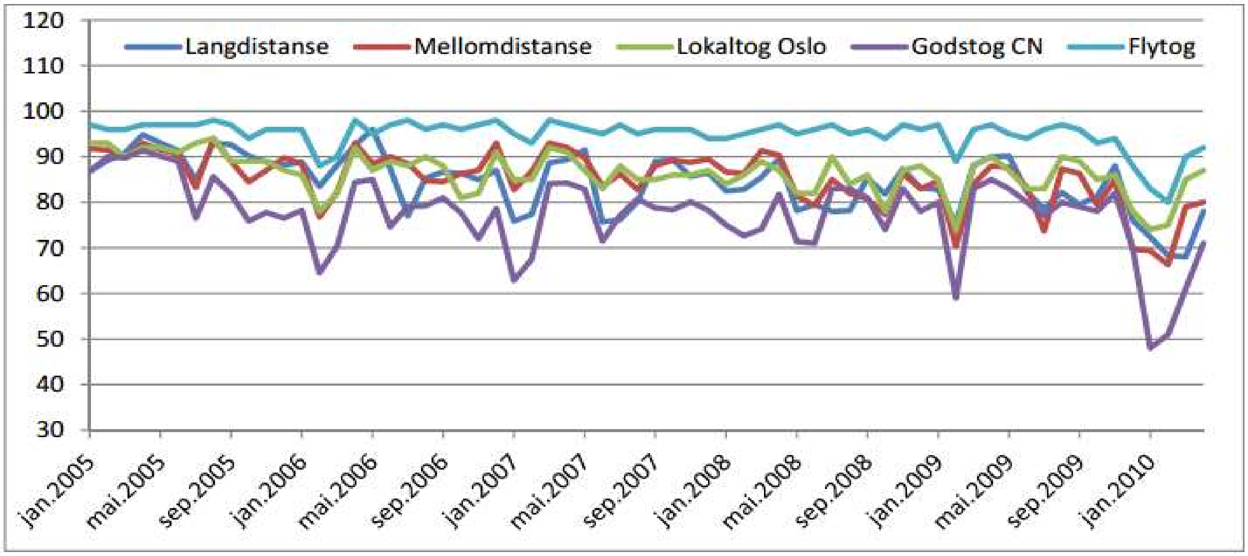


Figure 2.1: Punctuality measured as the percentage of punctuality to the final destination (Olsson et.al 2010).

Punctuality is a critical issue in railways as the provision of reliable arrival time most often out ways the provision of faster journey with less certain arrival times (Hariss, 1992). (Harris1992) points out three major reasons why punctuality is being taken worse than it actually is as:

- Passengers tend to have selective memory of concentrating more on poor performances on top of good once
- More often passengers take late trains than punctual once
- Train operators tend to avoid early running, as it might balance out late arrivals.

2.2 Punctuality and Delays

(Gylee 1990) The two terms are most often mentioned as similar terms but have different meaning although delay could be other version of punctuality for a given a train is not punctual, and had a negative deviation from predefined target time then we call it delayed. Delays are measured in time units whereas punctuality is expressed through percentage of numbers. Primarily there are two types of delays but different authors use different terminologies and scope of definitions in presenting them. (Gylee 1994) uses the term primary and secondary delays to signify delays with their size to impact. The primary once being, the most impacting and the secondary once being shadowed by the influence of the primary once.

Table2.1: variables affecting punctuality

Variables affecting punctuality by Harris	**Variables affecting punctuality by Olson&Haughland**
1. Length of train in carriage: length of a train is assumed to have influence in virtue of time taken to go across up and down hills and accelerate to regain speed in case of speed restrictions.	1. Number of passengers and occupancy ratio: it was found out that number of passengers with higher rate of occupancy and punctuality has a negative correlation. With increased number of passengers, it was noticed that the trains tend to be not punctual.
2. Previous number of station stops: this is more related to the lateness caused by loading and unloading as the train stops more frequently.	2. Infrastructure Capacity utilization : it was noticed that with increased capacity comes increased punctuality

3. Previous distance covered: here it is assumed that with increased distance traveled the probability of encountering defective tracks and wreckage is high.	3. Cancelation and regularity: this showed that cancelation and punctuality have a positive correlation, cancellation and delay being apparent at the same time.
4. Age of the motive power unit: this is a factors more related to aging parameter decreasing reliability of the train engine and power units	4. Speed restriction: the correlation was found to be weak and sometimes negative opposite to what is expected. This might be counter balanced by the 4% allowance the Norwegian timetable takes in to account. This is the main thematic area of this thesis.
5. Track occupation: this is more related to secondary type of delays whereby delay or failure of one train propagates in to other train delays on the congested and busier tracks.	5. Departure and arrival punctuality. Here the relationship and correlation between departure delays and delays associated with arrival was investigated and it marked strong correlation.

From the above mentioned and discussed factors which affect punctuality we will go in depth to investigate the effect of speed restrictions on punctuality. This is because speed reductions are often highlighted as major causes of delays.

2.3 Speed Restriction

Speed restrictions or speed reduction is one of the variables that affect punctuality of trains. In the presence of speed restrictions both freight and passenger trains need to make technical adjustments so as to make it through the speed restriction zones. The railway groups' standard GK/RT0038 (Railway Group Standard, 2000) defines speed restriction as "a set out principles governing the signing and advice of permissible speeds, temporary speed restrictions and emergency speed restrictions on running lines to ensure that train drivers have sufficient information to control their trains safely". Speed restrictions influence the travel time of the trains in virtue of time taken so as to adjust to the limit placed by the restrictions. At times when the train approaches the speed restriction zone the operators need to decelerate to attain the placed speed restriction and have to keep the speed constant throughout the zone. In addition while exiting from the speed restriction zone the operator again needs to accelerate to regain the optimal permissible speed set. Enticed with this there will be train category and operator experience dependent associated time losses.

Most often the time taken to pass a speed restriction zone is merely a pure physics calculation, which we will see later in the upcoming sections. But there are scenarios of varied intensity which are taken in to account when it comes to the retardation and acceleration of the trains.

The maximum allowable operating speed of the train on main line is based on a variety of safety factors. It is therefore necessary to have speed enforcement devices installed to minimize the potential for errors or operating procedure violations. A speed check enforcement device must be installed along the main line to ensure that a posted speed is not exceeded if it is determined that excessive speed at this location may pose a threat to public or passenger safety. The speed check must trigger the trains' automatic braking system once the train exceeds the posted speed limit.

Note: Speed restrictions may be due to curves, special work, or speed controls approaching a terminal station. (Railway Group Standard, 2000)

2.3.1 Headway

Headway is an important variable when analyzing LRT is the operating headway.

Headway is defined as the time between LRT vehicles operating in the same direction. Headway can vary over the day by demand but for our purposes is considered an important factor. 10min headway indicates that a LRT vehicle will be generated from each direction approximately every 10min. Since the analysis considers two operation of the LRT vehicles arrive at the intersection every 5min. The term "headway" usually is defined as the time between the front bumper of one vehicle and the front bumper of the next, while in this study, vehicle headway that of the most interest is the time interval between the back bumper of one vehicle and the front bumper of the next, more precisely, called gap.

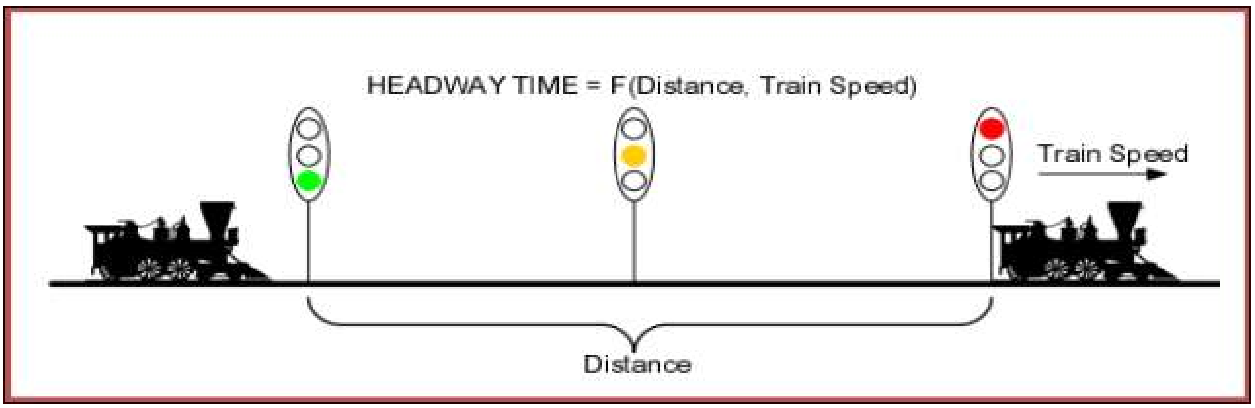


Figure2.2: headway process

2. 4 Passenger flows for train delay reduction

The train delay is caused by not only the overcrowded train schedule but also the congestion at railway station. Passengers choose their train door in consideration of crowded condition at platform as well as structure of origin and/or destination station. An overconcentration to a train door lengthens the stopping time. It is possible to reduce the dwell time at railway station by controlling passenger flows at platform. Therefore, management of the passenger flows is one of the effective solutions to the train delay problem. This study focuses on the passenger's flow at the station and develops a system which reproduces the complex passenger's walking behavior taking into account the station facilities. Using this system, the paper describes the acquired knowledge of the examination of measures to reducing train delays. However, the train running time becomes the major cause during the later rush hours. So it would appear that the train delay is occurred by increases in the dwell time and then its influence extends to the train running time. In other words, the train delay is caused by the passenger factor and later on extends to the train operation factor. Therefore, management of passenger flow offers a basic measure for controlling the increase in the train dwell time and thus becoming one of the effective measures to the problem of train delay. (HIBINO, Naohiko YAMASHITA, Yoshihisa KARIYAZAKI, Keiji MORICHI, Shigeru, 2010)

Figure following show an increased travel time of each train against the train schedule for a specific link consisting of 15 stations.

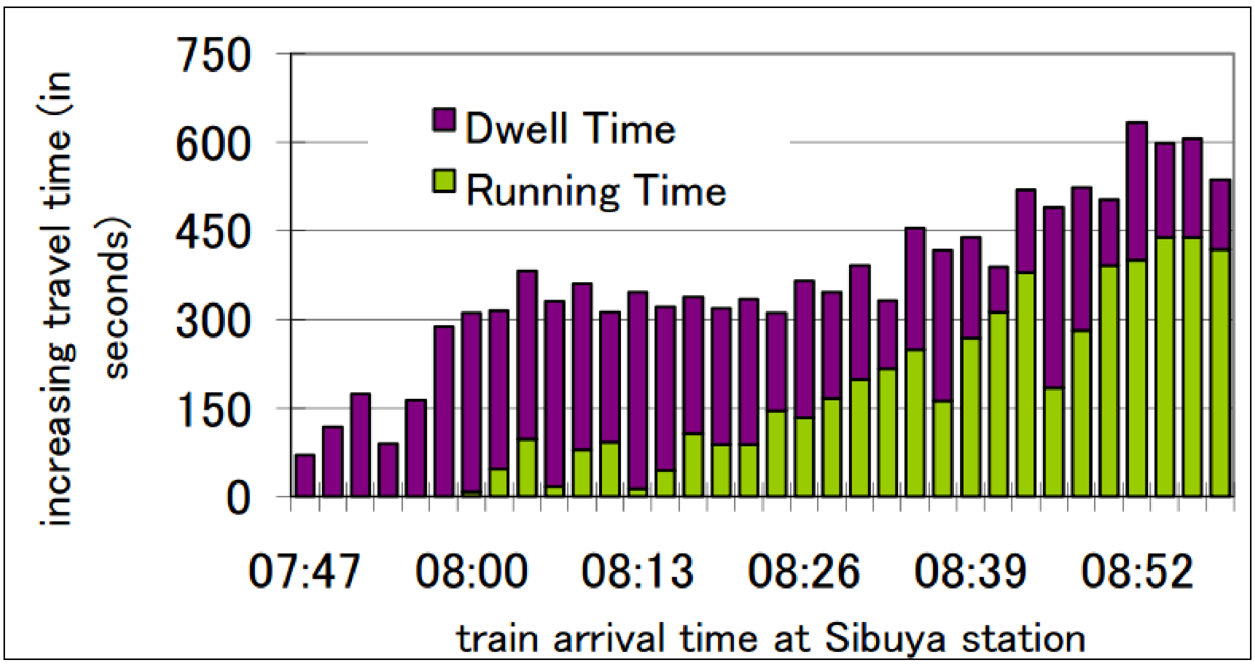


Figure 2.3: increased amount of travel time (Pachl 2002)

Previous studies has shown that train dwell time was affected by multiple factors, such as door opening/closing time, passenger flow (i.e. boarding and alighting) time, and signal headway. In most of these studies, the number of boarding and alighting passengers was considered to estimate dwell time. (Koffman1986) took into account the number of on-board passengers and fare collection methods (pre-paid or on-board payment). (Lin,TM;Wilson,NHM, 1992) also considered the number of on-board passengers (especially standees) to estimate dwell time. Other factors such as width/number of car doors, height/gap of platforms, and gender/age of passengers, etc were also discussed in previous studies. However, these factors had not been used with quantitative models. Note that not the entire dwell time can be utilized for boarding or alighting. Some systems, such as Calgary's light rail transit and the TTC subway, have an enforced safety delay of a few seconds once the doors have closed before the train can move (Tom Parkinson, 1996). Consequently, a piece of dwell time will be lost.

According to the above discussions, passenger flow time is the largest component of dwell time and deserves an in-depth analysis. The development of a passenger flow time model relies on accurate field data. In past studies, counters and stopwatches were typically used to record the number of passengers and passenger flow time (Tom Parkinson, 1996) . The total passenger flow time is usually estimated by calculating the time interval between the last passenger to board and the first passenger to alight. The average flow time for each passenger is then calculated by the total flow time divided by the number of passengers.

the levels of reliability (operated trains) and punctuality of scheduled train services are useful for infrastructure managers and train operators in planning, management and marketing, and for customers in making their mode and route choice. For railway regulators these measures are needed to check whether train operators together with infrastructure managers are providing the promised (or contracted) quality of service to the customers.

Although punctuality and reliability measures are important, they give only limited information about train delays. According to public reports on punctuality, the large number of smaller delays for trains that are not actually considered as delays have a considerable impact on the quality of operations (Yuan 2006). This is because trains are not registered as being delayed before a certain threshold of delay is reached, even though passengers may miss a connecting train due to this smaller delay. The threshold of delay varies by country, for example, in the Netherlands a delay of three minutes[1] is statistically regarded as being as serious as a delay of 20 minutes (Yuan 2008), as a train is considered as either delayed or not delayed. Seemingly, it is relatively easy to apply punctuality as a measure of operational quality. However, there are significant differences when using punctuality as an evaluation parameter. Punctuality can be related to trains or passengers. If a train is on schedule, this does not mean that all passengers inside the train are punctual. A passenger is delayed inside a punctual train if he/she has missed the previous connection due to a delayed feeder train. However, it is also possible that a passenger is punctual, or even ahead of time, when using a previously delayed train instead of the originally scheduled one (Martin 2008).

2.4.1 Factors Affecting Dwell Time

Train dwell time is the time a train stands at the platform usually for the purpose of allowing passengers to board or alight. It is devoted to the loading and unloading processes of the train, along with door opening and closing processes. Thus, boarding and alighting at stations are likely the most significant factors causing dwell time variations.

Kraft, in his studies on street transit systems highlighted seven main categories of factors affecting dwell time: human, modal, operating policies, operating practices, mobility, climate and other system elements. Each of these factors was further subdivided into selected areas for analysis and where possible, the effects of each of the factors on dwell time were quantified by the author. In a more recent report, Douglas categorized the factors affecting dwell time into five categories, which are passenger volume, passenger profile, train design, station design and operational factors.

Passenger volume, which refers to the number of passengers alighting and boarding a train, is considered as the main factor influencing its dwell time. The dwell time is determined by the number of passengers alighting and boarding and the speed at which they alight and board. Mixed flow of passengers tends to lengthen the time of dwell time as compared to uni-directional flow. Based on Weston's model, 35 s is needed for 40 passengers per door to alight or board (uni-directional) but the dwell time increases to 40 s for a mixed flow of 20 alighting and 20 boarding passengers.

Train design also influences boarding and alighting times. The number of doors and their width will affect the alighting and boarding speed. Wider doors enable more passengers to board and alight, thus increase the rate of boarding and alighting process, though it may take slightly longer for the doors to open. Wider doors lead to 10% shorter times and narrower doors to 10% longer times than the mean value.

The dwell time estimated increases with the number of passengers boarding and alighting but at a declining rate. This model therefore incorporates an 'alighting/boarding congestion effect'. The additional time needed in the event of a mixed flow (boarding and alighting at the same time) is also accounted for in the model.

2.4.2Previous Dwell time models

Various models had been developed by researchers to study the dwell times of trains of rail passenger services. One of the earliest train dwell time models was found to be a model developed by (Wirasinghe & Szplett 1984) for Calgary LRT. Referring to Table 2.2, three separate equations were produced based on the percentage of boarders for a train. The coefficients for alighting passengers ranged from 0.4 s to 1.4 s per passenger, whilst the coefficients for boarding passengers ranged from 1.4 s to 2.4 s per passenger, where the lowest of each coefficient is found to be within the alighting and boarding category ($0.33 \leq \psi \leq 0.66$). Thus, the authors have proven that the number platform entrances and "friction" between boarding and alighting passengers have significant effect on dwell time and that dwell time should not be determined simply by using the average demand per door.

Table2.2: Predictive equations for dwell time.

Group description (Ψ= fraction of boarders)	**Predictive equation** $T=l +\lambda(a) + \mu(b)$*
Exclusive or dominant alighting $\Psi \leq 0.32$	T= 2 +1.0(a) + 2.4(b)
Alighting and boarding $0.33 \leq \Psi \leq 0.66$	T= 2 + 0.4(a) + 1.0(b)
Exclusive or dominant boarding $\Psi \geq 0.32$	T= 2 + 1.4(a)+ 1.4(b)
*l= lost time (S) λ= average time per passenger to alight (s) μ= average time per passenger to board (s) *a= average demand per door for alighting *b= average demand per door for boarding	

(Weston 1989), established a model for London Underground Ltd, which was later used as a main reference by many other researchers. He had incorporated a great number of variables into the model. As shown in Equation (1), the variables were number or boarding and alighting passengers, number of doors, peak door and average door factor, number of seats and the number of through passengers. Weston used a constant of 15 s for the process of door opening and closing, and for power to be applied for acceleration. However, the value should vary by rolling stock type and door type. The dwell time estimated increases with the number of passengers boarding and alighting but at a declining rate. This model therefore incorporates an ‘alighting/boarding congestion effect’. The additional time needed in the event of a mixed flow (boarding and alighting at the same time) is also accounted for in the model.(Weston 1989)

$$SS = 15 + 1.4\left[1 + \frac{F}{35}\frac{(T-S)}{D}\right].\left[\left(\frac{FB}{D}\right)^{0.7} + \left(\frac{FA}{D}\right)^{0.7}\left(0.027\left(\frac{FB}{D}\right)\left(\frac{FA}{D}\right)\right)\right] \text{..............} (1)$$

Where SS = station stop time (s), A = number of alighting passengers per train, B = number of boarding passengers per train, D = number of doors, F = peak door/average door factor, S = number of seats, and T = number of through passengers.

(Lam 1998) conducted a study on train dwell time at the Hong Kong MTR system. They established regression models for dwelling delays due to congestion and developed a simulation model to assess the reliability of the estimated train dwell time. This model is a combination of three separate models developed based on data collected at three different stations. When comparing these three models, it was found that the constants and the coefficients for the number of alighting and boarding passengers were in the same order and of approximate value. Therefore, a generalized model that includes a fixed time for doors opening and closing, and the number of boarding and alighting passengers per train was produced (refer to Equation (2)). (Lam 1998) also highlighted that dwell time does not increase infinitely with the increase of passengers as the train headway governs the maximum allowable dwell time of trains, which is around 3 minutes in Hong Kong. (Lam 1998),

$$DT = 10.5 + 0.021A + 0.016B \text{..........................} (2)$$

Where DT = train dwell time (s), A = number of alighting passengers per train, and B = number of boarding passengers per train.

(Puong 2000) developed a model to analyse dwell times for the Massachusetts Bay Transport Authority (MBTA) in Boston based on an observation of 54 dwell times of trains with three or four single doors per carriage. All dwell times observed were below 90 s. He estimated that there was a constant of about 12 s for the process of door opening and closing and train starting. For each boarding and alighting passenger at a door, it was estimated that 2.27 s and 1.82 s was required respectively. The presence of standing through-passengers has no effect on the dwell time (specifically boarding time) if there were only 5 or below. But if there were more than 5, its effect is at cubed rate, as can be seen from Equation (3). (Puong 2000)

$$DT = 12.22 + 2.27B_d + 1.82A_d + 0.00062TS_d\ 3\ B_d \ldots \ldots \ldots \ldots (3)$$

Where DT = train dwell time (s), Ad = number of alighting passengers per door, Bd = number of boarding passengers per door, and TSd = number of standing through-passengers per door.

Douglas was tasked by Transport for New South Wales (TfNSW) to review alternative ways of calculating train dwell time. As a conclusion, Douglas established a model to predict train dwell time for RailCorp in Sydney. In his model (refer to Equation 4), the variables included were number of boarding and alighting passengers per door and the number of standing through passengers per door. He also estimated the function time to be 10 s. A power function of 0.7 gave a better fit than a linear function for both alighting and boarding. There was consideration for mixed flow of passengers and crowding caused by standing through passengers in the model. The best fit variable for standing through passengers was a linear function that multiplied standing passengers by the combined total of boarding and alighting passengers. (Douglas 2012)

$$DT = 10 + 1.9A_d 0.7 + 1.4B_d 0.7 + 0.007(A_d + B_d)(Std_d) + 0.005(A_d.B_d) \ldots (4)$$

Where DT = train dwell time (s), Ad = number of alighting passengers per door, Bd = number of boarding passengers per door, and Stdd = estimated number of standing through-passengers per door.

And the last estimated method is about: (Scott Johnson 2009).

$$T_d = T_o + T_c + A_a N_a + A_b N_b \ldots\ldots (5)$$

Where: Td is the dwell time to is door open time (2 seconds); Tc is door clearance time (8 seconds); Na, Nb are the highest number of alighting and boarding passengers at the door, respectively. For boarding, if there are only few passengers at a station, they will probably not be uniformly spreading over all doors. Instead, it is assumed that at least one or two door will get more passengers and that door will dominate the dwelling time. Aa, Ab are the per passenger alighting and boarding time, respectively, and are the parameters to be estimated.

Multi-variable linear regression is used for the estimation and the result is:

Ab =2.4 seconds/person (Meng Li, Guoyuan Wu,, 2009)

Aa =1.4 seconds/person (Meng Li, Guoyuan Wu,, 2009)

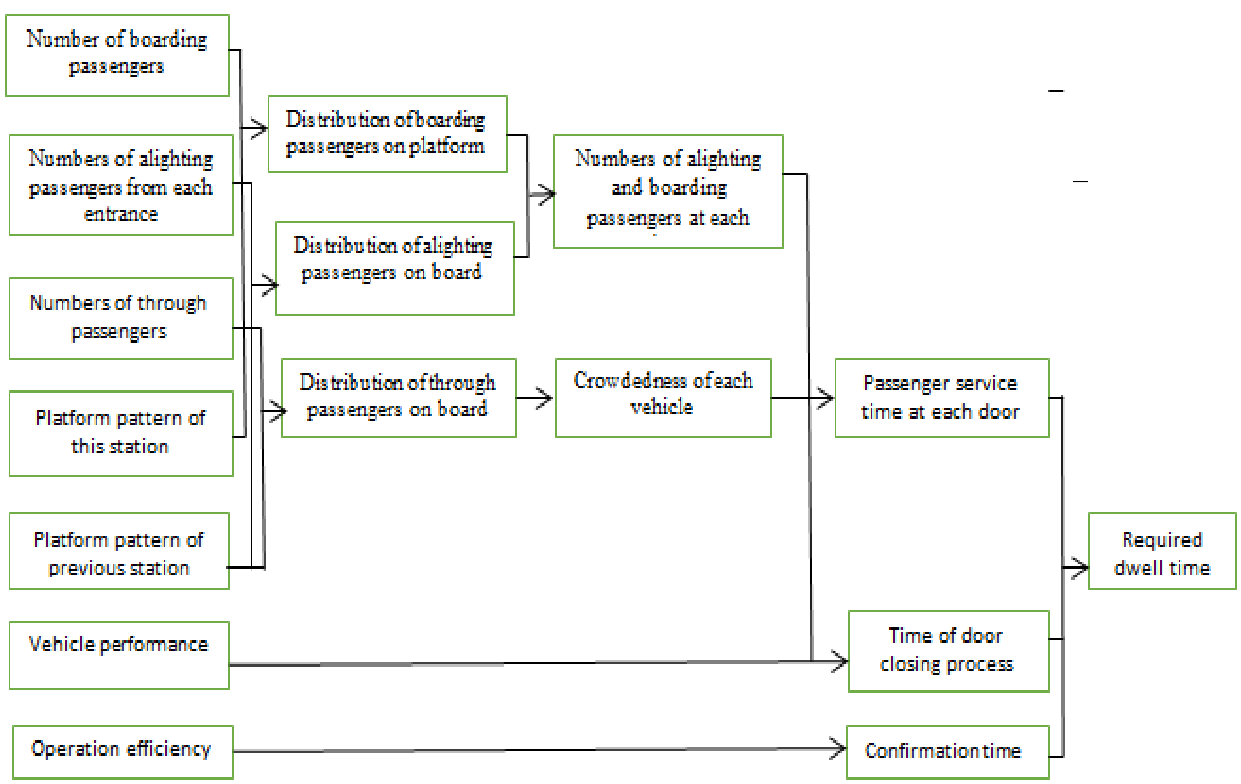


Figure 2.4: process of train dwell time (Pachl 2002)

2.4.2 Comparing dwell time models

These five studies show how dwell times data can be used to develop a model to calculate dwell times according to passenger volumes. The model by Wirasinghe & Szplett was one of the earliest dwell time models established and proved that "friction" due to a mixed flow has a significant effect on dwell time and that dwell time should not be determined simply by using the average demand per door. This conclusion proved to be an important basis for models developed thereafter. Generally, all five studies agree that the increase of passenger volumes increase the dwell time of trains at stations, though at different rates due to factors such as door widths, platform gaps and movement of passengers. The model by Weston was non-linear and predicted that dwell times increased but at a decreasing rate as total of boarding and alighting increased. By contrast, the passenger dwell times in models by Lam, et al. and Puong increased proportionally. It is considered that the Weston formulation is more realistic especially for boarding time. Similarly, Douglas' model is also considered more realistic as he had adopted Weston's model.

Table2.3: Parameters included train dwell time models

Paramaters				
Model	**Passenger volume**	**Mixed flow effect**	**Crowding effect**	**Others**
Wirasinghe& Szplett Model (1984)	Yes	Yes	No	Yes
Weston Model (1989)	Yes	Yes	Yes	Yes
Lam et al. Model (1998)	Yes	No	No	No
Puong Model (2000)	Yes	No	Yes	No
Douglas Model (2012)	Yes	Yes	Yes	No

Referring to Table 2.3, it is clear that the models developed by Weston and Douglas are the best as they have included the three most influential parameters, namely passenger volume, mixed flow effect and crowding effect, though the model by Douglas is a simplified version of

Weston's model. The Weston model can be considered as most relevant as it has been applied by Harris & Anderson on dwell time data for metros and suburban railways around the world.

2.4.3 Advantages of Dwell Time Models

The dwell time model established by Weston had later been tested by Harris & Anderson on over 30 railways around the world. Thus, the dwell time model could be applied to railways around the world but with adjustments to the variables involved (number of passengers boarding and alighting, numbers of doors, peak door/average door factor, numbers of seats, and numbers of through passengers). Lam's model provides a reasonable estimate for the average train dwell time at MTR stations, and the reliability analysis can be used to give a reliable range for the estimated train dwell time for assessment.

The model by Puong uncovered the effect of on-board crowding on boarding times for the stations. This model enabled critical stations to be identified for maintaining high-frequency service during peak periods. The dwell time model by Douglas could be extended into a forecasting model for a particular line by inserting initial timetable data and patronage forecasts. It can also predict boarding, alighting and on-board passenger loads for each station along the route for an individual service.

2.5 Conclusion

Dwell time is a key parameter of system performance, service quality and reliability in the rail passenger service. With known factors affecting dwell time, the dwell time at critical stations could be minimized, thus reducing the headway variations and enhancing service quality and reliability. All five models studied in this paper agree that dwell time is very much influenced by the passenger volume, though at different rates due to factors such as door widths, platform gaps and movement of passengers. A mixed flow of passengers and on-board crowding are also expected to increase dwell time. From this research, the numbers of alighting, boarding and standing through-passengers were found to be most influential and are dominant parameters for developing dwell time models. It is recommended that further research be conducted to study on train on-board crowding and how the different types of passengers affect the boarding and alighting time, which affects the dwell time of a train.

Chapter 3

3.1 Research Methodology

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

3.2 Research Process

This paper is done through the scientific research process and focus on the Addis Ababa Light Rail Transit (LRT) train operation system development case study. To do this, first different literatures, reference books, internet web-sites, articles and international journals those focus on train operations were accessed and the standardized railway operation is understood. Then the research problem and objective of the research were discussed. On the other hand scope of the research, significance of the study and the thesis structure were argued. The passenger transport operation factors are identified and discussed.

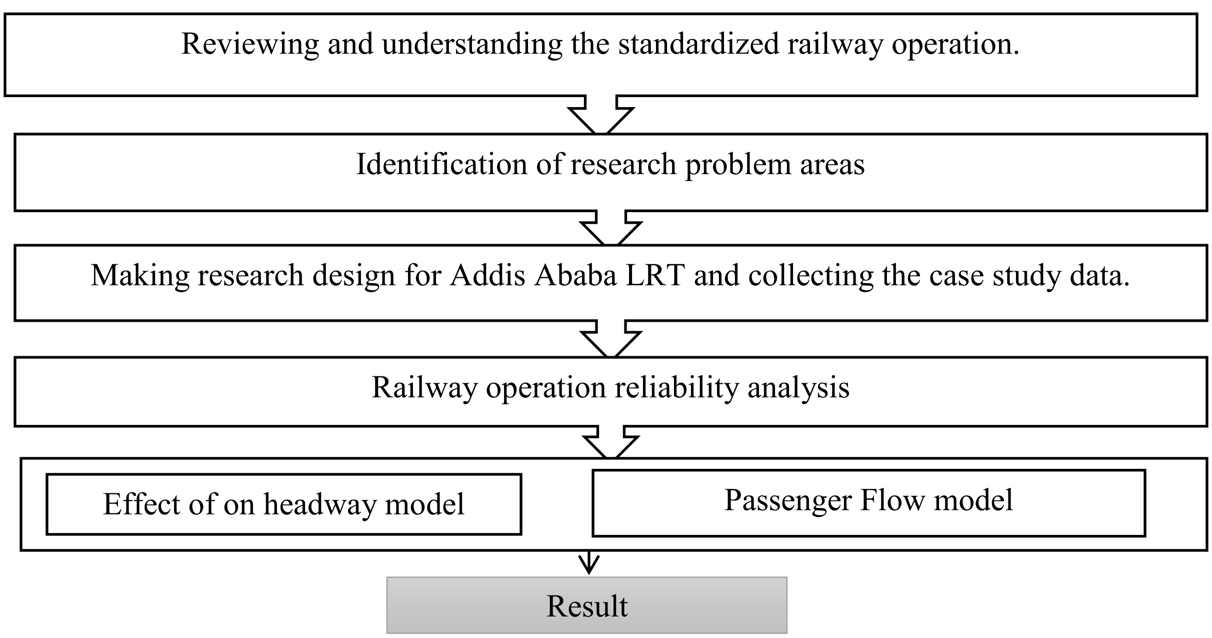


Figure3.1: Research process framework

3.3 Analytical model

3.3.1 Speed restrictions for train

- **SERVICE HEADWAY**

Design (minimum) train operating headway is a function of:

- Signaling system type and characteristics, including block lengths and separation;
- operating speed at station approaches and exits or other bottlenecks such as junctions; and
- Train length and dwell station

3.3.1Train delay on Headway

Headway time designed for the present Addis Ababa Light Rail design system is 6min (China railway group, 2017). That means 6min will be taken for the next train to follow the leading one. In the peak hour if there are 14trains on operation, 120min (technical details for operation timetable 2016) takes to complete one cycle of operation EW1-EW22 Running period (min), which covers around 32km, by a single train. So the average speed of a train will be:

$$V = \frac{S_{tot}}{t_{tot}} \qquad (1)$$

$$V = \frac{34.7km}{120min} = 17.35km/hr$$

Where:

V_a = average speed of the train

S_{tot} = total distance to cover one cycle of East-West

t_{tot} = total time to cover one cycle of East-West

The average speed (17.35km/hr) can be improved by using different approaches of light rail transit. Such the case of headway improvement by controlling directly the dwell time.

If additional of a huge volume passengers are becoming more prevalent in the normal time of operation and the demand of this transport service increases, it is difficult to manage this issue traffic using AALRT without improving.

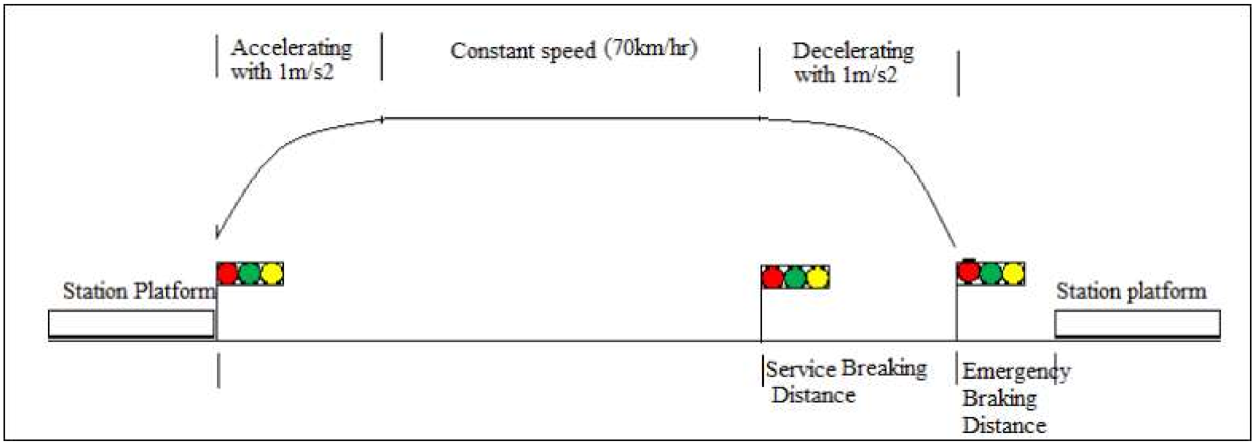


Figure 3.2: Speed profile and wayside signal

3.3.2 System of AALRT for some paramaters

Design Paramaters

The following parameters are taken from AA LRT.

Type of track construction

Independent or isolated from rail vehicles except for level crossings Composed of East-West line

East–West line,

Full length of East-West line of phase one is about 16.998km a total of 22 stations

Type of train = Tramcar whose length is 28.400m

Rated Passengers: 6 persons/m^2, 286 persons in one tram car in total.

Maximum speed = 70km/hr

Average Acceleration for Start-Up: 1m/s^2

Average Deceleration for Braking:

1） The Average Deceleration of Normal Braking with Rated Load （including control response time）: ≥1.0m/s^2

2） The Average Deceleration of Emergent Braking with Rated Load （including control response time）: $\geq 1.5 m/s^2$

3.2 LRT system Requirement

Early days, as train speeds increased, it became essential to provide some more powerful braking system capable of instant application and release by the train driver, described as a continuous brake because it would be effective continuously along the length of the train. Braking distance is a crucial parameter to calculate the possible travel speed for a certain railway line and for our case it is about the AALRT.

- **System Design**

The design and operation of the Addis Ababa LRT system must allow for a worst case hazardous situation. The system operation must be designed to achieve the safest operation possible consistent with the required operational efficiency. Fully automatic safety critical.

- **Braking Distance**

Braking distance depends on:

• the speed of the train when the brakes are applied;

• the deceleration rate available with a full-service brake application, which varies according to the coefficient of friction between wheel and rail;

• the delay from when the brakes are commanded by the train driver to when they are actually become effective (brake delay time)

The change in kinetic energy relates to the change in the train's speed that is the difference of the speed at which deceleration began (u) and when it stops i.e. final speed, v=0. The change in potential energy relates to the change in height of the train's center of mass due to the gradient of the track i.e. the difference in height at which deceleration began ($h1$) and the it is height at the stopping point ($h2$). Mathematically this can be expressed as:

$$maS + \frac{1}{2}mU^2 + mg(h_2 - h_1) = 0 \quad (2)$$

Where g is the acceleration due to gravity and $h2 \geq h1$

The change in height relates to the track gradient. The track gradient is the change of vertical height over the corresponding change in horizontal distance. i.e. tan *α*, where *α* is the angle of slope. For small *α*, which is the case for railways (mountain rack railways aside), tan α equals sin *α*. Sin *α* is the change in height ($h2 – h1$) over the stopping distance(S):

$$h_2 - h_1 = S(sin \propto) = S(tan \propto) \ldots\ldots \text{(3)}$$

Substituting (2) into (1) and rearranging:

$$S = (-U^2)/2(a - gtan \propto) \text{ ; For a} < 0 \ldots\ldots \text{(4)}$$

The term –g tan *α* is the gravitational acceleration. For uphill track gradients (h2 ≥ h1), gravity assists deceleration.

To calculate braking distances it is therefore a matter of knowing the train braking parameters for each type of train and the gradient of the track and apply Newtonian physics Equation 4. However to compensate for these simplifications and the variable factors, an allowance of 15-20% is usually added. This distance is the minimum distance that needs to be provided. Brake delay time.

Allowing 15-20% does not compensate for ignoring the brake delay time. For example, consider a train that has a brake deceleration rate of 1ms-2, and a brake delay time of 5s. Assuming an initial speed of 100km/h and level track, the required braking distance is 524m. Ignoring the brake delay time, the braking distance would be 385m. Adding 20% increases this to 462m, i.e. some 62m short. This is much worse for long trains where the brake delay time is much longer.

3.3 Speed restrictions

If the speed limits are not known they can be approximated from the following equation:

$$V_{sl} = (87R(e + f))^{1/2} \ldots\ldots \text{(5)}$$

(The Arema Manual for railway engineering chapter 5)

Where; *vsl* = speed limit in *km/h*

R = radius of curvature in *meters*

e = super elevation ratio (height the outer rail is raised divided by track gauge) usually not greater than 0.10

f = comfort factor (ratio of radial force to gravitational force—0.13 is the maximum used in rail transit with some systems using as 0.05)

3.4 Station Close in Time

The time between a train pulling out of a station and the next train entering—referred to as close-in—is the main constraining factor on rail transit lines. This time is primarily a function of the train control system, train length, approach speed and vehicle performance. Close-in time, when added to the dwell time and an operating margin, determines the minimum possible headway achievable without regular schedule adherence impacts—referred to as the non-interference headway. When interference occurs, trains may be held at approaches to stations and interlocking. This requires the train to start from stop and so increases the close in time, or time to traverse and clear an interlocking, reducing the throughput. With throughput decreased and headways becoming erratic, the number of passengers accumulated at a specific station will increase and so increase the dwell time. This is a classic example of the maxim that when things go wrong they get worse.

The minimum headway is composed of three components:

- The safe separation (close-in time),
- The dwell time in the station, and
- An operating margin.

The best method to determine the close-in time is from the specifications of the system being considered, from existing experience of operating at or close to capacity or from a simulation. The classical expression for the minimum headway of the typical rail transit system is:

$$H(t) = (\frac{2BL}{Vap} + Dw + \frac{\sqrt{2L}}{2a})/(1 - M) \qquad (6)$$

Where; H (t) = headway in seconds

BL = block length approaching station (m)

Dw = station dwell time in seconds

SD = service stopping distance for level track (m)

L = length of the longest train (m) v ap = maximum approach speed (m/s)

a = average acceleration rate through the station platform clear-out (m/s2)

d = braking rate (m/s2)

M = headway adjustment combining operational tolerance and dwell time variance (constant)

3.5 Calculating line Headway

On a level, tangent (straight) section of track with no disturbances the line headway H *(*l*)* is given by:

$$H(l) = \frac{L+S_{min}}{V_l} \qquad (7)$$

Where *H (l)* = line headway in seconds

Smin = minimum train separation in meters

L = length of the longest train in meters

vl = line speed in m/s

The minimum train separation corresponds to the sum of the operating margin and safe separation distance shown in Figure below(fig3.3). It can therefore be further subdivided: (all in meters)

$$S_{min} = S_{sbd} + S_{td} + S_{om} \qquad (8)$$

Where; Smin = minimum train separation distance

Ssbd = safe braking distance

Std = train detection uncertainty distance

Som = operating margin distance

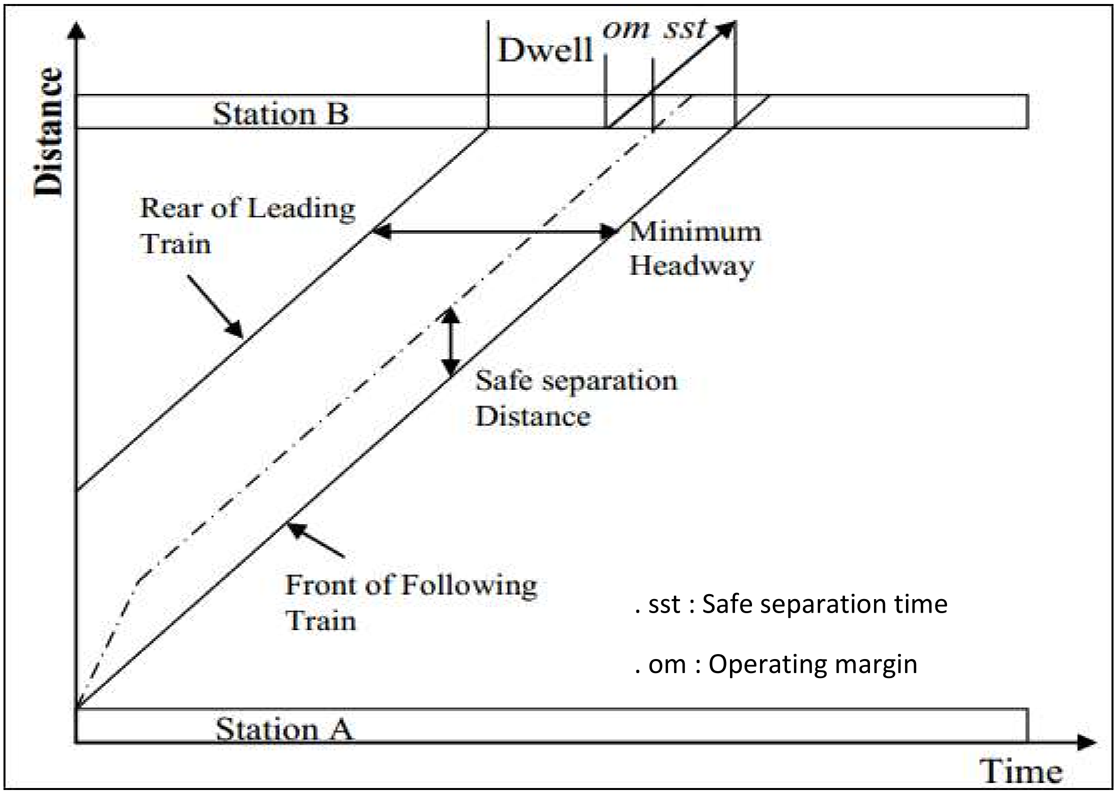


Figure 3.3: Distance-time plot of two consecutive trains (acceleration and braking curves omitted for clarity) (Alle 2007)

Substituting for Smin and removing Som produces:

$$H(l) = \frac{L+S_{td}+S_{sbd}}{V_l} \qquad (9)$$

3.5.1 Station Headway

Station headway, the time for one train to replace another at the maximum load point station, is by far the most common capacity limitation. Having derived an expression for line headway that uses readily available information with as few approximations as possible, it is possible to adapt this to station headway by

- changing line speed to approach speed and solving for this speed,
- adding a component for the time a train takes to clear the platform,
- adding the station dwell, and

• adding an operating margin.

The time for a train to clear the platform is:

$$tc = \sqrt{\frac{2(L+D)}{a_s}} \quad \text{..........(10)}$$

Adding Equation 2.10 to 2.11 see to the annexe plus components for dwell and an operating margin produces the station headway.

$$H(l) = \frac{\sqrt{2(L+D)}}{a_s} + \frac{L}{V_a} + \left(\frac{100}{K} + B\right)\left(\frac{V_a}{2d_s}\right) + \frac{a_s t^2{}_{as}}{2V_a}\left(1 - \frac{V_{la}}{V_{max}}\right) + t_{as} + t_{jl} + t_{br} + t_d + t_{om} \quad \text{..........(11)}$$

Where; H (l) = station headway in *seconds*

L = length of the longest train in *meters*

D = distance from front of stopped train to start of station exit block in *meters*

V_A = station approach speed in *m/s*

v_{max} = maximum line speed in *m/s*

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

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

t_{os} = time for overspeed governor to operate

t_{jl} = time lost to braking jerk limitation— (seconds) typically 0.5 seconds

t_{br} = operator and brake system reaction time

t_d = dwell time (seconds)

t_{om} = operating margin (seconds)

a_s = initial service acceleration rate in m/s^2

d_s = service deceleration rate in m/s^2

A 45-sec dwell time is used—typical of the busiest stations on rail transit lines operating at capacity—together with an operating margin time of 20sec. The brake system reaction time will use a moderate level of 1.5sec—this should be higher for old air brake equipment, lower for modern electronic control, particularly with hydraulically actuated disk brakes. Other factors remain at the levels used in the line headway analysis.

3.6.1 Methods to calculate passenger delays

The determination of train dwell time is an essential step in planning railway timetables. The magnitude of dwell time affects not only train operation efficiency but also punctuality. Passenger flow time was found to be the most important factor affecting dwell time and is the aim of this model. The relationship between passenger flow time and the number of passengers was statistically significant in the proposed linear regression models (Sigtenbjerggaard 2008). Moreover, the adjusted R-squares of the regression models for different train types range between 0.86 and 0.95(Nielson 200). The results demonstrated that the models have very good explanatory capabilities in estimating passenger flow time.

For efficient services, trains are scheduled to stop at stations with adequate dwell time for passenger boarding and alighting. Determining dwell time is crucial to the planning of timetables since insufficient dwell time would cause train delays, while excessive dwell time would lead to inefficient operation. In general, dwell time is defined as the time during which a train remains stopped at a railway station, primarily to allow passengers to board and alight (Hansen 2010). In contrast to "passenger flow time, dwell time for dispatching is easy to estimate since the required headway is determined by signaling system. Thus, the study focuses on the estimation of passenger flow time. The total passenger flow time is usually estimated by calculating the time interval between the last passenger to board and the first passenger to alight (Koffman 1984). The average flow time for each passenger is then calculated by the total flow time divided by the number of passengers. In order to accurately calculate the number of passengers for each door, automatic passenger counting (APC) systems have been applied to collect detailed passenger flow data for inside the Light Train, but for our case in Addis Ababa light there is no such kind of device to record the data so we will make collection data on the site exactly through several stations for both corridors.

3.6.2 Investigation method:

To trace detailed states of trains and passengers flow regarding related work, this thesis gave us a way to collect data that we need to proceed the survey:

Survey target:

- Train ID
- Car number
- Train stop
- Train start
- Passengers alighting
- Passenger boarding

Events that occur during train dwell time include (1) train stop, (2) door open, (3) passenger alighting, (4) passenger boarding, (5) door close, and (6) train start, as shown in Figure below.

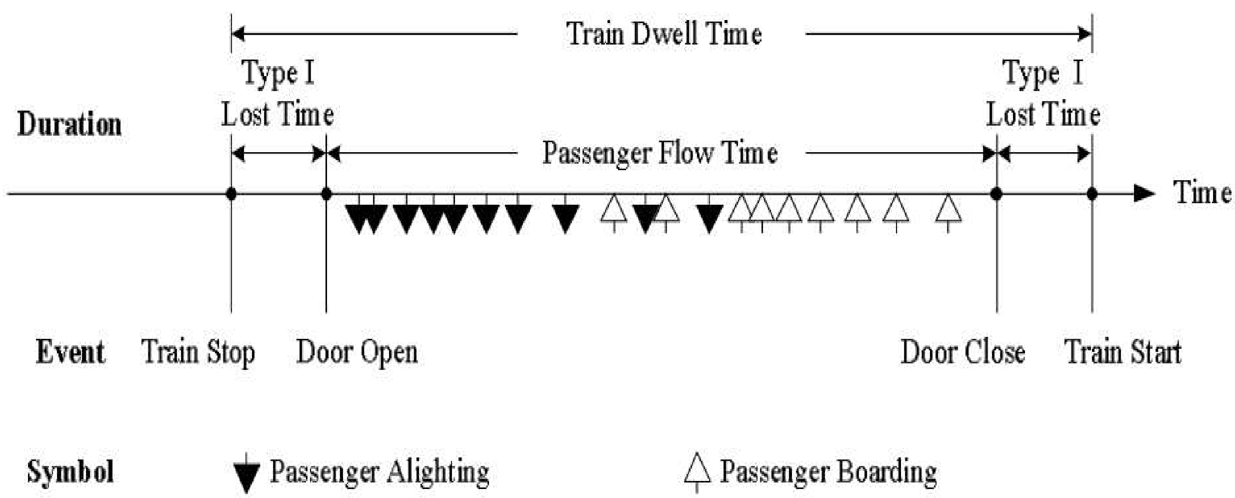


Figure 3.4: Events during train dwell time (Jyh-Cherng JONG, En-Fu CHANG 2011)

Table3.2: Format and meaning of investigation of AALRT for train 2:

Tue Jun 07 08:15:25.62	2040	2	Train stop
Tue Jun 07 08:15:38.796	2040	2	door open
Tue Jun 07 08:15:40.609	2040	2	passenger alighting
Tue Jun 07 08:15:21.265	2040	2	passenger alighting
Tue Jun 07 08:15:41.703	2040	2	passenger alighting
Tue Jun 07 08:15:42.328	2040	2	passenger alighting
Tue Jun 07 08:15:15.156	2040	2	passenger alighting
Tue Jun 07 08:15:43.953	2040	2	passenger alighting
Tue Jun 07 08:15:44.546	2040	2	passenger alighting
Tue Jun 07 08:15:45.703	2040	2	passenger alighting
Tue Jun 07 08:15:46.359	2040	2	passenger alighting
Tue Jun 07 08:15:46.937	2040	2	passenger alighting

Time stamp | Train ID | Train Number | Event type

3.6.3 Estimation method:

Dwell time is the time interval between train arrival and departure. To make the following analysis
clear, we divide dwell time into three parts (see Fig3.4 above):

- Type I Lost Time: The time interval between train stop and door opened.
- Passenger Flow Time: The time interval during which passengers alight from and board the train.
- Type II Lost Time: The time interval between doors closed and train start.

During the first and third intervals of train dwell time, passengers are unable to board or alight. Type I lost time can be obtained by calculating the time difference between train stop and door opened. Similarly, Type II lost time can be obtained by computing the difference between train start and door closed. The amount of lost time may vary among different trains and doors. This study employed descriptive statistics and confidence intervals to estimate lost time. The second interval (i.e., passenger flow time) is the time available for passengers to alight from or board a train. Since passengers queue up inside the train for alighting and at the platform for boarding, each door can be treated as a queuing system.

Table3.3: Pre-processing of the survey investigation of AALRT for train 2:

Time stamp	Train ID	Train number	Event Type
Tue Jun 07 08:15:25.62 A	204	2	Train stop
Tue Jun 07 08:15:38.796B	204	2	door open
Tue Jun 07 08:15:40.609	204	2	passenger alighting
Tue Jun 07 08:15:21.265C	204	2	passenger alighting
Tue Jun 07 08:15:41.703D	204	2	passenger alighting
Tue Jun 07 08:15:49.187	204	2	passenger alighting
Tue Jun 07 08:15:49.781	204	2	passenger alighting
Tue Jun 07 08:15:50.203	204	2	passenger alighting
Tue Jun 07 08:15:55.812	204	2	passenger alighting
Tue Jun 07 08:15: 56.718	204	2	passenger alighting
Tue Jun 07 08:15:57.328	204	2	passenger alighting
Tue Jun 07 08:16:15.156 E	204	2	passenger boarding
Tue Jun 07 08:16:40.890 F	204	2	passenger alighting
Tue Jun 07 08:16:11.812	204	2	passenger boarding
Tue Jun 07 08:16:57.15	204	2	passenger boarding
Tue Jun 07 08:17:19.734 G	204	2	Door close
Tue Jun 07 08:17:36.62 H	204	2	Train start

- Type I Lost Time ⟶ B-A=15.176 sec
- Type II Lost Time ⟶ H-G 16.886 sec
- Alighting Flow Time ⟶ D-C=20.438 sec
- Boarding Flow Time ⟶ F-E= 25.734 sec

3.6.4 Presentation of the models

All five models studied in this paper agree that dwell time is very much influenced by the passenger volume, though at different rates due to factors such as door widths, platform gaps and movement of passengers. A mixed flow of passengers and on-board crowding are also expected to increase dwell time. Hence, here it is represented the five models used to analyze dwell time:

$$SS = 15 + 1.4\left[1 + \frac{F}{35}\frac{(T-S)}{D}\right].[(\frac{FB}{D})^{0.7} + (\frac{FA}{D})^{0.7} + \left(0.027\left(\frac{FB}{D}\right)\left(\frac{FA}{D}\right)\right)] \qquad (1)$$

$$DT = 10.5 + 0.021A + 0.016B \qquad (2)$$

$$DT = 12.22 + 2.27B_d + 1.82A_d + 0.00062TS_d\,3\,B_d \qquad (3)$$

$$DT = 10 + 1.9A_d 0.7 + 1.4B_d 0.7 + 0.007(A_d + B_d)(Std_d) + 0.005(A_d.B_d) \qquad (4)$$

$$T_d = T_o + T_c + A_a N_a + A_b N_b \qquad (5)$$

Referring table 2.3, it is clear that the models developed by Weston, Douglas and Scott Johnson equation 2 and 5 are the best as they have included the most influential parameters namely:

- passenger volume
- mixed flow effect and,
- crowding effect

Chapter 4

4. Results and interpretation

4.1 Braking distance of EW line to the stations

- **Calculations:**

Train's parameters Average deceleration for braking: from 70km/h to stop:

1) The average deceleration of normal braking with rated load (including control response time): $=1.0 m/s^2$
2) The average deceleration of emergent braking with rated load (including control response time): $=1.5 m/s^2$

Braking delay time = included in deceleration Maximum speed = 70km/hr

Others parameters

Acceleration due to gravity = $9.8 ms^{-2}$

Gradient = variable

Calculation Assumptions:

The method of calculation assumes the following:

- Gravitational acceleration is $9.8 ms^{-2}$ for the entire AA LRT network.
- The mass of the train is uniformly distributed throughout the length of the train i.e. the center of mass is longitudinally in the center of the train.
- The braking coefficient is not a function of speed and is a constant for a specific train type.
- For the period of the brake delay, there is no ―acceleration‖ force from either gravity or the train's brake acting on the train, and after this time has elapsed there is full train braking force applied.
- Retardation due to track curvature and viscous drag can be ignored. By using Equation and line gradient profile information from Addis Ababa LRT design the following result

is obtained to each station of EW line. Each braking distance includes compensation allowance of 20% for the driver reaction time and others variable factors.

Table 4.1: Breaking distance to the stations of EW line

East to West line 1 braking distances to the stations meters			West to East line 2 braking distances to stations in meters		
To the stations	Without compensations allowance	With compensation allowance	To the Stations	Without compensation allowance	With compensation allowance
EW1	Starting station	0	EW22	Starting Stations	0
EW2	176	211	EW21	189	227
EW3	190	228	EW20	210	252
EW4	159	191	EW19	182	218
EW5	182	218	EW18	193	231
EW6	224	269	EW17	221	265
EW7	221	265	EW16	229	275
EW8	210	253	EW15	228	273
EW9	222	266	EW14	284	340
EW10	173	208	EW13	175	210
EW11	259	310	EW12	157	189
EW12	224	268	EW11	163	195
EW13	219	262	EW10	200	240
EW14	189	227	EW9	181	217

EW15	180	216	EW8	206	248
EW16	192	230	EW7	254	305
EW17	156	188	EW6	166	199
EW18	195	234	EW5	219	262
EW19	234	281	EW4	264	317
EW20	152	182	EW3	214	257
EW21	221	265	EW2	173	213
EW22	187	224	EW1	185	221

4.2 Speed Restrictions

The minimum curve radius for the maximum speed (70km/hr) is calculated using Equation 5 as follows assuming:

e = 0 (for the worest case of construction design) and

f = 0.13

$R = \frac{Vsl^2}{87*0.13} = 433\ m$ (The Arema Manual for railway engineering chapter 5)

.The structure of the track should ensure the safe operation, smooth travelling and comfortable ride and have enough strength, stiffness, stability, durability and proper elasticity in order to reduce maintenance. Track structure should be as simple as possible, whose components should be effective, general and interchangeable. Therefore it would be better to adopt standard components which will be easy to load and unload and convenient for construction and maintenance. Based on the experiences of municipal rail transport projects home and abroad and other projects this project intends to adopt reliable and economical scheme for track structure, so the average speed of the AALRT is around 18km/hr. (China railway group, 2017)

Therefore, all curve speed restrictions below radius 433m is shown below on the following table

Table 4.2: Speed limits on curve of EW line (China railway group, 2017)

East West track locations, between stations	Curve radius (m)	Speed limit (km/hr)	Comment
EW22-EW21	190	46.4	
	236	51.67	
EW19-EW18	200	47.56	Above speed profile
EW18-EW17	200	47.56	Above speed profile
EW17-EW16	254	53.6	Above speed profile
EW15-EW14	400	67.3	Above speed profile
EW14-EW13	400	62.92	Above speed profile

4.3 Headway calculation:

Based on a huge of passengers demand volumes and passengers service times in the daily operation of the AALRT, the operation of the AALRT could have a suitable headway time and travel speed then it will be used so all of these assumption has an impact on travel speed on a congested railway line by the same time can have a big repercussion on the capacity then suitable travel speed with a short headway will be more reliable in the daily operation service.

The following considerations are taken to calculate headway between two trains:

- Train load effect on braking distance is ignored
- Weather condition that affects the coefficient of friction between train wheel and track is neglected.
- In an open line sections wind effect is not considered.

- On braking distance calculations deceleration from maximum speed to zero is taken as constant but it changed as the initial acceleration, approximately linearly, then approximately exponentially until it is zero.
- Voltage fluctuations as the acceleration of a train is approximately proportional to the power applied to the motors
- By using Equation 11 and considering the above conditions the result of line headway with different speed of the train is given below.

Table 4.3: headway time for different speed operations

Speed(km/hr)	Time to travel length (sec)	Time to brake (sec)	Over speed acceleration time (sec)	Over speed time (sec)	Jerk allowance (sec)	Line headway
10	72	2.7	0.4	3	0.5	78.61
20	36	5.41	0.2	3	0.5	45.10
30	24	8.11	0.13	3	0.5	35.74
40	18	10.81	0.09	3	0.5	32.40
50	14.40	13.51	0.07	3	0.5	31.49
60	12	16.22	0.06	3	0.5	31.78
70	10.29	18.92	0.05	3	0.5	32.75
80	9	21.62	0.04	3	0.5	34.16
90	8	24.33	0.03	3	0.5	35.86
100	7.2	27.03	0.03	3	0.5	37.76

The time taken between two positions considering track profile and speed limits is calculated as follows.

Since the procedure remain the same to compute track profile and speed limits for all station EW1-EW22, so EW22-EW21 is showed to understand how the issue:

in this **table 4.4** we took only EW22-EW21 to show how to compute station to station time, the aim of this methodology is to draw finally the profile time duration and the calculation remain the same for all the station, hence this table showed which data we need to draw the profile time duration:

Table 4.4: The time taken for the train from Station EW22 to EW21

Distance (km)	Time (sec)
5.5-5.8	28.24
5.8-5.9	11.74
5.9-6.0	4.65
6.0-6.1	0.5
6.1-6.2	7.35
6.2-6.3	5.8
6.3-6.4	13.62
Station to Station	71
Dwell time	45
Total	116

Likewise all station to station time from EW22-EW1 is calculated and remain the same procedure that mean to draw each part of profile time duration distances and dwell time and the result is given below as follows **table 4.5**:

Table 4.5: Time taken for the train to travel between stations for 45sec dwell time

Station to Station distance	Distances in meters	Profile time duration+ dwell time
EW22 – EW21	1092	60.22 + 45 = 105.22
EW21 – EW20	863	54.094 + 45 = 99.094
EW20 – EW19	860	55.4 + 45 = 100.4

EW19 – EW18	724	49.12 + 45 = 94.12
EW18 – EW17	970	40.97 + 45 = 85.97
EW17 – EW16	1083	38.36 + 45 = 83.36
EW16 – EW15	804	40.75 + 45 = 85.75
EW15 – EW14	802	58.74 + 45 = 103.74
EW14 – EW13	746	67.09 + 45 = 112.09
EW13 – EW12	770	59.08 + 45 = 104.08
EW12 – EW11	952	58.92 + 45 = 103.92
EW11 – EW10	675	58.3 + 45 = 103.3
EW10 – EW9	583	66.57 + 45 = 111.57
EW9 – EW8	650	74.36 + 45 = 119.36
EW8 – EW7	435	62.2 + 45 = 107.2
EW7 – EW6	569	55.41 + 45 = 100.41
EW6 – EW5	691	64.09 + 45 = 109.09
EW5 – EW4	733	73.54 + 45 = 118.54
EW4 – EW3	725	73.54 + 45 = 118.54
EW3 – EW2	776	83.19 + 45 = 128.19
EW2-EW1	390	

Here also the calculation for the profile time duration remain the same just only for this **table 4.6** only the dwell is different, dwell time for 25sec and the result is given as follows:

Table 4.6: Time taken for the train to travel between stations for 25sec dwell time

Station to Station distance	Distances in meters	Profile time duration+ dwell time
EW22 – EW21	1092	60.22 + 25 = 85.22
EW21 – EW20	863	54.094 + 25 = 79.094
EW20 – EW19	860	55.4 + 25 = 80.4
EW19 – EW18	724	49.12 + 25 = 74.12

EW18 – EW17	970	40.97 + 25 = 63.97
EW17 – EW16	1083	38.36 + 25 = 65.36
EW16 – EW15	804	40.75 + 25 = 83.75
EW15 – EW14	802	58.74 + 25 = 82.74
EW14 – EW13	746	67.09 + 25 = 92.09
EW13 – EW12	770	59.08 + 25 = 84.08
EW12 – EW11	952	58.92 + 25 = 83.92
EW11 – EW10	675	58.3 + 25 = 83.3
EW10 – EW9	583	66.57 + 25 = 91.57
EW9 – EW8	650	74.36 + 25 = 99.36
EW8 – EW7	435	62.2 + 25 = 87.2
EW7 – EW6	569	55.41 + 25 = 80.41
EW6 – EW5	691	64.09 + 25 = 89.09
EW5 – EW4	733	73.54 + 25 = 98.54
EW4 – EW3	725	73.54 + 25 = 98.54
EW3 – EW2	776	83.19 + 25 = 108.19
EW2-EW1	390	

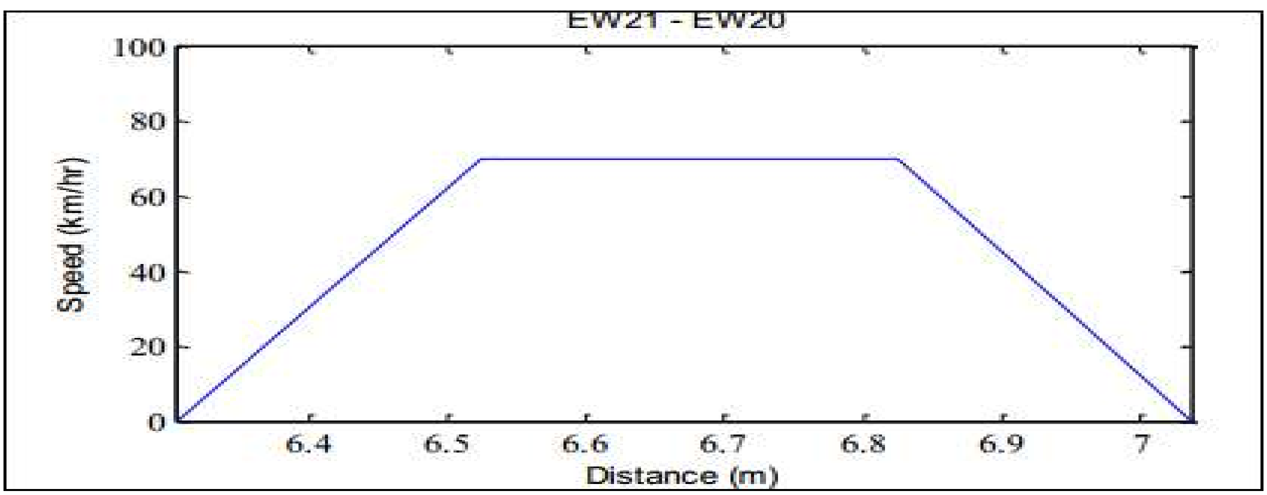


Figure 4.1: EW21-20 for speed profile

Thus the total time taken by the train from station EW22 to station EW1 is 2197.04 seconds. That is equal to 36.62 minutes for a 45sec dwell time firstly.

Therefore, the average speed on this line can be stated as:

$V_{av} = \frac{S_{tot}}{t_{tot}}$;

Where, Vav = Average speed of the line
Stot = Total distance of the line
Ttot = Total time to travel the total distance

EW line has a total length of 16.998km and the total time taken to cover this distance is found as 2197.04 sec. Thus the total time taken by the train from station EW22 to station EW1 is 2197.04 seconds. That is equal to 36.62 minutes.

Thus, the average speed of the line is,

$V_{av} = \frac{16998\ m}{2197.04\ sec}$=7.77 m/s= 27.85 km/hr

For dwell time 25sec time gives below, this result increased to

EW line has a total of 16.998km and the total time taken to cover is found as 1777.04sec. Thus the total time taken by the train from station EW22 to station EW1 is 1777.04 seconds. That is equal to 29.62 minutes.

$V_{av} = \frac{16998\ m}{1777.04\ sec}$= 9.57 m/s= 34.4 km/hr

The peak hour operational headway between two consecutive trains will be calculated as:

- The number of trains on the line = 10 trains
- The total time to cover the line distance = 36.62min (for 45sec dwell time)

  = 29.62min (for 25sec dwell time)

- Headway between trains = 36.62/10 = 3.662min (for 45sec dwell time)

  = 29.62/10 = 2.962min (for 25sec dwell time)

4.4 Predicted passenger flow of AA LRT E-W line stations

This table 4.8 describes passenger flow for boarding and passenger flow for alighting for each station per day and the purpose of the purpose of this is to see the different of each passenger took time to board or alight of the AALRT.

The above table shows the selected for trains stations recommendations:

The peak hour passenger flow of each station is determined by multiply with peak hour factor. Based on this passenger flow of each station, there is selection of the relative low passenger flow of stations to make the train passes these low passenger stations in off-peak hour. There is consideration of the spacing between stations to pass only one station from two sequence low number of passenger's stations except very low passenger flow sequence stations. In that case it is high passenger flow when both of boarding and alighting passengers at peak hour and it is remaining the same for all the following tables.

Table 4.8: EW line for passengers boarding and alighting

S/N	Station Name	Stations location	Passenger flow boarding per day	Passenger flow alighting per day	Recommandations
1	EW1	Ayat 2	1635	0	
2	EW2	Ayat 1	1511	6	high flow passenger
3	EW3	CMC intersection	1210	23	
4	EW4	Kotebe Mikael church	1193	68	
5	EW5	Municipal service institute	936	115	
6	EW6	S-ealite Mihret Church	686	142	
7	EW7	Ethiopian Communication	435	117	
8	EW8	Ethiopian Geological survey	380	149	
9	EW9	Megenagna	756	612	
10	EW10	Lem Hotel	1409	1909	high flow passenger
11	EW11	Togo	1513	1617	high flow passenger
12	EW12	Holiday Hotel	845	679	high flow passenger
13	EW13	Kidus Urael Church	958	564	high flow passenger
14	EW14	Yordanos Hotel	716	547	
15	EW15	St.Estifanos	675	680	
16	EW16	Addis Ababa Stadium	580	904	
17	EW17	Gambia Intersection(legahar)	376	1105	high flow passenger
18	EW18	Ethiopian Road department	146	963	high flow passenger
19	EW19	Mexico Square	76	1072	
20	EW20	Lideta Mariam Church	38	1122	
21	EW21	Coca cola Intersection	16	1742	high flow passenger
22	EW22	Torhailoch Hostipal	0	2284	

Based on the passenger transport survey the passenger flow of E-W route in Addis Ababa LRT is forecasted as 734.4 thousands persons/day. Line E-W goes along the important E-W transportation corridor in Addis Ababa. This line goes through city center, and is one of the most important contacting lines between city center and city western parts and western suburbs. The eastern and central parts of this line go through highly populated areas, the busiest commercial areas and Ayat residential area with large traffic flow; the western part of the line goes through western city and western suburbs. (China railway group, 2009)

To select low number of passengers, there is taken limitation by finding the total average number of passengers flow for both direction of W-E and E-W. It is considered that the limitation becomes less than the average number of passengers getting on/off train per hour for each station. So the average number of passengers getting on/off train per hour for W-E and E-W line is 1467 and 1478 respectively.

Here it will try to show how passengers can affect the dwell time during the train stations as follows:

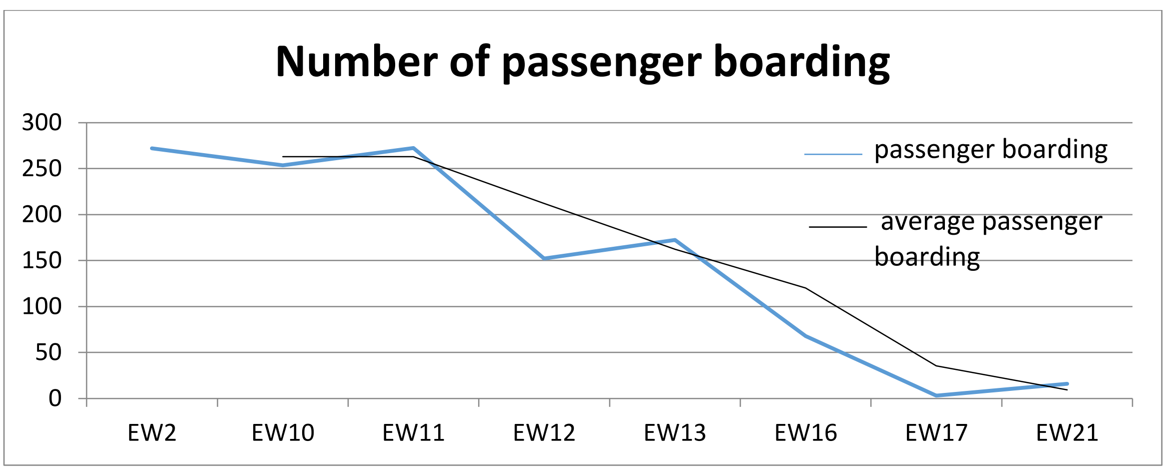


Figure 4.2: passenger boarding on train.

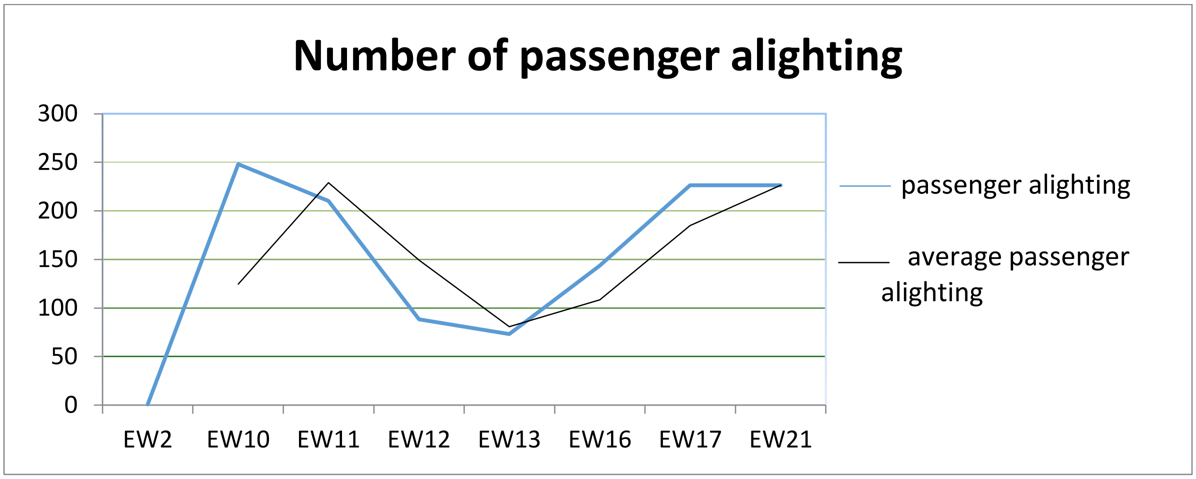


Figure 4.3: passenger alighting on train.

Based on the selection of high flow passengers' criteria we that only these station are the selected to draw how passengers affect the dwell time during the boarding and alighting time. Automatically we can see that passengers boarding took more time than the passengers alighting.

4.4.1 Dwelling time model estimation

The dwelling time model to be estimated is of the following form:

$$T_d = T_o + T_c + A_a N_a + A_b N_b \qquad (5)$$

Where:

Td is the dwell time

To is door open time (2 seconds); (Meng Li, Guoyuan Wu,, 2009)

Tc is door clearance time (8 seconds); (Meng Li, Guoyuan Wu,, 2009)

Na, Nb are the highest number of alighting and boarding passengers at the door, respectively.For boarding, if there are only few passengers at a station, they will probably not be uniformly spreading over all doors. Instead, it is assumed that at least one or two door will get more passengers and that door will dominate the dwelling time.

Aa, Ab are the per passenger alighting and boarding time, respectively, and are the parameters to be estimated.

Ab =2.4 seconds/person; (Meng Li, Guoyuan Wu,, 2009)

Aa =1.4 seconds/person; (Meng Li, Guoyuan Wu,, 2009)

Figure 15 plots the calculated dwelling time v. the observed dwelling time. The mode's R square value is 0.81 (adjusted R square is 0.76), with standard error of 5.66 and both parameters statistically significant at 95% confidence level.

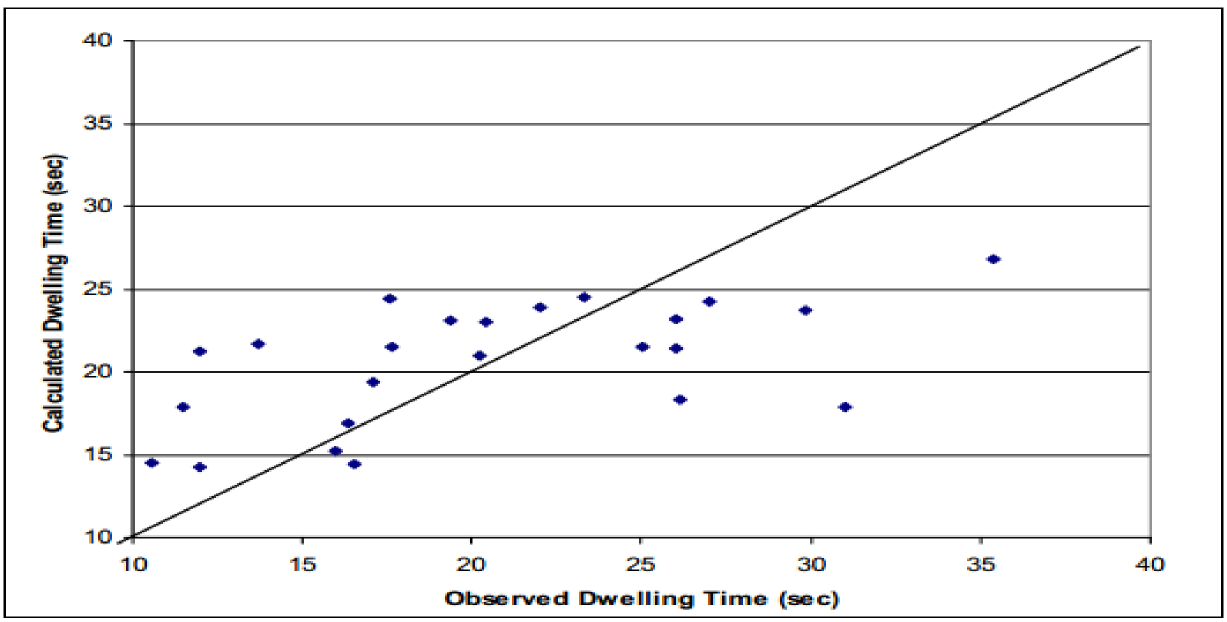


Figure4.4: Observed and calculated dwelling time of AALRT for EW10

Table4.8: Dwelling time data EW10

EW2		Boarding passenger	Alighting passenger	Average observed dwelling time
	AM	221	90	16.33
	M.D	271	248	17.11
	P.M	130	125	16
	Other			16.25
EW10	AM	210	190	12
	M.D	253	210	13.67
	P.M	150	130	11.5
	Other			10.57
EW11	AM	230	88	26
	M.D	272	160	26.04
	PM	200	110	35.35
	Other			23.28

The reason of this is to show how the factor of correction for the boarding and alighting passengers is used, computed then to obtain the real numbers of passengers in and out during the operation time.

But before we have to use for estimation dwell time, we must correct the data collected close to tickets place for each station as follows:

For station EW1 we collect for passenger boarding around:

- 1635 passenger boarding but actually we remarked that it is not the real data for that station we can count really only around 250≈300 passengers bought tickets so the correction of this value will be:

$$F_c = \frac{NPR}{NPE} \quad \text{...(1)}$$

Fc= factor of correction,

NPR= number of actually passengers bought tickets per station,

NPE=number of estimation passengers bought tickets per station.

Here also this **table 4.10** show the same case with the data concerned by the passenger flow boarding and the passenger flow alighting per day of each station but the only different is this one is the corrected one with some factor of correction to have the exact number of passenger paying the tickets as follows:

Table 4.10: EW line for passengers boarding and alighting corrected

S/N	Station Name	Stations location	Factor of correction for boarding	Factor of correction for alighting	E-W line direction		Result
					Passenger flow boarding per day	Passenger flow alighting per day	
1	EW1	Ayat 2	0.18	0.13	294.3	0	
2	EW2	Ayat 1	0.18	0.13	271.98	0.78	high flow
3	EW3	CMC intersection	0.18	0.13	217.8	2.99	
4	EW4	Kotebe Mikael church	0.18	0.13	214.74	8.84	
5	EW5	Municipal service institute	0.18	0.13	168.48	14.95	
6	EW6	S-ealite Mihret Church	0.18	0.13	686	18.46	
7	EW7	Ethiopian Communication	0.18	0.13	78.3	15.21	
8	EW8	Ethiopian Geological survey	0.18	0.13	68.4	19.37	
9	EW9	Megenagna	0.18	0.13	136.08	79.56	
10	EW10	Lem Hotel	0.18	0.13	253.62	248.17	high flow
11	EW11	Togo	0.18	0.13	272.34	210.21	high flow
12	EW12	Holiday Hotel	0.18	0.13	152.1	88.27	high flow
13	EW13	Kidus Urael Church	0.18	0.13	172.44	73.32	high flow
14	EW14	Yordanos Hotel	0.18	0.13	128.88	71.11	
15	EW15	St.Estifanos	0.18	0.13	121.5	88.4	
16	EW16	Addis Ababa Stadium	0.18	0.13	104.4	117.52	
17	EW17	Gambia Intersection (legahar)	0.18	0.13	67.68	143.65	high flow
18	EW18	Ethiopian Road department	0.18	0.13	26.28	125.19	high flow passenger
19	EW19	Mexico Square	0.18	0.13	13.68	139.36	
20	EW20	Lideta Mariam Church	0.18	0.13	6.84	145.86	
21	EW21	Coca cola Intersection	0.18	0.13	2.88	226.46	high flow
22	EW22	Torhailoch Hostipal	0.18	0.13	0	296.92	

4.5 Interpretation of the results

- **Speed restrictions:**

  All curve below radius 433m is showed above and it means that only around 10stations are above speed profile and seems expect these station the others are on curves, and when it didn't respect the designed speed profile it will reduce the reliability of the train services. So according to the logic it seems that all the mechanism will be disturbed only for this first problem.

- **Headway calculation:**

For different speed as show above, the headway can vary for different speed of Addis Ababa LRT. For example:

- For a speed of 20km/hr ⟶ 45.10 sec
- And for a speed of 30kmhr ⟶ 35.74 sec

9.36sec difference exactly appears about the headway time, then this result tell that increasing the speed can correct and avoid by the same time the delay occurring at this time and get a better reliability to obtain a sufficient and enough capacity and good punctuality.

And also profile time duration plus dwell time means for two different dwell times it gives us two profile times for the Addis Ababa LRT:

- First for a profile time duration plus a dwell time of 45sec
- And second for a profile time duration plus a dwell time of 25sec

From these results, it shows that fluctuate the dwell time can directly has a huge impact for the quality of the services of the Addis Ababa LRT when it is concerned about the punctuality, hence the reliability.

Then the total time to cover between EW1-EW22 decreases when the 45sec of dwell time is applied:

- 36.62min for a dwell of 45sec that's mean directly 3.662min of headway between consecutives trains.

- And 29.62min for a dwell time of 25sec and directly the headway between consecutives trains become 2.962min it is more improved for this one.

Not a big difference but at the end even around 7 to 8min it somehow satisfy the customers Here too the dwell time plays an important role for determining several parameters to increase the reliability of the Addis Ababa LRT.

- **Passenger flow interpretation:**

Through data collected about each station between EW1-EW22, it gives us an excel graph to have a close look between:

- Number of boarding passengers
- Number of alighting passengers

In generally the boarding time is longer than the alighting time of service peak hour; it is the same case for the graph drew above in result part. Therefore taking account to the time that passengers are boarding time exercise an influence over the dwell time that's mean the designed dwell time will be varied because of passengers boarding in some station. Hence, here again the passengers will affect too the headway time, the travel time to cover all over the EW line of Addis Ababa and directly attain the reliability, hence the punctuality of the train.

By the dwell time model estimation, one model of estimation selected to compute as the above result show the difference the observed and the calculation of passengers. Compared between observed and calculated dwelling time through 3stations select based on the number of passenger boarding and alighting and it seems that the observed dwelling time much greater than the calculated it mean there is a difference between what the design standardize for the Addis Ababa LRT and the actual dwelling time observed. Therefore a correction will be necessary at the coming time to correct and have again a better reliable service, hence a good punctuality.

Table 4.11: comparison between the existing and the improvement design

	Existing design	Comapring the assumption parameters with the existing design	
Station Dwell Time	20 sec	Assumption 1	Assumption 2
		25 sec	45 sec
Average Speed	18 km/hr	Results	
		34.4km/hr	27.85km/hr
Operational headway between 2 trains	6 min	2.962 min	3.662 min
The minimum line headway capacity	45.1 sec	35.74sec	35.74 sec
Time to take to cover to total EW line distance	60 min	29.62 min	36.62 min

The assumption of the dwell time since the points mentioned as follow are the very crucial to determine and made it:

- Based on passenger demand volumes,
- vehicle capacity and
- passengers service times

Customers satisfaction

In the existing system the headway between two consecutive trains is 6min mean theoretical headway (Z.tao,D.Hong,L.Hongxu, june 2013), which means passengers should have wait for 6min in order to take the next train. But if an adjusting on the dwell time in case of correcting a perfect headway time to avoid the waiting time if it assume having a 45sec of dwell time the headway will decrease to 3.66min as calculated in result 4.4 and the time in which the passengers will wait to take the next train decreased by 39%. Not only that, but also the duration of time which takes to travel from one place to the other decreased with significant amount. For example, to cover the total length of EW line, which has 16.998km length, needs 1hr in existing system. But with adjusting the dwell time of 45sec it will reduce to 36.6min as calculated in result 4.4. Thus, the passengers can travel faster than the existing system.

Chapter 5

5. Conclusions and Recommendation

5.1 Conclusions

- The objective of this research is to reduce of trains operation delay on the AALRT network by passing low passenger flow stations in peak hours by using the reliability of dwell time variables. The railway operation problem consists of several interrelated sub-problems. These are problems related to demand, infrastructure, time table schedule, reliability of the railway operation. As it has being seen on the result, it can be concluded that the objectives of the thesis has attained, because this paper tried to show how we can analyzed the reliability through theses parameters (dwell time, travel speed, headway time). So here is some result that explains how through reliability we can improve some of these variables.
- The comfort while alighting, standing inside train, boarding from Addis Ababa light rail transit train, is not as such easy because per meter square a number of passengers standing are beyond maximum capacity.
- The minimum line headway capacity improved from 45.1 sec to 35.74 sec.The average speed improved from 18km/hr to 27km/hr. The peak hour headway between each 20 trains improved from 6min to 3.662min based on preliminary design documents in which the passengers will wait to take next train decreased by 39%.
- This problem of reliability operation of AALRT can minimized also by providing good signal, strong management and automatic block of crossings traffic when train is approached.

5.2 Recommendation

It is recommended that the improvement or minimization cost function of train timetabling which reflects waiting time cost, in-vehicle time cost of passengers (user cost) subject to load factor constraint, waiting time constraint and the dwell time cost (which influences both the operator and user cost) accommodating on a single objective function even they are conflicting each other should be done. The facility and function provided on station for passenger starting from scheduling and time tabling is not definite. The headway time and dwell time didn't respected, that may also contribute other constraint for safety and result in congestion; it is recommended to provide good signal, strong management and automatic block of crossing traffic when train is approached.

The proposed survey technique and analysis method significantly reduce the effort spent in collecting detailed information on train dwell time, especially for railway agencies without AFC(automatic fare collection) and APC(automatic passenger collecting) systems. It is recommended to implant such tools inside Addis Ababa LRT, they could avoid serious delay caused by insufficient dwell time or inefficient operation resulted from excessive dwell time.

Bibliography

China railway group. (2009). *Addis Ababa LRT Project North-South line.* Ethoipia: ERC.

Assad, A. (1980). *Models for rails transport.* Netherland: transportation reserach.

Bergmark, R. (1996). *Railroad capacity and traffic analysis using SIMON.* WIT Press, Southampton, United Kingdom.

Billionnet, A. (2003). *Using integer programming to solve the train-platforming problem.* Transportation Science, .

Bruinsma, F. R. (1998). *Unreliability in public transport chains.* Netherland: Technical report, Tinbergen Institute of Amsterdam.

Caprara, A. F. (2002). *Modeling and solving the train timetabling problem.* operations research area.

Carey, M. ,. (2000). *Testing schedule performance and reliability for tarin stations.* Operational Research Society,.

Carey, M. ,. (2003). *Scheduling and platforming trains at busy complex stations.* Transportation Research .

Carey, M. (1999). *Exante heuristic measures of schedule reliability.* Transportation Research.

Carey, M. K. (1995). *Properties of expected costs and performance measures in stochastic models of scheduled transport.* European Journal Operational Research.

Carey.M, K. (1993). Stochastic approximation to the effects of headways on knock-on delays of trains. *transportation research part B*, 251-167.

Cordeau, J. (1988). *A survey pf optimization models for train rounting and scheduling.* Amsterdam: transportation science.

Google. (2005). *Definitions of reliability on the web.*

Goosen, J. (2004). *Models and algorithms for railway line planning models.* Netherlands: University of Maastricht.

Goverd e, R. P. (1999). *Optimal scheduling of connections in railway systems.* Netherland: Delft University press.

Groger, T. (. (2004). *Timetable simulation by sophisticated conflict resolution between trains paths.* WIT Press, Southampton, United KingDom.

Higgins, A. ,. (1995). *Modeling delay risks associated with train schedules.* German: Transportation Planning and Technology.

Higgins, A. K. (1998). *Modeling train delays in urban networks.* Germany: Transportation sceiences.

Hoogh iemstra, J. (1994). *An automatic timetable generator for the Dutch railway.* Netherland: Computational Mechanics, Southampton, United Kingdom.

Huisman, T. (2005). *Queuing models for railway systems.* Netherland: universiry of twente.

IEEE. (1990). *A Compilation of IEEE Standard Computer Glossaries.* New York.

Kaas, A. (2000). *Punctuality model for railways.* Danemark: WIT Press, Southampton, United Kingdom.

Konig, H. (2001). VirtuOS, simulation of railways. *Betrieb und Verkehr*, 50(1–2):44–47.

Kroon, L. (2001). *Operations reserach models in the planning of NS.* Netherland: Easmus university Rotterdam.

Kroon, L. G. (2003). *A variable trip time model for cyclic railway timetabling.* Germany: Transportation science university.

Liebchen, C. (2003). *Symmetry for periodic railway timetables.* Germany: Electronic notes in theoritical computer science .

Lin,TM;Wilson,NHM. (1992). *Dwell time Relation for Light Railway System.* Wasghinton DC.

M. A. Salido, F. L. (s.d.). Robustnes s in Railway Transportation Scheduling.

Medanic, J. D. (2002). Efficient scheduling of traffic on a railway line. *Journal of optimization theory and applications*, vol. 115, no. 3, pp. 587-602.

Nachtigall, K. (1996). *Periodic network optimization with different arc frequencies.* Germany: Habilitationsschrift, Universit¨at Braunschweig.

Nachtigall, K. V. (1997). Minimizing waiting times in integrated fixed interval timetables by upgrading railway tracks.

Nigel.B, B. (2012). *UK Railway Systems Reliability Modelling the Future – a case study.* United Kingdom: Network Rail.

Olsson, N. H. (2004). *Influencing factors on train punctuality–results from some Norwegian studies.* Norway: Transport Policy.

Pachl, J. (2002). *Railway Operation and Control.* Washington, United States: VTD Rail Publishing.

Peeters, L. .. (2001). *A cycle based optimization model for the cyclic railway timetabling problem.* Berlin.

Peeters, L. W. (2003). *Cyclic railway timetable optimization* . Netherland: Erasmus univesity of management.

Rietveld, P. ,. (2001). *Coping with unreliability in public transport chains: a case study for the Netherlands.* Netherland: Transportation Research.

Rietveld, P. ,. (2001). Coping with unreliability in public transport chains: a case study for the Netherlands. *Transportation Research Part A*, 35:539–559.

Rietveld, P. B. (1998). *Researching the reliability of transport systems and its influence on travel habits.* Netherland.

Robert, M. P. (2005). *Punctuality of Railway Operations and Timetable Stability Analaysis.* Netherlands: Netherlands TRAIL Research School for Transport, Infrastructure and Logistics, and financed by Delft Univesity of Technology.

Schwanhaußer, W. (1994). *the status of Germany railway operations management in research and practice.* Germany: transportation research.

Serafini, P. U. (1989). *A mathematical model for Periodic Event.* SIAM Journal of Discrete Mathematics.

T. Huisman and R.J. Boucherie. (2012). Running times on railway sections with heterogeneous train traffic. *Transportation Research Part B, 35*, 271–292.

Tom Parkinson. (1996). *Rail Transit Capacity.* USA: Transportation Research Board, National Research Council.

Van Nes, R. (1997). *Design of multimodal transport network, a hierarchal approach* . Netherland: Technical University Delft.

Vromans, M. J. (2005). *Reliabilityof Railway Systems.* Netherlands: c2005, M.J.C.M. Vromans.

Wahlborg, M. (1996). *Simulation models: important aids for Banverket's planning process.* WIT Press, Southampton, United Kingdom.

Weigand, W. (1981). *Delay propagation in long distance traffic networks.* German.

Wendler, E. (1995). *Influences of modern signalling systems on railway capacity.* Netherland: Kerkrade.

Yuan, J. H. (2004). *Analyses of scheduled and real capacity utilization of a major railway Dutch stations.* Netherland: WIT Press Southampton, United Kingdom.

Yuan. J, H. I. (2007). optimizing capacity utilization of stations by estimating knock-on train delays. *transportation methodological part B*, 202-217.

Zwaneveld, P. K.-P. (1996). *Routing trains through railway stations: model formulation and algorithms.* Transportation Science,.

Appendix A: Speed profile of EW line

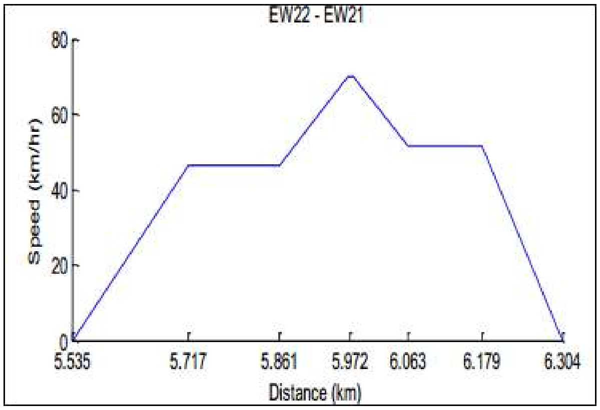


Figure A.1: EW22-EW21 stations

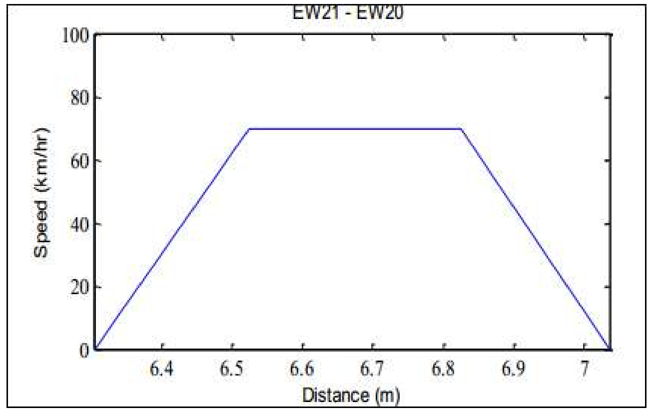


Figure A.2: EW21-EW20 stations

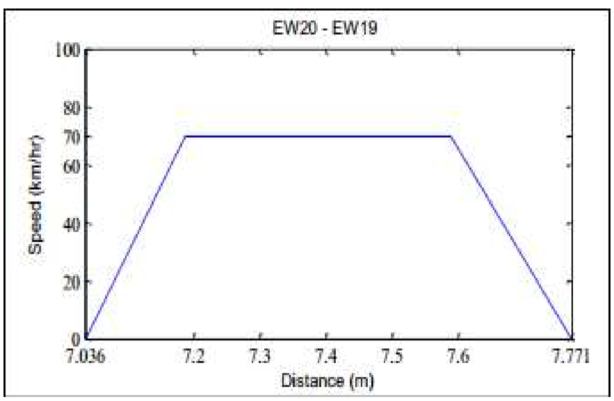


Figure A.3: EW20-EW19 stations

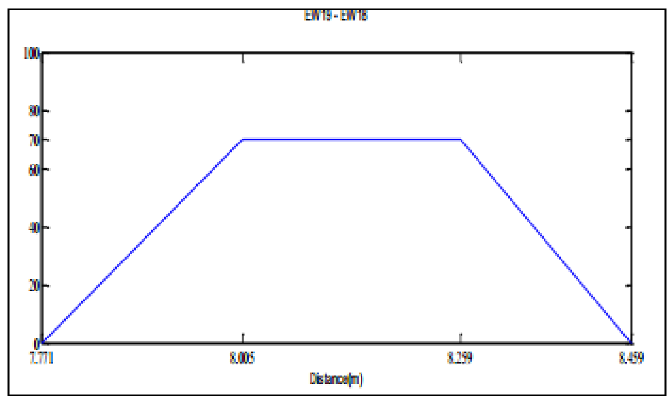


Figure A.3: EW19-EW18 stations

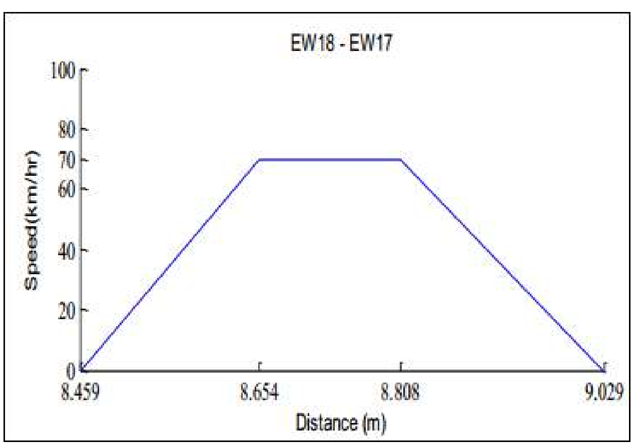


Figure A.4: EW18-EW17 stations

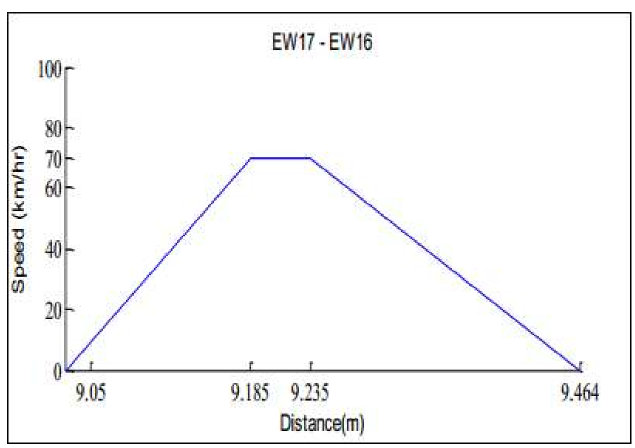


Figure A.5: EW17-EW16 stations

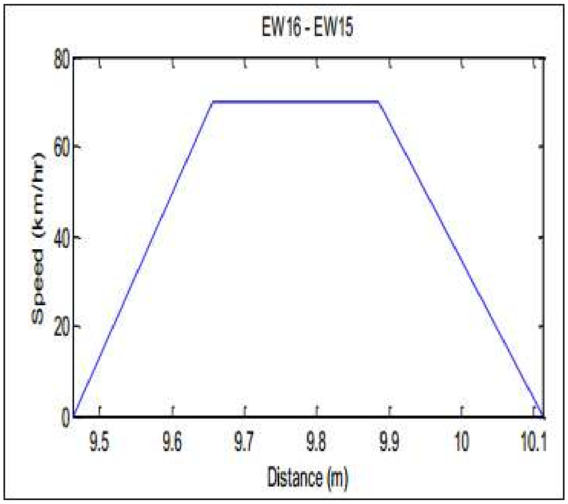


Figure A.6: EW16-EW15 stations

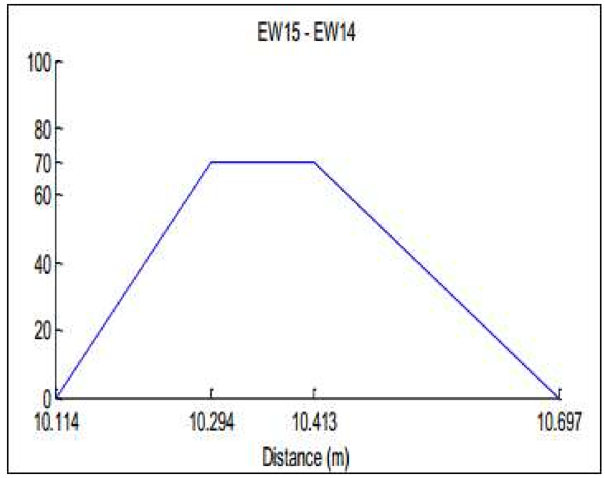


Figure A.7: EW15-EW14 stations

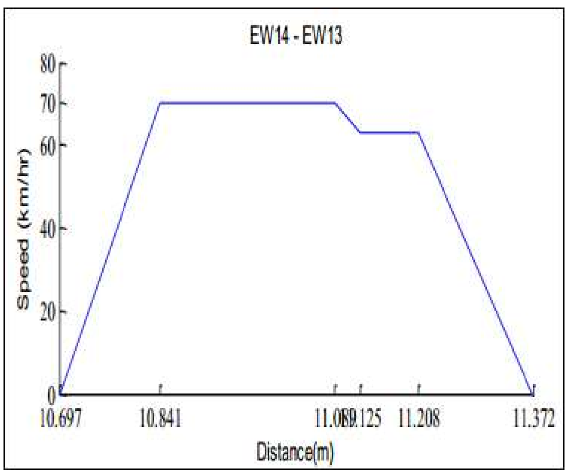


Figure A.8: EW14-EW13 stations

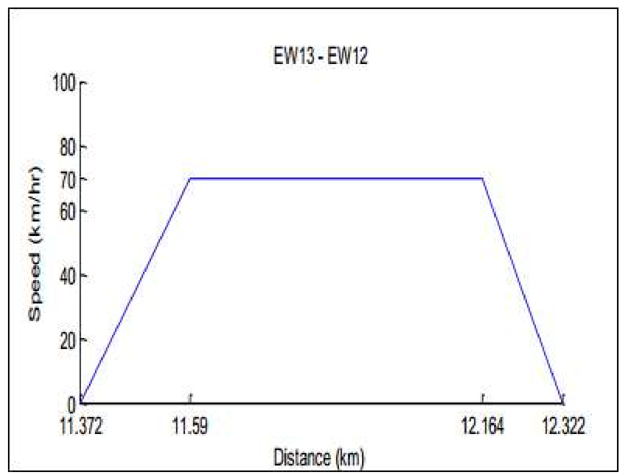


Figure A.9: EW13-EW12 stations

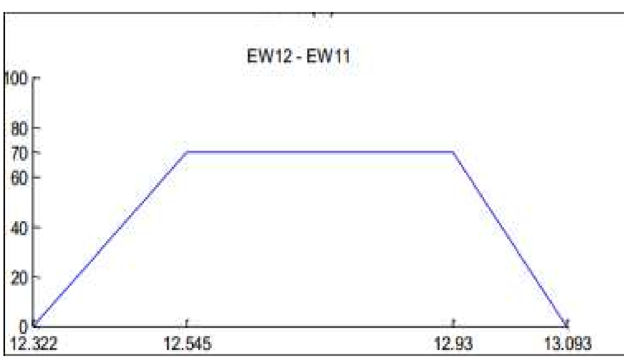


Figure A.10: EW12-EW11 stations

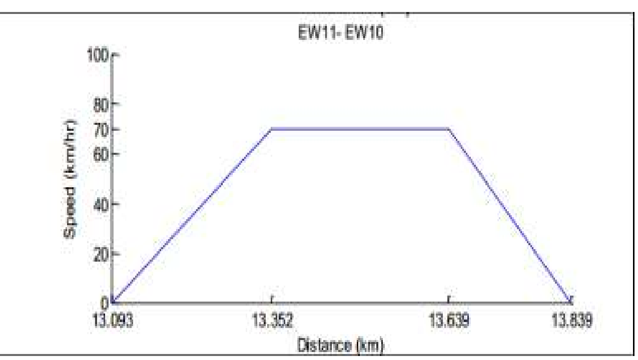


Figure A.11: EW11-EW10 stations

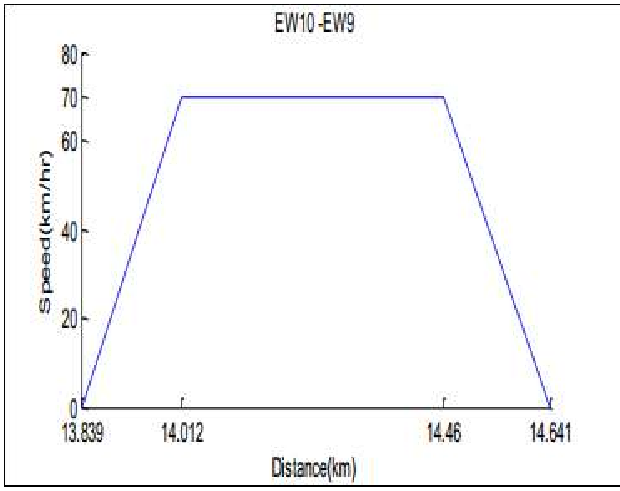


Figure A.12: EW10-EW9 stations

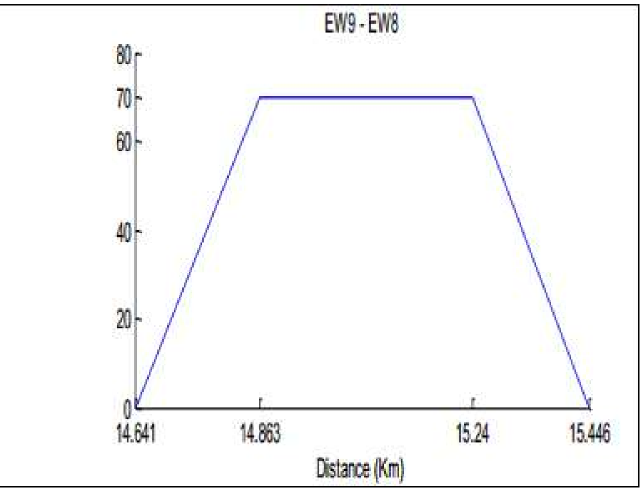


Figure A.13: EW9-EW8 stations

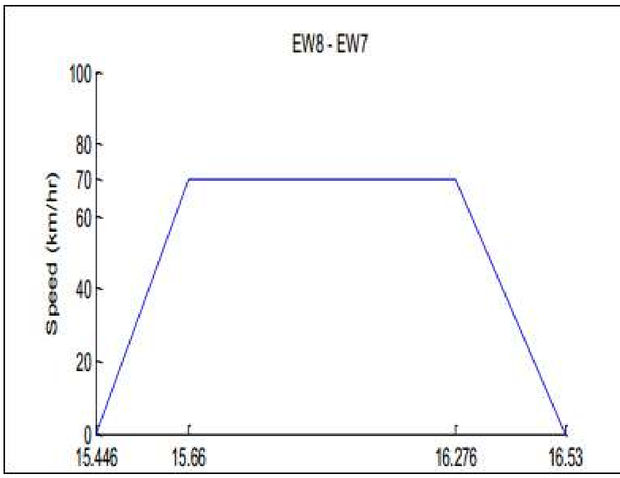


Figure A.14: EW8-EW7 stations

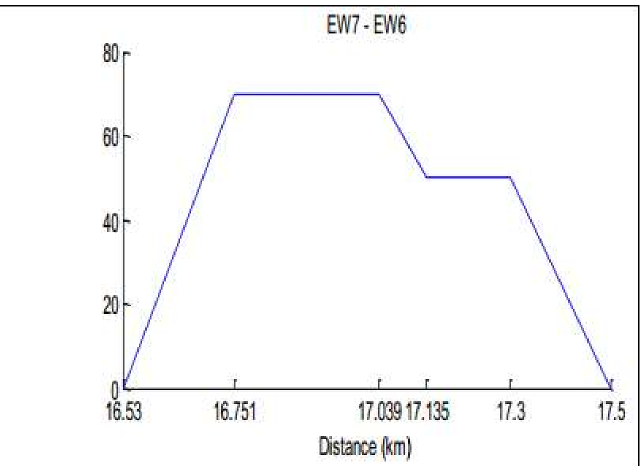


Figure A.15: EW7-EW6 stations

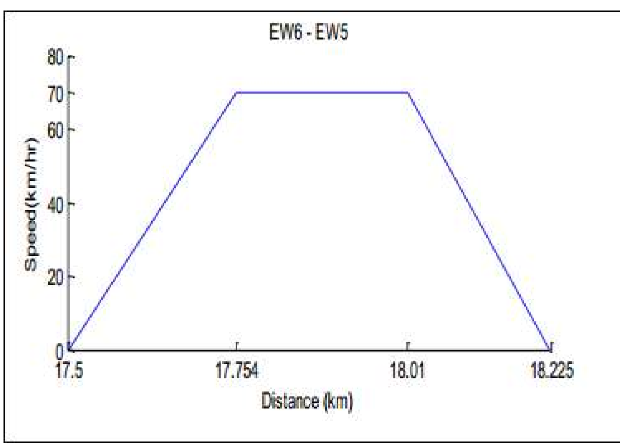


Figure A.16: EW6-EW5 stations

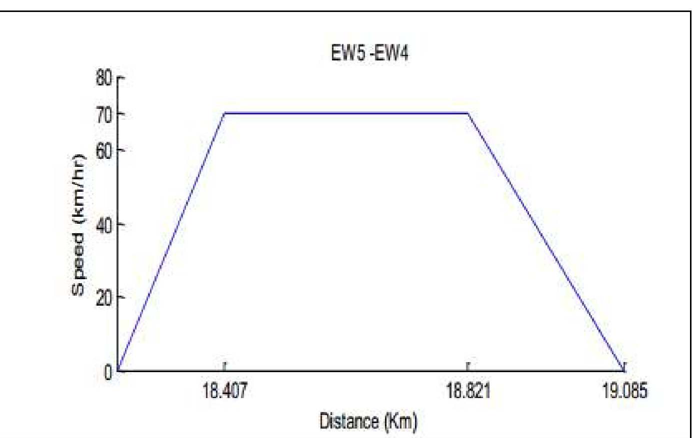
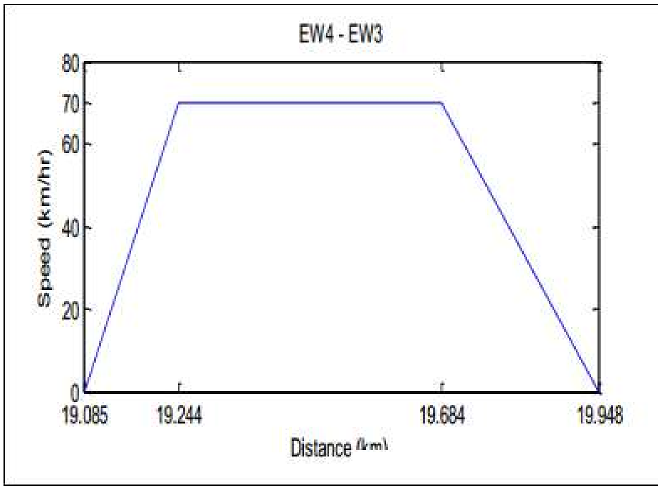


Figure A.17: EW5-EW4 stations



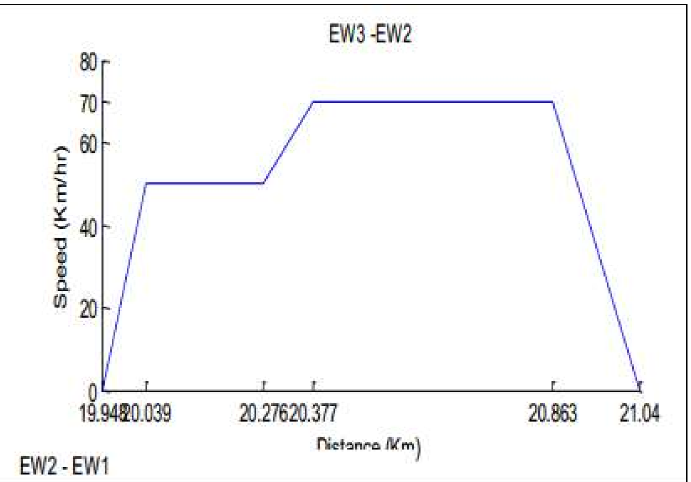


Figure A.18: EW4-EW3 stations

Figure A.19: EW3-EW2 stations

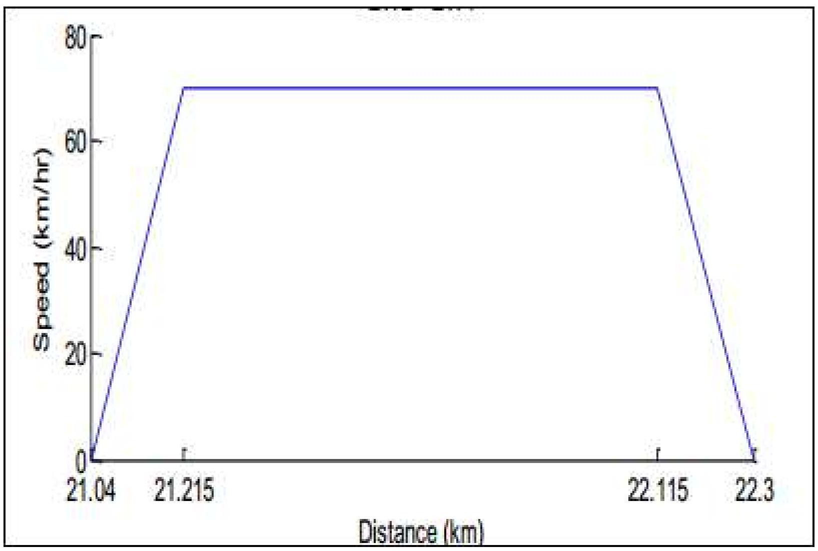


Figure A.20: EW2-EW1 stations

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