

# Investigation on the Performance of Train Timetable for the Case of Addis Ababa Light Rail Transit (AA-LRT)

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## Abstract

One of the most decisive elements to have a good performance in a railway operation is the train timetable. With a good train timetable: the train can go faster, more frequently, more safely with efficient service to the passengers and with optimal use of the available resources. So that, investigating and studying of the current train timetable specifically for the newly operated AA-LRT timetable has a fundamental importance to design a new train timetable with better quality. The main parameters which have a big influence on the design of train timetable are the headway time, dwell time, trip time, speed, braking distance, synchronization of trains etc. So that, these parameters are discussed in detail and their values are calculated. To check the validation of these calculated values, simulating software called Arena is used. In the Arena software parameters like headway, dwell time, speed, synchronization time, the number of trains and safety block are used as inputs. When these parameters are simulated, it runs correctly and gives valid result including visualizing animation to show the real traffic movement. So that, from the output of the simulation a decision is made for each parameter to compare with the existing timetable and to give an attention to their effect on the design of the timetable. Finally, based on the calculated values and simulating results a better result for the main parameters of the timetable is found such as for the current speed a headway time of 7.5 minutes should be used and for the current available number of trains a speed of 30km/h with headway of 5.55 minutes are the optimal values.

**Keywords:** Animation, Arena Software, Dwell Time, Headway, Performance, Train Timetable.

## 1. Introduction

Transport plays an important role in supporting economic, environmental and social objectives. Among these railway transport is one best example. The development in science and technology manifests itself in railways in its present form, beginning from steam engines in early 19<sup>th</sup> century, through diesel engines, electrified railways, and high-speed trains, benefitting and significantly influencing the development of every country. Since the world's first railway journey, the railway systems have evolved hugely. Speed, comfort, costs, and high quality of service demand led engineers to continuously invent new machines and devices to develop the rail transport. Going with this development, more and more requirements appeared. Nowadays, one wants the train to go faster, more frequently, more safely, while being cheaper and environmentally friendly as well as to modernizes the image of a city and a country

In railway transport, the railway timetabling is one of the main factors (Emma V. Anderson 2008) to have a good traffic management system. Generally speaking, a good train timetable can enable to use resources optimally (like time, human power, electric power consumption, the rail infrastructure, the trains, etc.), and it minimizes possible traffic accidents, it increases the attractiveness of railways, minimizes possible delay, announce train services to potential customers and the customers at large can be satisfied.

Having flexible and reliable train scheduling and routing is a central part of the planning process to have good traffic management, comfort, costs, and to maintain the quality of service demand for a railway company. Its design is concerned with the problem of selecting a set of lines and determining the headway, the arrival time, the traveling time and the departure time for a set of trains at a sequence of stations (Bernd Schittenhelm 2013).

## 2. General Characteristics of Addis Ababa Light Rail Transit (AA-LRT) System

Addis Ababa is the capital city of Ethiopia and it has a newly introduced railway system (start operation on Sep. 2015) called Addis Ababa Light Rail Transit (AA-LRT). It has two main routes having a total length of 34.25 km (including the reserved track for future extension). The north-south line is 16.90 km from 'Kality' to 'Menelik II squared' and the east-west line is 17.35 km from 'Ayat' to 'Torhailoch' with a 2.662km common line to both routes (see figure 1). It already starts service for passengers by a total of 41 trains including five trains which are not ready for operation due to technical problems. Out of these 41 trains, 20 trains are allocated to the east-west line (EW) and 21 are to north-south line (NS) including the reserved trains and trains with a technical problem (Hu Weiwu & Zeng Wei 2015).

The Addis Ababa railway line is double track and it is a homogeneous system, i.e. the trains are all the same as well as the track lines are uniform and all are electrified track lines. See table 1 for a summary of all its main characteristics.

Table 1: The main characteristics of the AA-LRT (Hu Weiwu & Zeng Wei 2015)

<ul style="list-style-type: none"> <li>• Its operational speed is 20-70kmph with maximum speed of 80kmph</li> <li>• The maximum regression speed of a passenger train is 10km/h.</li> <li>• Its infrastructure line comprises tunnels, bridges, and the ground level.</li> <li>• It negotiates steep gradient(50%)<sup>1</sup> and sharp curves</li> <li>• It gives service 16 hours per day</li> <li>• Standard Gauge (1.435 meters) and double track for the whole route</li> <li>• Expected headway: 6 minutes with a potential of reducing to 90 seconds</li> <li>• The fare system is passenger-km based</li> <li>• Minimum Curve Radius: 50m for mainlines, 30m for parking garage</li> <li>• Minimum vertical curve Radius: 1000m</li> <li>• The operation of train adopts the mode of manned visual driving</li> </ul>	<ul style="list-style-type: none"> <li>• The battery capacity can support a failed train for at least 30 minutes for the functions of door control, emergency lighting, onboard equipment, and communication system.</li> <li>• Steel rail: all the main and auxiliary tracks and the depots use 50kg/m steel rails with cut-length of 25m.</li> <li>• Sleeper arrangement: the arrangement is 1,600pairs/km for main tracks and 1,440pairs/km for tracks inside and outside the garages in rolling stock depots.</li> <li>• Average acceleration for startup: 1m/s<sup>2</sup></li> <li>• Average deceleration for braking :-                         <ul style="list-style-type: none"> <li>✓ The average deceleration of normal braking with rated load (including control response time): ≥1.0m/s<sup>2</sup></li> <li>✓ The average deceleration of emergency braking with rated load (including control response time): ≥1.5m/s<sup>2</sup></li> </ul> </li> <li>• It is fully electrified railway and hence environmentally friendly</li> </ul>
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### 3. Stations of the Addis Ababa Light Rail Transit (AA-LRT)

The platform of the AA-LRT stations has a length of 60m. It has a total of 22 stations in the east-west (EW) line and similarly 22 stations in the North-south (NS) line but, it has a total of 39 stations in both routes with five stations in common (see figure 1 below). The name of the stations is written in two ways, the first one is they use the local name of the city. The other and systematic name (i.e. easy to handle) uses the abbreviation letters EW following a number of the east-west direction and the letters NS following some number of the stations of north-south directions. The naming of stations for the EW direction starts from EW1, EW2, EW3, ..., EW22, to mean 'Ayat', 'Meri', 'CMC', ..., 'Torhailoch', and for the NS line is NS6, NS7, NS8, ..., NS27 to mean 'Kality', 'Abo Mazoria', 'Saries', ..., 'Menelik II square'. The common lines are represented either as EW16, EW17, EW18, EW19 and EW20 or NS16, NS17, NS18, NS19 and NS20. These names can be used interchangeably but most of the time the name EW is used.

<sup>1</sup> 50% = 50/100, just like 4% = 4/100

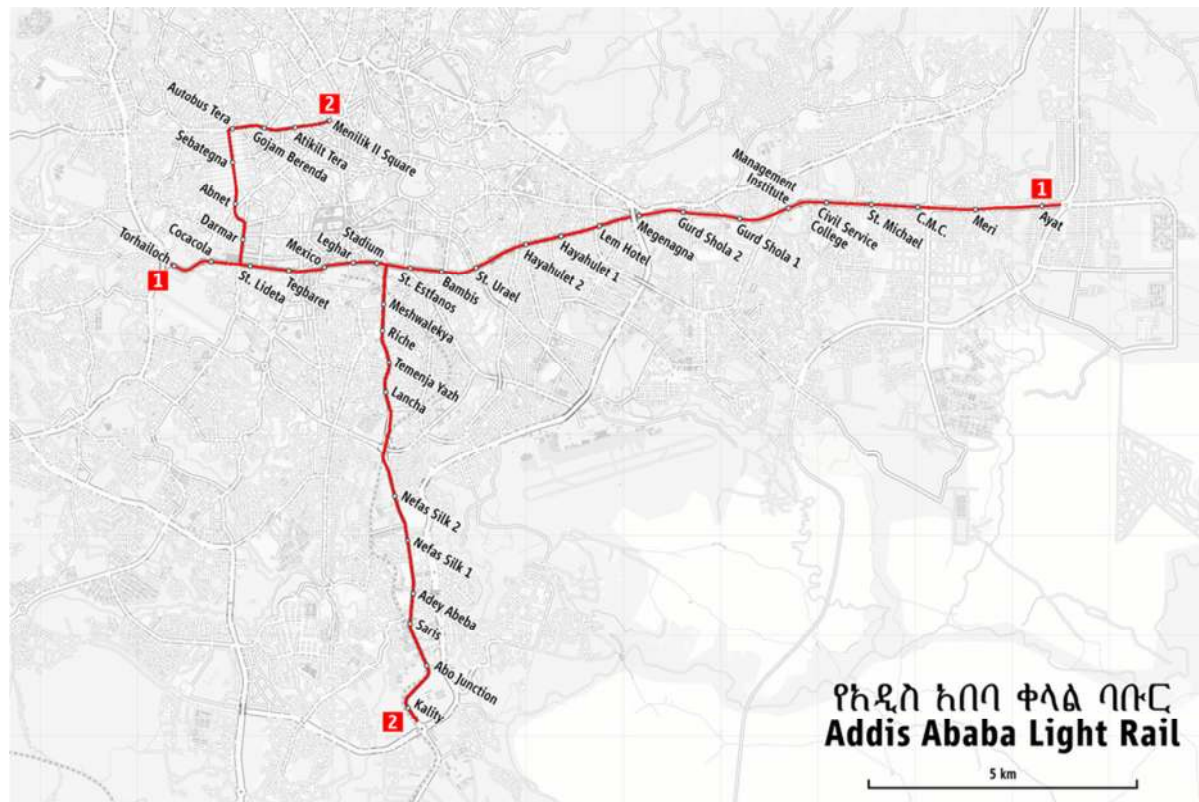


Figure 1: Map of rail lines and stations of the AA-LRT

#### 4. Railway Timetable

Railway timetable is a program for space and time-wise running of railway passenger and/or freight traffic on a railway line. A timetable for a railway line or railway network, at least it contains a list of stations per railway line with the arrival and departure times for trains. Operating economy wise the timetable is the result of the traffic production planning for a given time period i.e. the validity period for the timetable (Bernd Schittenhelm 2013).

To have an effective railway transport service it involves many procedures for railway operators (Leon W.P. Peeters 2003). Obviously, the timetable is not the only plan that needs to be composed in order to operate a railway system but also areas like demand estimation, rail line planning, rolling stock scheduling and crew scheduling too. This also indicates the dependencies between the timetabling process and other railway planning processes.

**Demand Estimation:** Travel demand is estimated as the number of people that wish to travel from an origin to a destination. Some methods to know the demand are passenger counts, passenger interviews, and counting ticket sales.

**Rail Line Planning:** A rail line is a direct train connection between an origin station and a destination station, via a certain route through the railway network.

**Timetabling:** Once the rail line plan is complete, a timetable for its train lines can be constructed.

**Rolling Stock Scheduling:** This deals with the assignment of train units to the rail lines in the timetable. When allocating the trains it is with the consideration of peak and off-peak hours since train canceled from or added to the timetable service regularly happens.

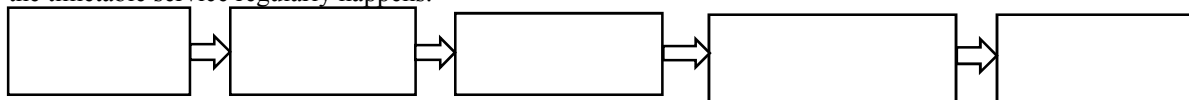


Figure 2: Operation areas and steps in a railway planning process

**Crew Scheduling:** Each train has to be manned by a driver and one or more assistants. Hence, the crew scheduling needs to respect labor rules such as working day, lunch and breakfast time, shifting of working times, etc. Generally, this category involves complex situations to make a plan (David Barney, David Haley & George Nikandros 2012).

#### Main Advantages and Disadvantages of Railway Timetable

**Advantages:-**a train timetable have so many advantages, some of them are

- It helps to use resources efficiently, it minimizes traffic accidents
- It helps to give satisfactory service to the customers.
- It helps to complete tasks on their time.
- It helps to control the traffic movement.
- It indicates to know the customer's demand to add/remove trains
- It helps to arrange the working time for the staff members in a shift based system

**Disadvantages:** - timetable has also several disadvantages. Some of them are

- There is no positive confirmation that the track ahead is clear, only that it is scheduled to be clear. The system does not allow for engine failures and other such problems, but the timetable should be set up so that there should be sufficient time between trains for the crew of a failed or delayed train to walk far enough to set warning signals to alert any other train crew.
- The timetable system is inflexible. That is trains cannot be added, delayed, or rescheduled without advance notice.
- Another problem is a corollary of the above one: that is the system is inefficient. To provide flexibility, the timetable must give trains a broad allocation of time to allow for delays, so the line is not in the possession of each train for longer than is otherwise necessary.

## 5. Timetable Design Model for Addis Ababa Light Rail Transit (AA-LRT)

In this part, the key parameters that have a big influence in the design of any railway timetable and specifically for AA-LRT timetables such as train speed, block safety, braking distance, dwell time, headway, capacity and synchronization of trains are discussed in detail.

### 5.1 Train Speed

Speed is one of the key parameters for designing a timetable. In designing a timetable the train speed has a lot of effects in most of the other parameters to be considered. For instance, the train speed affects the headway consequently; this headway has a huge effect on the train capacity. That is if the train runs slowly it decrease the capacity because it needs more travel time and hence they need more headway. In contrast, if the train speed increase, the capacity of the line increases because it needs less headway time to the train which follows the train ahead. Also, the braking distance mostly depends on the train speed. In the AA-LRT the speed designed ranges from 20-70km/h and hence for a matter of comparison for selecting the best case speeds like 20, 30, 45, 55 and 70km/h are selected for the parameters in most of the following sub-topics.

### 5.2 Section (Block) and its Safety System in AA-LRT

The scope of the lines between two adjacent end walls of two adjacent stations is defined as section or block (Hu Weiwu & Zeng Wei 2015). The scope of the lines connected to the up line between two adjacent end walls of two adjacent stations is defined as up section from x-station to y-station. The scope of the lines connected to the down line between two adjacent end walls of two adjacent stations is defined as down section from x-station to y-station. For instance, take EW1 station to EW2 station, the section and its naming is as follows.

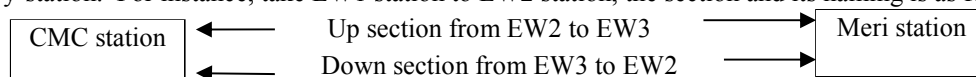


Figure 3: Naming system of a section in AA-LRT

**Boundaries between the Station and Section:** - Tracks on the inside of the edges at both ends of the station platform are in station tracks and a track between the adjacent edges of two adjacent stations is a section (Hu Weiwu & Zeng Wei 2015).

Under normal circumstances, the operation of the train must ensure spacing of one station matching with one section (Hu Weiwu & Zeng Wei 2015). It allows only one train occupancy between two adjacent signals in the same direction within one route (except train succor), and the train runs with the display of ground signal (Hu Weiwu & Zeng Wei 2015).

### 5.3 Dwell Time

Dwell time is the duration between the stopping time of the train at a station and the departure time from the station. It is measured between the instance the train wheel stops and the instance it starts to move again. The minimum dwell time is the necessary time for passengers to alight and board the train and sometimes it includes the door opening time.

The first lost time can be obtained by calculating the time difference between train stop and door opened. Similarly, the second lost time can be obtained by computing (Jyh-Cherng JONG & En-Fu CHANG 2012) the difference between doors closed and train start traveling. In the Current AA-LRT situation the lost time in the third interval is longer than the lost time in the first interval. The main reason for this difference is

that when the door is closed the train driver will come to his side's door as a rule for a matter of checking as the doors are closed and for indicating as the train is immediate to start traveling and of course to give the drivers code of greetings. Hence, during this activity, there is some lost time which leads to more time lost in the third interval than the first interval although they use the same mechanism (via electrically sliding) to open and close the doors.

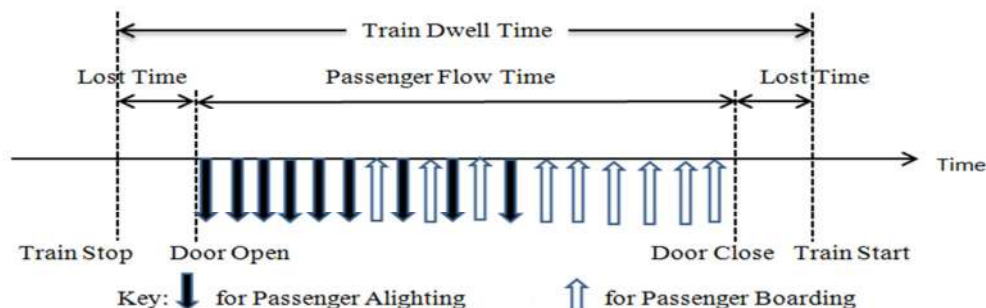


Figure 4: Activates during train dwell time

The duration of the second interval depends on the number of passengers flow. In some stations, the number of passengers can be fewer than other stations and hence the duration varies from one station to other stations. For instance in the case of AA-LRT stations like 'Megenagna' (EW9), 'Lem Hotel' (EW10), 'Stadium' (EW16), 'Autobus Tera' (NS24), and 'Saris' (NS8) have a lot of passenger movement hence they need longer dwell time than others which have few number of passenger movements. According to (TOM PARKINSON 1996), the proportion of dwell time productively used for passenger movements ranges from 31 to 64% of the total dwell time.

Generally, station dwells are governed by

- Average number of passengers alighting and boarding
- Number, width and height of the train door.
- Platform of the station ( i.e. the platform must be capable enough to reduce congestion)
- Door operation that is opening and closing time and door warning time. Here the opening and closing time of doors is considered as a part of dwell time since doors must be opened and closed while the train is still standing at the platform. But, still the opening and closing time is very few seconds since the door operations are done electronically for the case of AA-LRT.
- Dispatching time: This is the time when the driver prepares for departure (for instance to check if the doors are closed and to make the departing symbol) or waits for permission of signals to depart. In some cases, this also includes the door closing times.
- Buffer time: is the additional time which can be used to compensate for arrival delays and/or variations in alighting or boarding times

Currently, the AA-LRT has a dwell time ranging from 25 to 60 seconds. This difference comes due to the nature of each station such as the number of passengers boarding and alighting at each station, location of the station, layout of the station (whether the station is shared or not), door opening/closing time, the status of the block ahead (free or occupied). Generally, train dwell time is one of the most unpredictable components of railway operations mainly due to the varying volumes of alighting and boarding passengers.

#### 5.4 Braking Distance

Braking distance is the distance the train travels from when the train driver makes a full-service brake application to when the train stops. The braking distance depends on the speed of the train, geography of the track (gradient and curve) and on the response of the brake. The change in braking rate affects both the braking time and the safe separation time (distance). Generally, braking capacity in a railway is small due to minimal friction between metal wheels and rails.

Full-service brake (also called emergency brake) is the maximum rate of deceleration so as to minimize the risk of injury to passengers or damage to goods or cause damage to the train. The typical value (China Railway Group Limited 2009) of deceleration of AA-LRT is  $1\text{m/s}^2$  and its maximum rate is  $1.5\text{ m/s}^2$  for full service.

#### Effect of Train Mass

To stop a train it requires a work. This work equals the sum of the change in the train's kinetic energy and the change in (David Barney, David Haley & George Nikandros 2012) its potential energy (change in height due to the gradient of the rail line).The work is the energy in decelerating the train over the stopping distance, i.e. the product of the train's mass, the train's deceleration rate (deceleration is negative of acceleration) and the stopping distance.

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 ( $h_1$ ) and its height at the stopping point ( $h_2$ ). Hence mathematically it is given as:-

$$(m)(a)(s) = \frac{1}{2}m(v^2 - u^2) + mg(h_2 - h_1) \quad \dots\dots\dots \text{Equation 1}$$

Where:  $m$  = mass of the train,  $a$  = acceleration of the train,  $g$  = acceleration due to gravity,  $s$  = braking distance,  $v$  = final speed of the train which is zero,  $u$  = speed of the train when it starts decelerating,  $h_1$  = the height of the track from ground when the train starts decelerating,  $h_2$  = the height of the track from the ground when the train stops.

Mass is common in all the terms in equation 1, and therefore can be canceled out. This suggests that mass has no direct effect on stopping distance. However, mass has an effect on the stopping distance as the location of the train's center of mass varies with the mass distribution. Mass also affects the deceleration rate of a particular item of rolling stock. For freight wagons, where the mass can vary from no load to full load (David Barney, David Haley & George Nikandros 2012), there are two levels of brake force used i.e. 'empty' and 'loaded'.

$$(a)(s) = \frac{1}{2}(v^2 - u^2) + g(h_2 - h_1) \quad \dots\dots\dots \text{Equation 2}$$

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.  $\tan\alpha$ , where  $\alpha$  is the angle of the slope (refer figure 5 below). For small  $\alpha$ , which is the case for railways,  $\tan\alpha$  equals  $\sin\alpha$ .  $\sin\alpha$  is the change in height ( $h_2 - h_1$ ) over the stopping distance( $s$ ) which is given as follows.

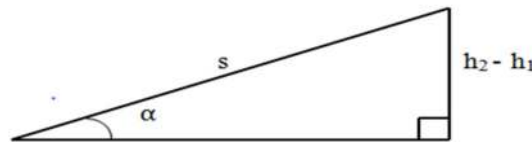


Figure 5: Sample of the gradient for braking distance calculation.

$$h_2 - h_1 = s(\sin\alpha) = s(\tan\alpha) \quad \dots\dots\dots \text{Equation 3}$$

Here if  $h_2 - h_1 > 0$ ,  $\tan\alpha$  will be positive that is the gradient (slope) is uphill where as if  $h_2 - h_1 < 0$ ,  $\tan\alpha$  will be negative that is the gradient is downhill, hence the decision depends on the sign of  $\tan\alpha$  and of course on  $\alpha$  too.

Now substituting equation 3 to 2, and then putting final speed,  $v = 0$  gives

$$s = -u^2 / (2(a - g(\tan\alpha))) \quad \dots\dots\dots \text{Equation 4}$$

Where 'a' is the deceleration, hence it is negative.

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. However, to compensate for these simplifications and the variable factors, an allowance of 15-20% is usually added (David Barney, David Haley & George Nikandros 2012).

In the AA-LRT the maximum grade of the main track is 55‰, and the minimum grade is 0‰. For intervals with a grade of 30‰ or above on the main track, see table 2 and 3 below.

To find the braking distance we need the speed when the brake applies to the train. The range of the speed in the AA-LRT is from 20km/h to 70km/h. But in some track lines, the speed is not as these ranges. For instance, there is a restricted speed when the track involves a curve, level crossing or due to any other special case.

Here is the calculation of the braking distance between some selected stations using the formula of equation 4. But, this may not indicate for the whole section, instead, it is for some part of the given section (block). The blocks used here are selected based on the length of the block, which have a big effect on the calculation of headway time and synchronization of trains.

- For EW22-EW21 here  $u = 50\text{km/h} = 13.889\text{m/s}$ ,  $\alpha = -55/1000$ , the speed is restricted to 50km/h due to the curve in between the stations.  $s = (-u^2)/(2(a - g\tan\alpha)) = - (13.889)^2 / [2(-1-9.8\tan(-0.055))] = 97.368\text{m}$

Table 2: Intervals with a grade of 30‰ or above on the main track of the EW line

Interval	Grade (‰)	Length of grade section (m)
EW22-EW21	-55	142
EW21-EW20	55	435
EW20-EW19	-55	280
EW19-EW18	46	165
EW17-EW16	-46	155
EW15-EW14	-49	356
EW13-EW12	44.5	195
EW12-EW11	-53.5	315
EW9-EW8	43.5	205
EW7-EW6	53.5	220
EW4-EW3	40	145
EW2-EW1	-50	225
EW2-EW1	50	90

- EW15-EW14 here  $u = 60\text{km/h} = 16.6667\text{m/s}$ ,  $\alpha = -49/1000$ , the speed is restricted to 60km/h due to the curve in between the stations.  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (16.6667)^2/[2(-1-9.8\tan(-0.049))] = 140.208\text{m}$
- EW2-EW1(up direction) here  $u = 70\text{km/h} = 19.4444\text{m/s}$ ,  $\alpha = 50/1000$ , here it has no restricted speed hence we can take the operated speed i.e. 70km/h  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (19.4444)^2/[2(-1-9.8\tan(0.050))] = 187.4393\text{m}$
- EW1-EW2 (down direction) here  $u = 70\text{km/h} = 19.4444\text{m/s}$ ,  $\alpha = -50/1000$ , here it has no restricted speed hence we can take the operated speed i.e. 70km/h  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (19.4444)^2/[2(-1-9.8\tan(-0.050))] = 190.665\text{m}$ . Similarly, for  $u = 20\text{km/h}$ ,  
 $s = 15.565\text{m}$ , for  $u = 30\text{km/h}$ ,  $s = 35.02\text{m}$ , for  $u = 45\text{km/h}$ ,  $s = 78.795\text{m}$ , for  $u = 55\text{km/h}$ ,  $s = 117.71\text{m}$
- EW19-EW20 here,  $u = 60\text{km/h} = 19.444\text{m/s}$ ,  $\alpha = -55/1000$ , the speed is restricted to 60km/h due to the curve in between the stations.  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (16.6667)^2/[2(-1-9.8\tan(-0.055))] = 140.21\text{m}$ . Similarly, for  $u = 20\text{km/h}$   
 $s = 15.578\text{m}$ , for  $u = 30\text{km/h}$ ,  $s = 35.050\text{m}$ , for  $u = 45\text{km/h}$ ,  $s = 78.864\text{m}$ , for  $u = 55\text{km/h}$ ,  $s = 117.809\text{m}$
- NS23-NS22 here  $u = 70\text{km/h} = 19.4444\text{m/s}$ ,  $\alpha = -46/1000$ , here it has no restricted speed hence we can take the operated speed i.e. 70km/h,  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (19.4444)^2/[2(-1-9.8\tan(-0.046))] = 190.542\text{m}$
- NS16-NS15 here  $u = 20\text{km/h} = 5.5556\text{m/s}$ ,  $\alpha = -47/1000$ , the speed is restricted to 20km/h due to the curve involvement in that station.  $s = (-u^2)/(2(a - g\tan\alpha)) = - (5.5556)^2/[2(-1-9.8\tan(-0.047))] = 15.557\text{m}$
- NS12-NS11 (upward direction) here  $u = 45\text{km/h} = 12.5\text{m/s}$ ,  $\alpha = 45/1000$ , the speed is restricted to 45km/h due to the curve involvement in that station.  $s = (-u^2)/(2(a - g\tan\alpha)) = - (12.5)^2/[2(-1-9.8\tan(0.045))] = 77.528\text{m}$ .
- NS11-NS12 (downward direction) here  $u = 45\text{km/h} = 12.5\text{m/s}$ ,  $\alpha = -45/1000$ , the speed is restricted to 45km/h due to the curve involvement in that station.  
 $s = (-u^2)/(2(a - g\tan\alpha)) = - (12.5)^2/[2(-1-9.8\tan(-0.045))] = 78.731\text{m}$  Similarly, for  $u = 20\text{km/h}$ ,  
 $s = 15.552\text{m}$ , for  $u = 30\text{km/h}$ ,  $s = 34.99\text{m}$ , for  $u = 55\text{km/h}$ ,  $s = 117.61\text{m}$ , for  $u = 70\text{km/h}$ ,  $s = 190.5\text{m}$ .

These braking distance calculations are the minimum possible distance for the maximum possible operated speed. In the AA-LRT a minimum of one empty block must separate for consecutive trains. To do so, these blocks must be long enough for the braking distance plus a safety distance. So, when we compare the distance between stations and the braking distance, the braking distance is much shorter than the distance between any stations, hence, this criterion is fulfilled.

Table 3: Intervals with a grade of 30% or above on the main track of the NS line

Interval	Grade (%)	Length of grade section (m)
NS27-NS26	-50	225
NS26-NS25	47	295
NS25-NS24	55	150
NS24-NS23	-54	370
NS23-NS22	-46	420.171
NS23-NS22	55	326
NS22-NS21	-46	615
NS21-NS20	-48.866	107
NS20-NS19	-55	280
NS19-NS18	46	165
NS17-NS16	-46	155
NS16-NS15	-47	160
NS15-NS14	-43	72
NS14-NS13	-55	142
NS12-NS11	50	185
NS12-NS11	45	185
NS12-NS11	42	155
NS12-NS11	-40	130
NS12-NS11	-50	110
NS10-NS9	-47	103
NS10-NS9	-44	258
NS9-NS8	-50	130
NS8-NS7	-40	115

### 5.5 Headway Time

In its simplest case, headway time is the time gap between two consecutive trains running to the same direction through the same rail line. Hence to protect any collision, theoretically, these two trains must be separated by at least the braking time plus the length of the train ahead.

That is:  $H = \frac{s + L}{v}$  ..... Equation 5

Where: H = headway time, s = the braking distance, L = the length of the train, V = speed of the train.

But, using only this headway time has many risks, in case, the train ahead is suddenly stopped it can collide with the train following it and even it is impossible to design signals with this minimum headway time. To solve this problem the two trains running consecutively must have a gap time (separation distance of at least one section) called headway time to avoid any collision and to reduce delays in the process.

Hence, the designed headway time is a function of Block (section) length, Operating speed, Station dwells, Train length and, Operating margin time.

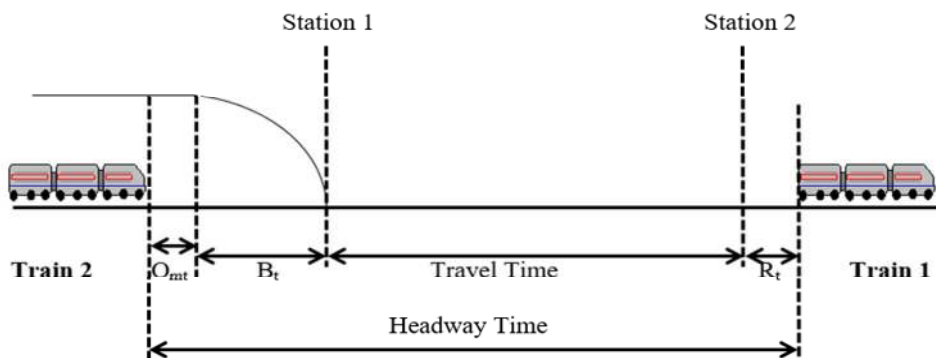


Figure 6: Diagram indicating the headway time components

So that the headway time is given by the following formula according to of the ERTMS and after calculating the headway time for each section (signals) we will take the maximum headway time from these individual headways. So for our case in AA-LRT, the headway between all consecutive pair of stations (M. Abrila, F. Barber, L. Ingolotti, M.A. Salido, & P. Tormos, A. Lova 2007) is calculated as follows.

$H_t = T_t + B_t + R_t + D_t + O_{mt}$  ..... Equation 6

Where: -  $H_t$  = Headway Time,  $T_t$  = Travel Time between two consecutive stations,  $B_t$  = Braking Time,  $R_t$  = Release Time,  $D_t$  = Dwell Time,  $O_{mt}$  = Operating Margin Time

**Notations:** In this part some notations are used. These are capital letters followed by a subscript small letter and



a subscript number. Their indication is that the letters are abbreviations for some terms according to the subtopic discussed and the subscript numbers are represented for speeds. For instance,  $T_{t45}$  the  $T_t$  is for Travel time and the 45 is for traveling speed at 45km/h. Now let's see all elements one by one to obtain the required headway via mathematical formulas.

**Travel Time ( $T_t$ ):** - It is the time taken to cover one section that is to travel from one station to the next station. Hence, the total time is given as:

$$T_t = \text{Distance}/\text{Average speed} \dots\dots \text{Equation 7}$$

To find the numerical values we will consider all the [maximum, average and minimum] values of speed and the distance. In AA-LRT the operating speed ranges from 20-70km/h, the distance between stations for NS-line are [longest, average, shortest] given as [1972, 738.289, 445m] and for the EW-line are [longest, average, shortest] given as [1260, 761.928, 445m] using these distances let's calculate the possible travel time. To calculate the possible headway time this thesis considers the two lines (NS and EW line) independently and even the common line is considered explicitly. So that, the governed headway time can be found in common line or in the other two lines.

#### For North-South Line (NS)

$$T_{\text{average}} = \text{average distance}/\text{average speed} = 738.3\text{m}/45\text{kmph} = 59.1 \text{ seconds} = 0.984 \text{ minutes}$$

$$T_{\text{shortest}} = \text{shortest distance}/\text{maximum speed} = 445\text{m}/70\text{kmph} = 22.89 \text{ seconds} = 0.381 \text{ minutes}$$

Based on the different case the speed can be varied but the distance between stations is already fixed. Again let's see some travel time values for some selected speeds. Here, since we are concerned for the maximum governed headway, let's seek for the travel time using the maximum and average distances between the stations. Accordingly let's calculate the travel time for speeds of 20,30,45,55 and 70km/h, using the longest and average distances between the stations.

Travel time using the longest distance:

- $T_{20} = 1972\text{m}/20\text{kmph} = 1972/5.5556 = 354.9571 \text{ seconds} = 5.9159 \text{ minutes}$
- $T_{30} = 1972\text{m}/30\text{kmph} = 1972/8.3333 = 236.64 \text{ seconds} = 3.994 \text{ minutes}$
- $T_{45} = 1972\text{m}/45\text{kmph} = 1972/12.5 = 157.76 \text{ seconds} = 2.629 \text{ minutes}$
- $T_{55} = 1972\text{m}/55\text{kmph} = 1972/15.2778 = 129.076 \text{ seconds} = 2.151 \text{ minutes}$
- $T_{70} = 1972\text{m}/70\text{kmph} = 1972/19.4444 = 101.417 \text{ seconds} = 1.690 \text{ minutes}$

Again let's see using the Average distance between Stations

- $T_{20} = 738.289\text{m}/20\text{kmph} = 738.289/5.5556 = 132.8909 \text{ seconds} = 2.215 \text{ minutes}$
- $T_{30} = 738.289\text{m}/30\text{kmph} = 738.289/8.3333 = 88.595 \text{ seconds} = 1.477 \text{ minutes}$
- $T_{45} = 738.289\text{m}/45\text{kmph} = 738.289/12.5 = 59.0630 \text{ seconds} = 0.984 \text{ minutes}$
- $T_{55} = 738.289\text{m}/55\text{kmph} = 738.289/15.2778 = 48.3243 \text{ seconds} = 0.805 \text{ minutes}$
- $T_{70} = 738.289\text{m}/70\text{kmph} = 738.289/19.4444 = 37.969 \text{ seconds} = 0.6328 \text{ minutes}$

#### For East-West Line (EW)

With similar procedure as for NS-line, let's find the typical values for the EW-line

$$T_{\text{longest}} = \text{longest distance}/\text{lowest speed} = 1260\text{m}/20\text{kmph} = 226.789 \text{ seconds} = 3.780 \text{ minutes}$$

$$T_{\text{average}} = \text{average distance}/\text{average speed} = 761.928\text{m}/45\text{kmph} = 60.954 \text{ seconds} = 1.016 \text{ minutes}$$

$$T_{\text{shortest}} = \text{shortest distance}/\text{maximum speed} = 445\text{m}/70\text{kmph} = 22.89 \text{ seconds} = 0.381\text{minutes}$$

Again, let's calculate the travel time for speeds of 20,30,45,55 and 70km/h, using the longest and average distances between the stations of EW-line.

- $T_{20} = 1260\text{m}/20\text{kmph} = 1260/5.5556 = 226.789 \text{ seconds} = 3.780 \text{ minutes}$
- $T_{30} = 1260\text{m}/30\text{kmph} = 1260/8.3333 = 151.20 \text{ seconds} = 2.520 \text{ minutes}$
- $T_{45} = 1260\text{m}/45\text{kmph} = 1260/12.5 = 100.8 \text{ seconds} = 1.68 \text{ minutes}$
- $T_{55} = 1260\text{m}/55\text{kmph} = 1260/15.2778 = 82.473 \text{ seconds} = 1.375 \text{ minutes}$
- $T_{70} = 1260\text{m}/70\text{kmph} = 1260/19.4444 = 64.801 \text{ seconds} = 1.080 \text{ minutes}$

Again let's see using the Average distance between stations which is 761.928m

- $T_{20} = 761.928\text{m}/20\text{kmph} = 761.928/5.5556 = 137.1459 \text{ seconds} = 2.286 \text{ minutes}$
- $T_{30} = 761.928\text{m}/30\text{kmph} = 761.928/8.3333 = 91.432 \text{ seconds} = 1.524 \text{ minutes}$
- $T_{45} = 761.928\text{m}/45\text{kmph} = 761.928/12.5 = 60.954 \text{ seconds} = 1.016 \text{ minutes}$
- $T_{55} = 761.928\text{m}/55\text{kmph} = 761.928/15.2778 = 49.872 \text{ seconds} = 0.831 \text{ minutes}$
- $T_{70} = 761.928\text{m}/70\text{kmph} = 761.928/19.4444 = 39.185 \text{ seconds} = 0.653 \text{ minutes}$

#### For the Common Line

In the common line there are five stations and the distance between each station is as follows: [EW16-EW17-EW18-EW19-EW20] = [445-560-688-735] meters respectively and their average distance is 607meteres. Based on this data let's consider some typical values.

$$T_{\text{longest}} = \text{longest distance}/\text{lowest speed} = 735\text{m}/20\text{kmph} = 132.299 \text{ seconds} = 2.205 \text{ minutes}$$

$$T_{\text{average}} = \text{average distance}/\text{average speed} = 607\text{m}/45\text{kmph} = 48.56 \text{ seconds} = 0.809 \text{ minutes}$$

$T_{\text{shortest}} = \text{shortest distance} / \text{maximum speed} = 445\text{m} / 70\text{kmph} = 22.89 \text{ seconds} = 0.381 \text{ minutes}$

Again let's calculate the travel time for speeds of 20,30,45,55 and 70km/h, using the longest and average distances between the stations of the common line-line.

Using the longest distance between stations which is 735m, the following results are obtained.

- $T_{20} = 735\text{m} / 20\text{kmph} = 735 / 5.5556 = 132.299 \text{ seconds} = 2.205 \text{ minutes}$
- $T_{30} = 735\text{m} / 30\text{kmph} = 735 / 8.3333 = 88.20 \text{ seconds} = 1.470 \text{ minutes}$
- $T_{45} = 735\text{m} / 45\text{kmph} = 735 / 12.5 = 58.8 \text{ seconds} = 0.98 \text{ minutes}$
- $T_{55} = 735\text{m} / 55\text{kmph} = 735 / 15.2778 = 48.109 \text{ seconds} = 0.802 \text{ minutes}$
- $T_{70} = 735\text{m} / 70\text{kmph} = 735 / 19.4444 = 37.80 \text{ seconds} = 0.63 \text{ minutes}$

Using the average distance between stations which is 607m

- $T_{20} = 607\text{m} / 20\text{kmph} = 607 / 5.5556 = 109.259 \text{ seconds} = 1.821 \text{ minutes}$
- $T_{30} = 607\text{m} / 30\text{kmph} = 607 / 8.3333 = 72.840 \text{ seconds} = 1.214 \text{ minutes}$
- $T_{45} = 607\text{m} / 45\text{kmph} = 607 / 12.5 = 48.56 \text{ seconds} = 0.809 \text{ minutes}$
- $T_{55} = 607\text{m} / 55\text{kmph} = 607 / 15.2778 = 39.731 \text{ seconds} = 0.662 \text{ minutes}$
- $T_{70} = 607\text{m} / 70\text{kmph} = 607 / 19.4444 = 31.217 \text{ seconds} = 0.520 \text{ minutes}$

**Release Time ( $R_t$ ):** After the train make some dwell at a station and then it starts traveling. Then the release time is the time required for the entire length of a train to cross a signal at a station. Mathematically it is given as:

Release time = Length of the train/Speed ..... Equation 8

Now to find the release time for the case of AA-LRT this thesis considers the maximum possible length of the train (i.e. considering the worst case), which is found when two trains are coupled. Hence, they make a total length of about 59 meters.

Hence  $R_t = 59\text{m} / \text{speed}$ , now let's see some numerical value for selected speeds of 20, 30, 45, 55, 70km/h

- $R_{t20} = 59\text{m} / 20\text{kmph} = 59 / 5.5556 = 10.620 \text{ seconds}$
- $R_{t30} = 59\text{m} / 30\text{kmph} = 59 / 8.333 = 7.080 \text{ seconds}$
- $R_{t45} = 59\text{m} / 45\text{kmph} = 59 / 12.5 = 4.72 \text{ seconds}$
- $R_{t55} = 59\text{m} / 55\text{kmph} = 59 / 15.2778 = 3.862 \text{ seconds}$
- $R_{t70} = 59\text{m} / 70\text{kmph} = 59 / 19.4444 = 3.034 \text{ seconds}$

### Braking Time ( $B_t$ )

This time is the time taken by the train to cover the braking distance after the driver applies the brake when approaching to the station. Mathematically it is given as:

$B_t = \text{Braking distance} / \text{Speed}$  ..... Equation 9

To see numerical values lets calculate the braking time in between two stations having the longest distance. The braking time to find here is the maximum braking time found in between the sample stations using the allowed maximum speed.

#### For NS Line

- $B_{t20} = 15.553\text{m} / 5.5556\text{ms}^{-1} = 2.80 \text{ seconds}$  this is the braking time between stations of NS11-NS12 with a speed of 20km/h
- $B_{t30} = 34.99\text{m} / 8.3333\text{ms}^{-1} = 4.199 \text{ seconds}$  this is the braking time between stations of NS11-NS12 with a speed of 30km/h
- $B_{t45} = 78.731\text{m} / 12.5\text{ms}^{-1} = 6.298 \text{ seconds}$  this is the maximum braking time between stations of NS11-NS12
- $B_{t55} = 117.61\text{m} / 15.2778\text{ms}^{-1} = 7.698 \text{ seconds}$  this is the braking time between stations of NS11-NS12 with a speed of 55km/h
- $B_{t70} = 190.5\text{m} / 19.444\text{ms}^{-1} = 9.798 \text{ seconds}$  this is the braking time between stations of NS11-NS12 with a speed of 70km/h
- $B_{t70} = 190.542\text{m} / 19.444\text{ms}^{-1} = 9.79 \text{ seconds}$  this is the braking time between stations of NS23-NS22

#### For EW-line

- $B_{t20} = 15.565\text{m} / 5.5556\text{ms}^{-1} = 2.801 \text{ seconds}$  this is the braking time between stations of EW1-EW2 with a speed of 20km/h
- $B_{t30} = 35.05\text{m} / 8.3333\text{ms}^{-1} = 4.21 \text{ seconds}$  this is the braking time between stations of EW1-EW2 with a speed of 30km/h
- $B_{t45} = 78.795\text{m} / 12.5\text{ms}^{-1} = 6.304 \text{ seconds}$  this is the braking time between stations of EW1-EW2 with a speed of 45km/h
- $B_{t55} = 117.71\text{m} / 15.2778\text{ms}^{-1} = 7.705 \text{ seconds}$  this is the braking time between stations of EW1-EW2 with a speed of 55km/h
- $B_{t70} = 190.665\text{m} / 19.444\text{ms}^{-1} = 9.81 \text{ seconds}$  this is the braking time between stations of EW1-EW2 with a speed of 70km/h

- $B_{160} = 140.208\text{m} / 16.6667\text{ms}^{-1} = 8.41$  seconds this is the braking time between stations of EW1-EW2 with a speed of 60km/h

**For the common line**

- $B_{120} = 15.578\text{m} / 5.5556\text{ms}^{-1} = 2.804$  seconds this is the braking time between stations of EW19-EW20 with a speed of 20km/h
- $B_{130} = 35.050\text{m} / 8.3333\text{ms}^{-1} = 4.21$  seconds this is the braking time between stations of EW19-EW20 with a speed of 30km/h
- $B_{145} = 78.864\text{m} / 12.5\text{ms}^{-1} = 6.309$  seconds this is the braking time between stations of EW19-EW20 with a speed of 45km/h
- $B_{155} = 117.809\text{m} / 15.2778\text{ms}^{-1} = 7.711$  seconds this is the braking time between stations of EW19-EW20 with a speed of 55km/h
- $B_{170} = 190.83\text{m} / 19.444\text{ms}^{-1} = 9.81$  seconds this is the braking time between stations of EW19-EW20 with a speed of 70km/h

**Dwell Time ( $D_t$ ):** As figure 6 on page 11 indicates, to find the possible headway it involves two stations. So that, these stations are considered in finding the headway. For instance, the stations having the maximum distance in between them are to be taken their dwell time. To be specific the maximum distance is found in NS11-NS12, EW1-EW2 and EW19-EW20 for all the three sections and their average dwell time is taken as 30 seconds and hence 60 seconds in two consecutive stations.

**Operating Margin Time ( $O_{mt}$ ):** This time is the constant time in which the train spends for the reaction time to give commands (e.g. to apply the brake). The constant time is set by the infrastructure managers and most of the time it is a small number. Numerically 5-10 seconds. For AA-LRT it has about duration of 7 seconds.

**Headway Time:** now we are at a point of finding the required headway at different sampled stations and using different sampled speeds based on the calculations of the main elements of the headway in the above subtopics.

**In the NS Line:** For the longest distance with speeds of 20,30,45,55 and 70km/h, the headway becomes

- $H_{120} = T_{120} + B_{120} + R_{120} + D_t + O_{mt} = 132.891 + 2.800 + 10.620 + 60 + 7 = 435.377 \text{ sec} = \underline{7.26 \text{ minutes}}$
- $H_{130} = T_{130} + B_{130} + R_{130} + D_t + O_{mt} = 236.640 + 4.19 + 7.080 + 60 + 7 = 307.839 \text{ sec} = \underline{5.13 \text{ minutes}}$
- $H_{145} = T_{145} + B_{145} + R_{145} + D_t + O_{mt} = 157.760 + 6.298 + 4.72 + 60 + 7 = 235.778 \text{ sec} = \underline{3.93 \text{ minutes}}$
- $H_{155} = T_{155} + B_{155} + R_{155} + D_t + O_{mt} = 129.076 + 7.698 + 3.862 + 60 + 7 = 207.636 \text{ sec} = \underline{3.46 \text{ minutes}}$
- $H_{170} = T_{170} + B_{170} + R_{170} + D_t + O_{mt} = 101.417 + 9.798 + 3.034 + 60 + 7 = 181.249 \text{ sec} = \underline{3.02 \text{ minutes}}$

**In the EW Line:** For the longest distance with speeds of 20,30,45,55 and 70km/h

- $H_{120} = T_{120} + B_{120} + R_{120} + D_t + O_{mt} = 226.79 + 2.801 + 10.620 + 60 + 7 = 307.21 \text{ sec} = \underline{5.12 \text{ minutes}}$
- $H_{130} = T_{130} + B_{130} + R_{130} + D_t + O_{mt} = 151.20 + 4.210 + 7.080 + 60 + 7 = 229.49 \text{ sec} = \underline{3.83 \text{ minutes}}$
- $H_{145} = T_{145} + B_{145} + R_{145} + D_t + O_{mt} = 100.80 + 6.304 + 4.720 + 60 + 7 = 178.83 \text{ sec} = \underline{2.98 \text{ minutes}}$
- $H_{155} = T_{155} + B_{155} + R_{155} + D_t + O_{mt} = 82.473 + 7.705 + 3.862 + 60 + 7 = 161.04 \text{ sec} = \underline{2.69 \text{ minutes}}$
- $H_{170} = T_{170} + B_{170} + R_{170} + D_t + O_{mt} = 64.801 + 9.810 + 3.034 + 60 + 7 = 144.65 \text{ sec} = \underline{2.41 \text{ minutes}}$

**In the Common Line:** For the longest distance with speeds of 20,30,45,55 and 70km/h are considered in the common line. The stations from EW16 to EW20 are the common lines for the trains coming from two independent directions. Hence in this intersection route the headway time is reduced by half because it involves trains coming from different routes. Due to this reason the headway found in calculation using the characteristics of the common line is doubled.

- $H_{120} = T_{120} + B_{120} + R_{120} + D_t + O_{mt} = 132.30 + 2.81 + 10.62 + 60 + 7 = 212.723 \text{ sec} = 3.55 \text{ minutes}$   
 Note: the headway in this line must be doubled hence  $3.55 \times 2 \rightarrow \underline{7.1 \text{ minutes}}$
- $H_{130} = T_{130} + B_{130} + R_{130} + D_t + O_{mt} = 88.20 + 4.21 + 7.08 + 60 + 7 = 166.49 \text{ sec} = 2.775 \times 2 \rightarrow \underline{5.55 \text{ minutes}}$
- $H_{145} = T_{145} + B_{145} + R_{145} + D_t + O_{mt} = 58.80 + 6.31 + 4.72 + 60 + 7 = 136.829 \text{ sec} = 2.28 \times 2 \rightarrow \underline{4.56 \text{ minutes}}$
- $H_{155} = T_{155} + B_{155} + R_{155} + D_t + O_{mt} = 48.80 + 7.71 + 3.86 + 60 + 7 = 127.37 \text{ sec} = 2.123 \times 2 \rightarrow \underline{4.25 \text{ minutes}}$
- $H_{170} = T_{170} + B_{170} + R_{170} + D_t + O_{mt} = 37.80 + 9.81 + 3.04 + 60 + 7 = 117.65 \text{ sec} = 1.96 \times 2 \rightarrow \underline{3.92 \text{ minutes}}$

**Conclusion:** The above-calculated headway values are classified into three different parts. That is headway in the common line, headway in the other parts of NS-line as well as on the other parts of EW line. In both the EW and NS lines a common headway must be used due to the following two reasons. The first reason is that since both lines use a common line so that to share this common line uniformly for trains' coming from different lines they should come with uniform frequency. So, that to come with uniform frequency trains coming from different lines toward the common line must have a common headway but, they should be synchronized properly.

The second reason is that having a common headway has some advantages. To mention having a common headway helps to use the common synchronizing method, to have a uniform way of designing the timetable, to have uniform allocating resources, to use similar speeds in both lines, etc. So, that to own these advantage the calculated headway on the three different parts (common line, EW line and NS line) is already given in the above section. Now, to be safe in any circumstance it is a must to take the maximum calculated headway from

all the three parts. Comparing the headways calculated in the above section according to the sampled speeds, the maximum headway is to be taken in order to be safe throughout the lines (see the double underlined headway values for each part found above); it will be found as follows.

$H_{120} = 7.26$  minutes,  $H_{130} = 5.55$  minutes,  $H_{145} = 4.56$  minutes,  $H_{155} = 4.25$  minutes,  $H_{170} = 3.92$  minutes

Hence, the recommended headways for the AA-LRT for the speeds of 20, 30, 45, 55, and 70km/h are 7.26, 5.55, 4.56, 4.25 and 3.92 minutes respectively. These headways are the maximum calculated values from all the three parts (the common line, EW line and NS line). For a matter of simplification (easily handling the numbers) let's approximate the headways to the next higher integer i.e. to 8, 6, 5, 5, and 4 minutes for  $H_{120}$ ,  $H_{130}$ ,  $H_{145}$ ,  $H_{155}$ , and  $H_{170}$  respectively. Here the most interesting part is that the headway found in all the three parts are close to each other although the dominant part is from the calculated headways of the common line. Since all headways calculated from the three parts are close to each other this can be taken as another encouragement for using a common headway for all the lines.

### 5.6 Capacity

Here in this thesis capacity refers to two things, though they are related to each other. These are Train capacity and Line Capacity.

**Train Capacity:** The maximum number of passengers (TOM PARKINSON & IAN FISHER 1996) in a train. If two trains are coupled together the number of passengers will be doubled. Mathematically it is given as:-

Number of passengers = Number of passenger seats + valid standing area in the train  $\times$  allowable number of standing persons per  $m^2$

For the case of AA-LRT, a train has a capacity of 317 passengers in total. Specifically, each train has 65 seats and 6 persons/ $m^2$  for standings.

**Line Capacity:** Line capacity refers (TOM PARKINSON & IAN FISHER 1996) to the maximum number of trains that can be operated over a line in a peak hour that is in one direction on a single track. Mathematically it is given as

$$L_c = \frac{60}{H_t} \dots\dots\dots \text{Equation 10}$$

Where:  $L_c$  = Line Capacity       $H_t$  = Headway time in minutes

Based on the headway we found earlier the maximum possible number of trains will be as follows based on their speed.

$L_{c20} = 60/H_{120} = 60/8 = 7.5$ trains,  $L_{c30} = 60/H_{130} = 60/6 = 10$ trains,  $L_{c45} = 60/H_{145} = 60/5 = 12$ trains

$L_{c55} = 60/H_{155} = 60/5 = 12$ trains,  $L_{c70} = 60/H_{170} = 60/4 = 15$ trains

These trains are for a single direction only. So, for both directions, the number of trains should be doubled i.e. the number of trains in one depot (at 'Kality' or 'Ayat') should be as follows:

$L_{c20} = 15$  trains,  $L_{c30} = 20$ trains,  $L_{c45} = 24$ trains,  $L_{c55} = 24$ trains and  $L_{c70} = 30$ trains

**Design Passengers Capacity:** The maximum number of passengers in a train traveled past a single point in an hour, in one direction on a single track (TOM PARKINSON & IAN FISHER 1996).

$$C_{DP} = C_L \times C_T \dots\dots\dots \text{Equation 11}$$

Where:  $C_{DP}$  = Design Passengers Capacity (p/h),  $C_L$  = Line Capacity (trains/h),  $C_T$  = Train Capacity (p/train).

In practice, part of the infrastructure capacity must also be reserved for traffic control to manage disruptions.

Now let's see numerically for the nominated speeds.

- $C_{DP20} = C_L \times C_{T20} = 7.5 \times 317 = 2377$ passenges/h
- $C_{DP30} = C_L \times C_{T30} = 10 \times 317 = 3170$ passenges/h
- $C_{DP45} = C_L \times C_{T45} = 12 \times 317 = 3804$ passenges/h
- $C_{DP55} = C_L \times C_{T55} = 12 \times 317 = 3804$ passenges/h
- $C_{DP70} = C_L \times C_{T70} = 15 \times 317 = 4755$ passenges/h

This number will be doubled when two trains are coupled together. Furthermore to find the total passengers traveled in one hour in all directions it will be multiplied by four. And then to find total passengers travel in a day it will be multiplied by 16 (the service hours per a day).

### 5.7 Travel Time

Travel time is defined as the time taken to complete a given trip. As the speed increases, travel time required to reach the destination also decreases and vice-versa. Hence, travel time is inversely proportional to the speed. However, in practice, the speed of a train fluctuates over time and the travel time represents an average measure. Additionally, the travel time includes the time spent on the stations i.e. the dwell times. So the total travel time is given as:

$$T = T_d + \frac{S}{V} \dots\dots\dots \text{Equation 12}$$

Where:  $T$  = total travel time from origin station to final destination station,  $S$  = the distance from the origin station to destination station,  $T_d$  = the total dwell time of all stations,  $V$  = the average speed  
 To see numerical values:  $T_d$  = sum of all dwell times from origin stations to destination = 11 minutes.

**For NS-Route for Average Speeds of 20, 30, 45, 55 and 70km/h**

- $T_{20} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 16.9\text{km}/20\text{kmph} = 11 + 50.7 = 61.7 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 16.9\text{km}/30\text{kmph} = 11 + 33.8 = 44.8 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 16.9\text{km}/45\text{kmph} = 11 + 22.5 = 33.5 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 16.9\text{km}/55\text{kmph} = 11 + 18.5 = 29.5 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 16.9\text{km}/70\text{kmph} = 11 + 14.5 = 25.5 \text{ minutes}$

**For EW-Route for Average Speeds of 20, 30, 45, 55 and 70km/h**

- $T_{20} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 17.35\text{km}/20\text{kmph} = 11 + 52.1 = 63.1 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 17.35\text{km}/30\text{kmph} = 11 + 34.7 = 45.7 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 17.35\text{km}/45\text{kmph} = 11 + 23.1 = 34.1 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 17.35\text{km}/55\text{kmph} = 11 + 19 = 30 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 11 \text{ minutes} + 17.35\text{km}/70\text{kmph} = 11 + 14.9 = 25.9 \text{ minutes}$

**5.8 Synchronizing Train Departure/Arrival**

When trains from different track lines share part of their routes, their departure times should be synchronized to offer a higher frequency service on that common part and to reduce a possible waiting delay at the entrance of the common line. In this thesis the common line for the NS and EW line from Stadium station to ‘St.Lideta station’ (or the reverse direction). As an example, if these two train routes have a headway time of ‘ $t$ ’ time at the separate route, then they will have headway time of half of ‘ $t$ ’ ( $t/2$ ) at the common line if they are well synchronized. Synchronization can also be applied to spread the multiple trains of the common line evenly across the cycle time.

To synchronize the trains (say in the up direction), trains coming from ‘Kality’ and ‘Ayat’ must use the common line when they arrive at the Stadium station. So that, these trains should have half of the scheduled headway time to the other uncommon routes after they enter the common line. To put the specific synchronization time the time taken in which the train arrives at the stadium must be calculated based on the distance from both depots to the Stadium station. For the train starting traveling from ‘Ayat’ towards ‘Torhailoch’, to find its time taken to reach at stadium station is given as:

$$t = \frac{S}{v} + d_t \quad \dots\dots\dots \text{Equation 13}$$

Where:  $S$  = Total distance from ‘Ayat’ station to ‘Stadium’ station,  $v$  = Speed of the train,  $d_t$  = Total dwell time at all station from ‘Ayat’ to ‘Stadium’ stations

Similarly, for the train starting traveling from ‘Kality’ towards ‘Menelik II square’, to find its time taken to reach stadium station is given by equation 13 but, obviously, the stations will be stations from ‘Kality’ to ‘Stadium’ and hence there will be a difference on distance covered and total dwell times.

**Numerical Examples:** These numerical examples will be used as an input to the simulation model provided in the simulation part.

**For the Upward Direction:** The time taken from ‘Ayat’ to ‘Stadium’, using the formula ( given in section 5.7: Travel Time), the total distance from ‘Ayat’ to ‘Stadium’ is about 13km and the total dwell time in between this line is 8 minutes hence the time taken for the selected speeds will be:-

- $T_{20} = T_d + S_{total}/V_{ave} = 8 \text{ minutes} + 13\text{km}/20\text{kmph} = 8 + 39 = 47 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 8 \text{ minutes} + 13\text{km}/30\text{kmph} = 8 + 26 = 34 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 8 \text{ minutes} + 13\text{km}/45\text{kmph} = 8 + 17.3 = 25.3 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 8 \text{ minutes} + 13\text{km}/55\text{kmph} = 8 + 14.2 = 22.2 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 8 \text{ minutes} + 13\text{km}/70\text{kmph} = 8 + 11 = 19 \text{ minutes}$

**Time Taken from ‘Kality’ to ‘Stadium’ stations:** The total distance from ‘Kality’ to ‘Stadium’ is about 8.982km and the total dwell time in between this line is 5.5minutes hence the time taken for the selected speeds will be

- $T_{20} = T_d + S_{total}/V_{ave} = 5.5 \text{ minutes} + 8.982\text{km}/20\text{kmph} = 5.5 + 27 = 32.5 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 5.5 \text{ minutes} + 8.982\text{km}/30\text{kmph} = 5.5 + 18.5 = 24 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 5.5 \text{ minutes} + 8.982\text{km}/45\text{kmph} = 5.5 + 11 = 16.5 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 5.5 \text{ minutes} + 8.982\text{km}/55\text{kmph} = 5.5 + 9.8 = 15.3 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 5.5 \text{ minutes} + 8.982\text{km}/70\text{kmph} = 5.5 + 7.7 = 13.2 \text{ minutes}$

Now to synchronize each train coming from both lines to the upward direction, for instance for speed 30km/h the first few trains coming from ‘Ayat’ arrives at ‘Stadium’ as the following patterns [with headway of 6minutes (for 30km/h) and assuming the first train starts at 00:00 o’clock]. The patterns are (in minutes):- 34, 40, 46, 52, 58,

64, 70...

Similarly for the first few trains coming from 'Kality' arrives at 'Stadium' according the following patterns [with headway of 6minutes (for 30km/h) and assuming the first train starts at 00:00 o'clock]. The patterns are (in minutes):- 24,30,36,42,48,54,60,66,62,68,74,.....

According to the pattern, the first train coming from 'Ayat' should be arrived earlier than its schedule by one minute on the way to Stadium in order to have 3 minutes headway time in the common route. Hence, the trains coming from Ayat will arrive at Stadium as according to the following patterns(in minutes): 33, 39, 45, 51, 57, 63, 69, 75, 81, 87, 93,... and trains coming from 'Kality' will arrive at Stadium according the following pattern(in minutes):24, 30, 36, 42, 48, 54, 60, 66, 72, 78, 84, 90,...

**For the Downward Direction (Time Taken from 'Torhailoch' to 'St.Lideta' Stations) :** The total distance from 'Torhailoch' to 'St.Lideta' is about 1.553 km and the total dwell time in between this line is 1.5 minutes hence the time taken for the selected speeds using equation 12 of travel time, will be:

- $T_{20} = T_d + S_{total}/V_{ave} = 1.5 \text{ minutes} + 1.553\text{km}/20\text{kmph} = 1.5 + 4.66 = 6.2 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 1.5 \text{ minutes} + 1.553\text{km}/30\text{kmph} = 1.5 + 3.5 = 5 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 1.5 \text{ minutes} + 1.553\text{km}/45\text{kmph} = 1.5 + 2 = 3.5 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 1.5 \text{ minutes} + 1.553\text{km}/55\text{kmph} = 1.5 + 1.7 = 3.2 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 1.5 \text{ minutes} + 1.553\text{km}/70\text{kmph} = 1.5 + 1.3 = 2.8 \text{ minutes}$

**Time Taken from 'Menelik II Square' to 'St.Lideta' stations:** The total distance from 'Menelik II Square' to 'St.Lideta' is about 5.3 km and the total dwell time in between this line is 4 minutes hence the time taken for the selected speeds will be:

- $T_{20} = T_d + S_{total}/V_{ave} = 4 \text{ minutes} + 5.3\text{km}/20\text{kmph} = 4 + 15.9 = 19.9 \text{ minutes}$
- $T_{30} = T_d + S_{total}/V_{ave} = 4 \text{ minutes} + 5.3\text{km}/30\text{kmph} = 4 + 11 = 15 \text{ minutes}$
- $T_{45} = T_d + S_{total}/V_{ave} = 4 \text{ minutes} + 5.3\text{km}/45\text{kmph} = 4 + 7 = 11 \text{ minutes}$
- $T_{55} = T_d + S_{total}/V_{ave} = 4 \text{ minutes} + 5.3\text{km}/55\text{kmph} = 4 + 5.8 = 9.8 \text{ minutes}$
- $T_{70} = T_d + S_{total}/V_{ave} = 4 \text{ minutes} + 5.3\text{km}/70\text{kmph} = 4 + 4.5 = 8.5 \text{ minutes}$

Now to synchronize each train coming from both lines to the downward direction, for instance for speed 30km/h the first few trains coming from 'Torhailoch' arrives at 'St.Lideta' according to the following patterns [with a headway of 6minutes (for 30km/h) and assuming the first train starts at 00:00 o'clock]. The patterns are (in minutes):- 5, 11, 17, 23, 29, 35, 41, 47, 53, 59, 65, 71, 77...

Similarly for the first few trains coming from 'Menelik II Square' arrives at 'St.Lideta' according to the following patterns [with headway of 6 minutes (for 30km/h) and assuming the first train starts at 00:00 o'clock]. The patterns are (in minutes):- 15, 21, 27, 33, 39, 45, 51, 57, 63, 69, 75, 81, 87...

According to the pattern, the first train coming from 'Menelik II square' should be arrived earlier than its schedule by one minute on the way to 'St.Lideta' in order to have 3 minutes headway time in the common route. Hence, the trans coming from 'Menelik II Square' will arrive at 'St.Lideta' as according to the following patterns (in minutes): 14, 20, 26, 32, 38, 44, 50, 56, 62, 68, 74, 80, 86, 92... and trains coming from 'Torhailoch' will arrive at 'St.Lideta' according the following pattern (in minutes): 5, 11, 17, 23, 29, 35, 41, 47, 53, 59, 65, 71, 77...so on. Similarly, for the other speeds we can find the corresponding arrival time patterns using the same procedure.

#### **Comparisons between Parameters of the Current and Calculated Timetables**

The calculations done in this chapter are based on the standard formulas, such as the braking distance, time, speed, line capacity and the headway. To design the safety block (refer figure 6) it is based on the standard methods especially used on European Rail Traffic Management System (ERTMS) systems. Hence as far as the standard ways are used, the calculation results are valid. Moreover, since these calculated values are used as input for the simulations done in the simulation part, the output gives valid results. Currently, the trains of the AA-LRT travels at a speed close to 20 km/h, with a headway 15 minutes in the peak hours, but according to the details stated above, the headway can be reduced to 7.26 minutes for the peak ours. Additionally, if we want to reduce this headway time we must increase the speed of the train according to the headway we want to have.

According to the peak hours, headway time of the current AA-LRT the line capacity is only 4 trains. But practically, every train is overcrowded usually by the passengers; this indicates a mismatch between passengers and the number of trains. Hence to reduce the overcrowding, it is required to increase the number of trains consequently, the line capacity will be increased. By increasing the line capacity it needs to decrease the headway time. So that, to achieve these requirements increasing the speed may seem the only solution. But, the calculated values of the previous sections suggested that without increasing the speed we can improve the headway time to some extent and consequently a lot of parameters can be improved such as the line capacity, waiting time of passengers, dwell time, travel time, etc.

As an example, with this current speed (i.e. 20km/h) the current timetable has headway time of 15 minute and hence the line capacity is 4 trains per hour for a single line and direction. With the same speed, the

headway can be reduced to 8 minutes and the line capacity can be increased to 7.5 trains per hour for a single direction [see the detail calculations on the previous sections]. So, due to these modifications, the waiting time of passengers can be reduced and the overcrowded can be reduced by the increase of frequency and the number of trains (i.e. line capacity). To improve beyond this, the speed must be increased. Consequently, most of the problems can be solved (minimized) further.

Table 4: Comparisons between parameters of the current and calculated timetables

Speed (km/h)	Current Values		New Values	
	Headway Time (min)	Line Capacity (Number of Trains in 1 hr. for one route)	Headway Time (min)	Line Capacity (Number of Trains in 1 hr. for one route)
20	15	8	7.26	15
30	-	-	5.55	20
45	-	-	4.56	24
55	-	-	4.25	24
70	-	-	3.92	30

The main cause for the difference on some parameters between the current and calculated parameters is that the current timetable doesn't use optimal values according to the speed it uses. Such as the headway, synchronization, travel time, braking distance, line capacity etc. These parameters are already modified even if for the same speed (see table 4 above). Hence, an easy task of comparisons can be made between parameters currently used and the calculated ones.

Another point is that the synchronizations of trains. In the current timetable when two trains coming from different directions towards the common line, often they meet each other at 'Stadium' and 'St.Lideta', so that one train must wait for some minutes until the section ahead is free. This indicates as the synchronization of the train is not correctly implemented. Hence, one solution for this occurrence is presented in detail in section 5.8.

Apart from the current timetable, the expected headway for the future time is 6 minutes with a capability of reducing to 90 seconds. Hence, according to the calculated results the 6-minute headway can be achieved when the speed is close to 30km/h but the headway of 90 seconds seems impossible to achieve with a range of speed from 20-70km/h. With the maximum operated speed i.e. 70km/h, the minimum possible headway is 3.92minutes. If we consider the headway of 90 seconds, at the common line the headway will be halved i.e. 45 seconds. But, some sections (blocks) in the common line require more than 45 seconds for traveling even by the maximum operated speed. Again, outside of the common lines a lot of blocks (sections) require more than 90 seconds to travel even with the highest possible speed. Hence reducing the headway to 90 seconds is not feasible unless collision or unwanted waiting time can happen. But why the design engineers say the headway can reduce to 90s? The reason behind this is that, because it was planned before the design is completed but in the process there are some changes, to mention the operating speed was decreased and the distance between stations becomes more non-uniform than it was planned before the railway design was begun.

Finally, after calculating the values of the main parameters a comparison between the existing and calculated parameters is done. Hence, the result indicates that the main parameters to design the timetable depends on speed and for a different speed, different values of the parameters can be achieved. That is why most of the calculations on the previous sections are done based on some selected speeds. Hence, a decision can be made by comparing between one speed (and its calculated parameters) on one side and on another speed (and its calculated parameters) on the other side. Further, the effect of all these parameters is clearly seen on the output of the Arena simulating software discussed in the next topic.

## 6. The Simulation Design

To simulate the model of the AA-LRT it divides into four parts, i.e. one part for each direction (route) of the AA-LRT having the effect of common line in mind. In this section, the design for one route namely for up direction of NS-route is given. For the remaining directions i.e. the For the up direction of EW-route, EW-downward and NS-downward directions the simulation design is not given because all the designs are very similar with that of NS-up direction except the direction and some related cases.

Table 5: Simulation parameters

Simulation parameters	Typical values for AA-LRT
Speed	operational speed:20-70km/h, for the simulation part 30km/h is used
Headway time	varies according to the speed and typical value of 6 minutes is used
Dwell time	typically 30 seconds
Distance	the distance between each adjacent stations in meters
Resources	the block (section) of the railway line
Type of transporter	has two options: free and guided path, and the guided path is used
Type of queue	first in first out (FIFO)
Acceleration	1m/s <sup>2</sup>
Deceleration	1m/s <sup>2</sup>
Number of trains	depends on headway, typically 10 trains for a single line, one direction is used, that is the line capacity
Synchronization time	33 minute for trains coming from ‘Ayat’ and 24 minutes for trains coming from ‘Kality’

In the simulation design, each block will take input parameters like the resource used(in this case the track line and number of trains available), the distance between each station, the velocity of the train , the dwell time at each station, the headway, acceleration, deceleration etc.

After feeding these inputs to the simulation design, it gives simulation report. In the simulation report, there is almost all information of the model we designed and based on the report it is possible for further modifications/ improvements of the simulation design. The simulation report includes processing time, total time, a number of trains, queuing time, time delay at stations, efficiency and utilization of the resources etc.

The simulated model is given in Figure 7, for up direction of NS route. Tis figure 7 is snipping sheet of the designed model from the arena software. Further, the main blocks and flow charts used in this design are of two types.

- 1) **Flowchart modules:** like Create, Seize, Release, Leave, Enter, Route, Station, Decide and Dispose. In the simulating model the stations of AA-LRT are represented by the Enter module. The Enter model will take the input of dwell time at each station. The distance between the stations to be traveled by the transporters is accessed in the Network and Network Link data modules. When traveling the train, block safety ahead is controlled using the Size and Release modules whether it is occupied or free. If it is occupied, the train will wait at the station until the block ahead is free. The shape and color of the Enter and Leave model are similar and the only difference is in the Leave module there is a blue bar above the block module. Similarly, the shape and color of the Seize and Release model are similar and the only difference is in the Release module there is a blue bar above the block module. The depot is represented by the Create module and the end stations (‘Torhiloch’ and ‘Menelik II square’ stations) are represented by Dispose module. The Decide module decides as which entity will go to which train at the common line starting at the ‘St. Lideta’ station to Stadium station and finally send the train to its destination.
- 2) **Data modules:** It includes Entities, Queue, Resources, Network, Network Link and Transporters. Here the Transporter is used to declare the transport type (the train in this case) and to give the permitted speed of traveling. In the Network Link, it accepts inputs of the distance (length) between each station.

## 6.1 Main Elements of the Simulation Design

- Leave: used to control the train in the system.
- Enter: represents for stations
- Seize: uses as a resource, and the resource in this thesis is the rail line (safety block).
- Release: Used to release the occupied resource (safety block) when the train reaches at the end of the block
- Decide: used to identify the train, whether it is coming from EW or SN.
- Transporter: Guided path unlike of free path it doesn’t depend only on the distance and velocity but also on the traffic of the system.
- Network: used to give a name to the link between each station.
- Network Link: used to give the distance between each station.
- Animated lines: The Zigzag line used to animate the transporters (trains) as how they travel.

## 6.2 Details of the Simulation Design

The student version of the Arena software is free but it has too many restrictions ([www.arenasimulation.com](http://www.arenasimulation.com), 2016) like the number of flow chart modules, a number of elements and number of cinema objects, consequently, in the design of the AA-LRT some parameters gone beyond the limitation of the arena student version.



Specifically the number of modules, Resources used, Network Link length, and the type of transporters to design the AA-LRT have been gone beyond the student version of arena software. To solve this, the following two cases have been done.

- 1) The first case is to optimize the available software with its restrictions. Hence after analyzing on the available flow chart models, some interesting modules which they can capable of working the task of two or more modules by a single module, such as the Leave and Enter module are found. The Enter module, for instance, is capable of working as a Station module and Exit module simultaneously. The Leave module is also capable of working as a Request module and Transport module simultaneously. The Network Link data module is also used its intersection point for two or more transport types. Based on these criteria the number of flowchart modules and data modules in the model design are minimized as far as possible.
- 2) Even with these opportunities, still it is not enough for the expected design. And the last option used is to design a single model representing one side and single direction only. That is at the first instance it was supposed to design two models having two routes (NS & EW upward direction and NS & EW downward direction) but, due to the arena limitation it forced to design four independent designs with one route each. But, with a consideration of the common lines as a train may come from the other direction. That is the stations are the same but with different trains coming from other direction. For instance, the simulation design starts for upward direction of 'Kality-Menelik II Square' route. In the design, the trains coming from 'Ayat' in the upward direction will be joined the system model at the 'Stadium station' after a duration time which takes the train to reach in 'Stadium' station from the 'Ayat' station. Then after, they leave the system when the trains coming from 'Ayat' reaches the 'St.Lideta' station. This analogy works similarly for all the remaining three designs (i.e. for the up and down direction of EW line and for the down direction of NS line).

Based on the above points the simulating design is given for NS-up direction and its main important input parameters and their characteristics are herein discussed in detail.

- The distance between each station will be given as inputs in unit length and to know its exact unit it needs to consider its velocity unit length. For instance, given two distances with the length of 100m and 100km, now to cover these distances if a train travels with a velocity of 10meter per minute and 10km per minute respectively the time taken will be the same to cover the given distances.
- The unit length is assumed to be in meters and the velocity is in meters per second (m/s). In some stations, the distance may have fractional numbers but the arena model accepts only integer numbers hence for these fractions they are approximated to their higher integer.
- The headway time when they start traveling from the initial station to the next station.
- The dwell time
- The working hours per day and the number of trains (i.e. the line capacity)

Hence, based on these points the simulating design is given for NS-up ward direction in figure 7 below

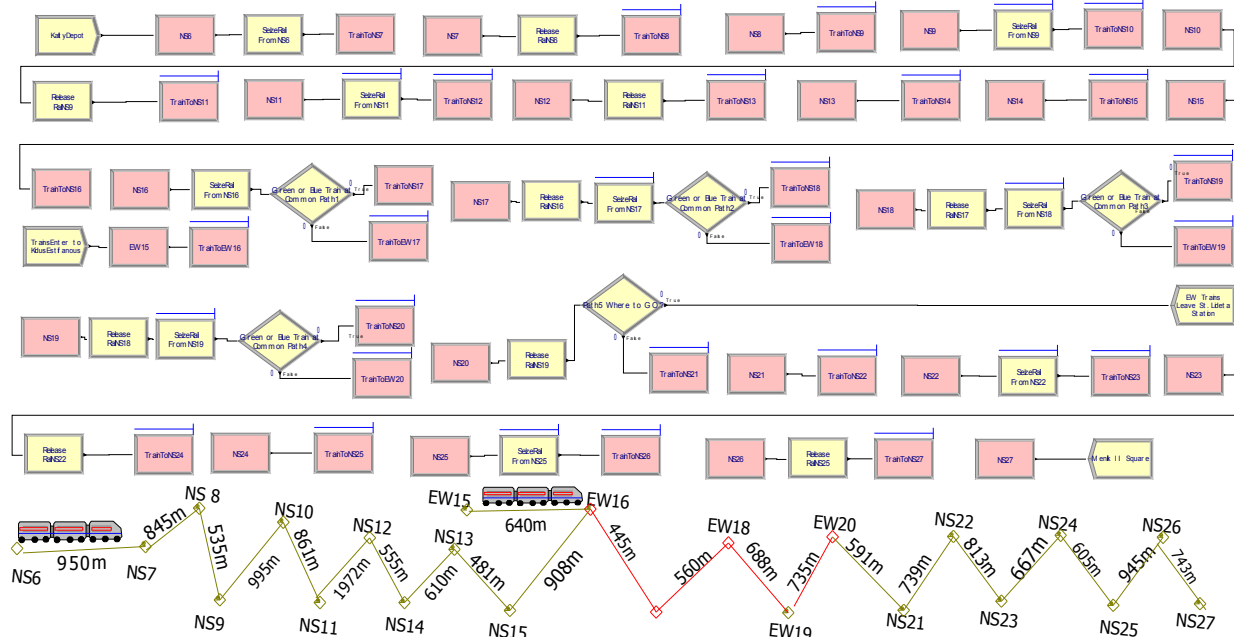


Figure 7: The simulation design of AA-LRT from 'Kality' to 'Menelik II square'

### 6.3 Key Performance Indicators of the Simulation

After giving the necessary inputs to the system model and ordered to run the system it gives the statistical analysis of the simulation result under some of the following groups according to the designed model. These are Entities, Stations, Resources, Queues, Processors, Transporters, Activity areas, etc.

#### Entity

The simulation result gives the details of the time spending on the trip from the origin station to the destination station.

Table 6: Simulation results showing time movement of trains of NS up direction (screenshot)

Wait Time	Average	Half Width	Minimum Value	Maximum Value
BlueTrain	11.0000	(Insufficient)	11.0000	11.0000
Transfer Time	Average	Half Width	Minimum Value	Maximum Value
BlueTrain	35.4038	(Insufficient)	35.4038	35.4038
Other Time	Average	Half Width	Minimum Value	Maximum Value
BlueTrain	0.00	(Insufficient)	0.00	0.00
Total Time	Average	Half Width	Minimum Value	Maximum Value
BlueTrain	46.4038	(Insufficient)	46.4038	46.4038
Number Out	Value			
BlueTrain	167.00			
WIP	Average	Half Width	Minimum Value	Maximum Value
BlueTrain	8.2578	(Correlated)	0.00	9.0000

#### Station

The station displays a number of entities (trains) transferring in each station. This indicates how much the station is busy during the whole day (see table 7 below). It also displays the total accumulating waiting time in each station during the whole working day.

Table 7: Stations usage during a service time for NS up direction (screenshot from the simulation results)

Number Entities Transferring	Average	Half Width	Minimum Value	Maximum Value
EW15.Station	0.00	(Insufficient)	0.00	0.00
NS10.Station	0.3851	0.005132810	0.00	1.0000
NS11.Station	0.3354	(Correlated)	0.00	1.0000
NS12.Station	0.7336	(Correlated)	0.00	1.0000
NS13.Station	0.2238	(Correlated)	0.00	1.0000
NS14.Station	0.2432	(Correlated)	0.00	1.0000
NS15.Station	0.1961	(Correlated)	0.00	1.0000
NS16.Station	0.5980	(Correlated)	0.00	2.0000
NS17.Station	0.3630	(Correlated)	0.00	1.0000
NS18.Station	0.4432	(Correlated)	0.00	1.0000
NS19.Station	0.5327	(Correlated)	0.00	1.0000
NS20.Station	0.5641	(Correlated)	0.00	1.0000
NS21.Station	0.2325	(Correlated)	0.00	1.0000
NS22.Station	0.2846	(Correlated)	0.00	1.0000
NS23.Station	0.3092	(Correlated)	0.00	1.0000
NS24.Station	0.2578	(Correlated)	0.00	1.0000
NS25.Station	0.2361	(Correlated)	0.00	1.0000
NS26.Station	0.3530	(Correlated)	0.00	1.0000
NS27.Station	0.2827	(Correlated)	0.00	1.0000
NS6.Station	0.00	(Insufficient)	0.00	0.00
NS7.Station	0.3717	0.005136795	0.00	1.0000
NS8.Station	0.3315	0.004873836	0.00	1.0000
NS9.Station	0.2191	0.004306755	0.00	1.0000

### 7. Conclusions

Since the operation of AA-LRT is in its starting stage most of the parameters are on their lower levels. That is in order to be familiar with service equipment, with the infrastructure itself and at large to be familiar with residents of the city. It is also necessary to go step by step to avoid any accident occurring due to lack of experience for both crew members and the societies as well. So, due to this reason the operation starts based on the lowest possible parameters.

Despite having few months of experience on operation it is necessary to study the appropriate parameters. Hence, by carefully study the way of operation better service can be obtained by updating few parameters while for the remaining parameters keeping unchanged. For instance without changing the

operational speed we can operate by lower headways. In the AA-LRT case currently the planners uses 15 minutes of headway when the speed is 20km/h. According to the calculated values, this large headway can be minimized up to 7.5 minutes without changing the speed. Consequently, more trains can give service when headway decreases. Hence the line capacity will be increased.

Generally to design the train timetable parameters like headway, dwell time, trip time, speed, signaling system, braking distance, synchronization of trains and other available resources should be considered. Hence, in this thesis these parameters are discussed in detail and their values are calculated and then checked their validations using the Arena software simulation.

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