ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

GRADUATE PROGRAM IN RAILWAY ENGINEERING

ASSESSMENT ON NOISE OF ADDIS ABABA LIGHT RAIL TRANSIT

A RESEARCH PAPER SUBMITTED FOR

PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR MASTER OF SCIENCE IN MECHANICAL (ROLLING STOCK) ENGINEERING

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DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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ABSTRACT

Rail transport is being one of the major modes of transportation and is becoming a backbone for the development of the country owing to its nature and suitability of the transport system. On the other hand, it is a source of ambient noises resulting in an uncomfortable environment for working and living around railways. Currently. in Ethiopia, a project like Addis Ababa Light Rail Transit transportation is affecting the community.

In order to ascertain the effect of Addis Ababa Light Rail Transit on the community, this paper is targeted on noise assessment. So as to conduct this noise assessment, direct measurement of noise in 100 m interval of the track and questionnaires are deployed. In questionnaire around 200 peoples are interviewed. To this end, results from a detailed questionnaire and measured values, which examine the effects of the noise on the people living around railways are analyzed and illustrated in graph and table.

The results are correlated as day time noise and night time noise with the Ethiopian noise standard which are 65dB (A) for day time and 55dB (A) for night time. From the measurement result, the day time noise is 84.18dB (A) and the night time noise is 57.18dB (A). When the results are compared to the standard, the day time noise is greater than the standard and the night time noise is normal (considering the instrument accuracy which is 2dB). The result also includes the questionnaire and it shows that as the age increases the noise sensitivity will also increase.

The results are also correlated to indoor noise and outdoor noise with a feasibility study of Addis Ababa Light Rail Transit (i.e. environmental assessment section) in order to scrutinize the operational time noise with the one that intended to be while the system was designed. The feasibility study had set 80dB (A) for outdoor, and 75dB (A) for indoor. However, the measured indoor noise is 74.4dB (A) and it is within the limit whereas the outdoor noise is 84.18dB (A) and it is beyond the range of the study. In addition to that, wear and speed have been measured at on the maximum and minimum noise rail locations to depict the relation of wear rate verses noise and speed verses noise graphically.

Finally, based on the results some of the recorded noises are greater when they are compared with the standard. In order to protect the community from railway noise pollution, noise mitigation like noise dampers and planting trees around the line has to be done.

Key words: Railway Noise; Speed; Wear rate; Sound level meter; Indoor noise; Outdoor noise;

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CHAPTER ONE: INTRODUCTION

1.1. Background

Rail transport is generally considered one of the most environmentally friendly transport modes and mass transportation. Increased rail transport is an expected and desirable outcome of government policies that seek to improve air quality and transport planning and integrate land-use planning. Rail transport plays a vital part in efforts to achieve sustainable cities and preserve the environment. (1) (2)

Addis Ababa Light Rail is a light rail transportation system in Addis Ababa, Ethiopia. A 17-kilometre line running from the city center to industrial areas in the south of the city opened on 20 September 2015. Service began on 9 November 2015 for the second line (west-east). The total length of both lines is 31.6 kilometers, with 39 stations. Trains are expected to be able to reach maximum speeds of 70 km/h. (3)

This Addis Ababa Light Rail Transit started the operation before a year and it is giving transportation service for thousands of people per a day. Sources from the Addis Ababa environment protection authority and the customers show, the light rail is alleviating the city transport problem, in the other hand it is the source of ambient noise.

In addition to this transit service, Ethiopian Railway Corporation has a plan to extend a high speed routes. As it expands, environment effect and the influence on the community in any aspects need to be assessed as the contribution of rail transport to noise pollution can be substantial. According to European Environment Agency figures for 2000, about 10% of the population in the EU-15 was exposed to significant noise from rail transport. (4)

Furthermore, rail noise can have adverse effects on residents living alongside railway lines, by disturbing sleep, causing stress and annoyance, and interfering with talking and hearing in general.

Railway noise constitutes a serious environmental concern in areas traversed by transit systems. The level of exposure to transit noise is a function of train technology and length, rail car type, vehicle speed, installed auxiliary equipment, type of track work, as well as the proximity of the railroad right of way to existing buildings, or planned land use. (5)

The growth of our rail transport network brings many benefits to the wider community but these effects which listed above need to be assessed, managed and balanced against protecting the amenity and wellbeing of the local community living beside rail lines. (6)

1.1.1. Noise and its effect

According to Environment Protection Authority of Australia Noise arises from many different types of sources and activities. The simple definition of noise is that it is unwanted sound, and as such, may have both direct physical and psychological effects on people if it is intense or persistent enough; causing sleep disturbance, interfering with normal conversations, or annoyance and stress. Evidence is accumulating that noise has real health effects on people. (7)

Railway noise is categorized as a discrete noise type that creates spikes in time-dependent noise diagrams. The continuity of this type of noise is low, hence it causes less sleep disturbance; but makes communication rather difficult due to its high magnitude. Dissemination of noise at highways may vary depending on rotations per minute of the engine even for similar types of vehicles being operated at the same speeds. Thus, it is almost identical for similar type of railway vehicles, which are operated at similar speeds. Road traffic progresses irregularly and it cannot be predicted in advance; however, railway traffic moves in accordance with a pre-determined plan. Since not everyone responds equally to sounds and the perception is dependent on constitution and mood, noise also contains a subjective component. Even if it is hard to give specific limit value but most countries have their own limit value. (8)

Noise pollution affects both human and animal health, Muscle contraction leading to nervous breakdown, tension, adverse effects health, work efficiency and behavior. Noise is generally harmful and a serious health hazard. It has far-reaching consequences and has many physical, physiological as well as psychological effects on human beings.

(i) Physical Effects

The physical manifestation of noise pollution is the effect on hearing ability. Repeated exposure to noise may result in temporary or permanent shifting of the hearing threshold of a person depending upon the level and duration of exposure. The immediate and acute effect of noise pollution is impairment of hearing (i.e. total deafness.)

Human ears have sensory cells for hearing. If these cells are subjected to repeated sounds of high intensity before they have an opportunity to recover fully, they can become permanently damaged leading to impairment of hearing. Besides the sensory cells, the delicate tympanic membrane or the ear drum can also be permanently damaged by a sudden loud noise such as an explosion.

(ii) Physiological Effects

The physiological manifestations of noise pollution are several as mentioned below:

(a) Headache by dilating blood vessels of the brain.

(b) Increase in the rate of heart-beat.

(c) Narrowing of arteries.

(d) Fluctuations in the arterial blood pressure by increasing the level of cholesterol in the blood.

(e) Decrease in heart output.

(f) Pain in the heart.

(g) Digestive spasms through anxiety and dilation of the pupil of the eye, thereby causing eye-strain.

(h) Impairment of night vision.

(i) Decrease in the rate of color perception.

(j) Lowering of concentration and effect on memory,

(k) Muscular strain and nervous breakdown.

(l) Psychological Effect

The psychological manifestations of noise pollution are:

(a) Depression and fatigue which considerably reduces the efficiency of a person.

(b) Insomnia as a result of lack of undisturbed and refreshing sleep

(c) Straining of senses and annoyance as a result of slow but persistent noise from motorcycles, alarm clocks, call bells, telephone rings etc.

(d) Affecting of psychomotor performance of a person by a sudden loud sound

(e) Emotional disturbance

Noise is annoying and the annoyance depends on many factors not merely the intensity of the sound but also repetition, because even a sound of small intensity (e.g. dripping tap or clicking of clock) may become annoying, simply by repetition. This means that to achieve a desirable level of amenity and wellbeing for residents' greater attention needs to be paid to the inclusion of noise control options in new residential developments around rail lines. (9)

1.1.2. Sources of railway noise

Rail noise is sound emissions arising from the operation of trains and trams. There are a wide variety of sources and causes of rail noise, such as locomotives accelerating, freight wagons braking, squeal noise in curves, vibration from rail corrugation and out-of-round wheels, vehicle coupling in shunting yards, and even the pantographs of high-speed trains. (10)

For this specific study it distinguishes three types of railway noise or, more precisely, three types of railway noise sources: rolling, traction and aerodynamic.

Rolling noise is caused by the interaction between the wheel and the track. The friction pair is of main interest in this case. The type of engine and train, and the ventilation system are the main sources of traction noise. The last of the three noise sources, i.e., aerodynamic noise, includes air motion and pantograph influence. Figure below presents noise source domination in the total noise level, depending on train speed. Rolling noise is measured in this model at 0 and 0.5 m above the rail head, traction noise is calculated at 0.5, 2, 3, 4 m and aerodynamic noise can be best measured at 0.5 and 4 m. (4)

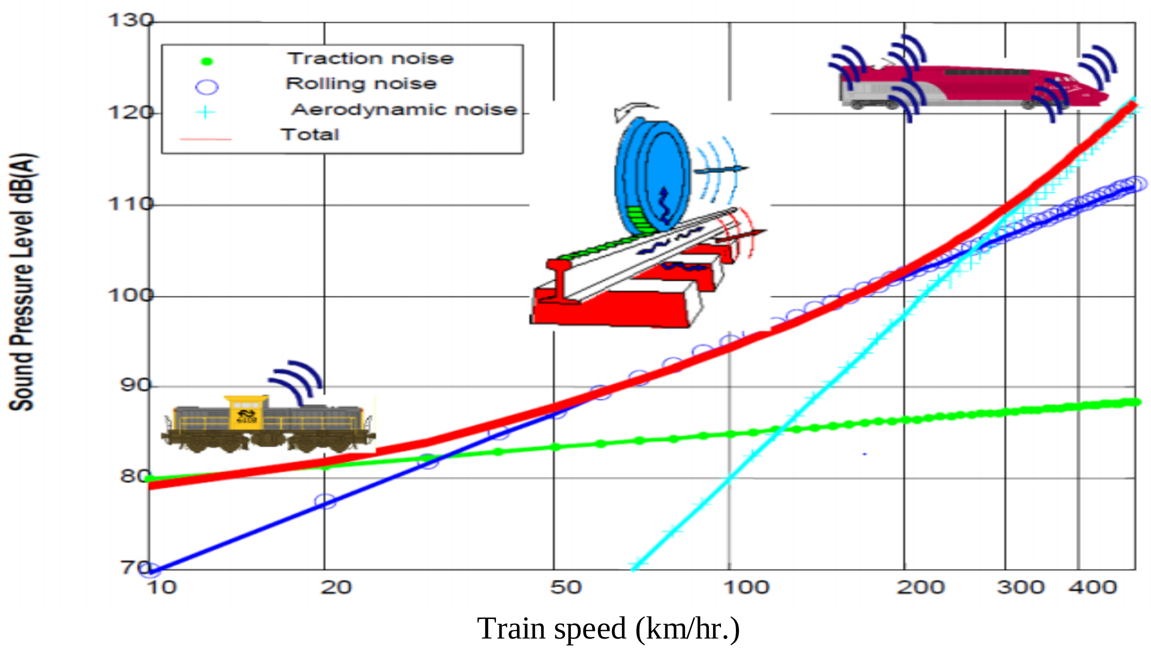


Figure 1: Sources of railway noise according to train speed (4)

This figure shows that between 30 and 200 km/h rolling noise is the dominant source. This is also the speed range which affects most people living near railway tracks. Low speed is only to be found in shunting yards, near stations or on factory railways. Speeds of more than 200 km per hour are only to be found on high speed lines. (4)

Noise from the vehicle– track interface can be generated through a number of mechanisms based around the continuously welded rail and on tight radius curves where wheel squeal and flanging noise can arise. As wheel-rail noise is generated at a relatively low height, it can often be more practical to reduce through mitigation measures than locomotive noise. Maintaining the condition of the track and the rolling stock is also an important factor in reducing noise from the vehicle–track interface. (4)

1.2. Statement of the problem

Rail transport has a great importance for the functioning of the economic system of each country. The Working condition of rail transport indirectly affects the efficiency and functioning of the entire economic system of a country and the community. Apparently, the economic impact is always the major concern for the Government and the society. Due to these facts, the noise hasn't given any considerable attention from government and AALRT administration as well.

Experience has shown that noise is the major concerns with regard to the effects of a light rail transit project on the surrounding community. As this transport mode is placed near population centers and nearby residences, the noise which is produced in everyday operation has immense annoyance on the community.

Therefore, this paper is intended to assess the level of the noise and effect of it on the community after conducting a detail study on Addis Ababa Light Rail Transit. Besides, to design appropriate remedial mechanism for alleviate the problem.

1.3. Objective

1.3.1. General objective

The general objective the paper is to assess noise of Addis Ababa light railway transit on the community and living around railway line.

1.3.2. Specific objective

- Determine the potential operational noise value of the railway line
- Compare the noise level value with the standard specifications
- Measure noise with sound level meter instrument
- Relate the relationship between of vehicle speed and noise
- Recommend for preparation of rail way noise guideline and control standards

1.4. Scope and limitation of the study

1.4.1. Scope of the study

Ethiopia is one of nearly joining country for light rail transit project and has its own plan to expand this transit to more network line to get more advantage. In other hand, as this rail network is expanded and the transport gets cover a wide range of place, the noise which generated from this system also become, certainly, worse and worse, and their effect as well.

From this intension the scope of the paper is assessing and interpreting the level of Addis Ababa light rail transportation noise impact with detail analysis. And then, the result will be correlated with prescribed standards.

In addition to this noise maps will be also calculated so as to show specific location where the impact is mostly worst. Finally based on the assessment the paper will recommend to use alternative mechanisms for the purpose of decreasing the impact.

1.4.2. Limitation of the study

To complete the paper, there were many limitations such as lack of high tech instruments for measuring noise wear rate and also licensed sound PlAN 7.4 Essential software to see the total noise map of Addis Ababa light rail transit.

1.5. Organization of the paper

In this study, the contents of the research works have been organized in five chapters.

The first chapter deals the historical background with problem and its approach. This chapter covers the, background, statement of the problem, objective of the study, scope and limitation of the study and organization of the paper.

Related literature review has been discussed in the second chapter. The literatures categorizes as in terms of methods, in terms of study area and conditions, in terms of controlling mechanism and in terms of standards and guideline. In the third chapter, experimental methodology and conditions of the study has been presented. In this chapter approach to answer the statement of the problem has been outlined and area of the study has been decided. The fourth chapter deals about data collection, presentation and analysis Also the result has been presented in terms of graph and table and discussed accordingly. Application of the research finding has been provided in this chapter also. And finally conclusion, recommendations and future work has been organized in chapter five.

CHAPTER TWO: LITERATURE REVIEW

2.1. In terms of methodologies

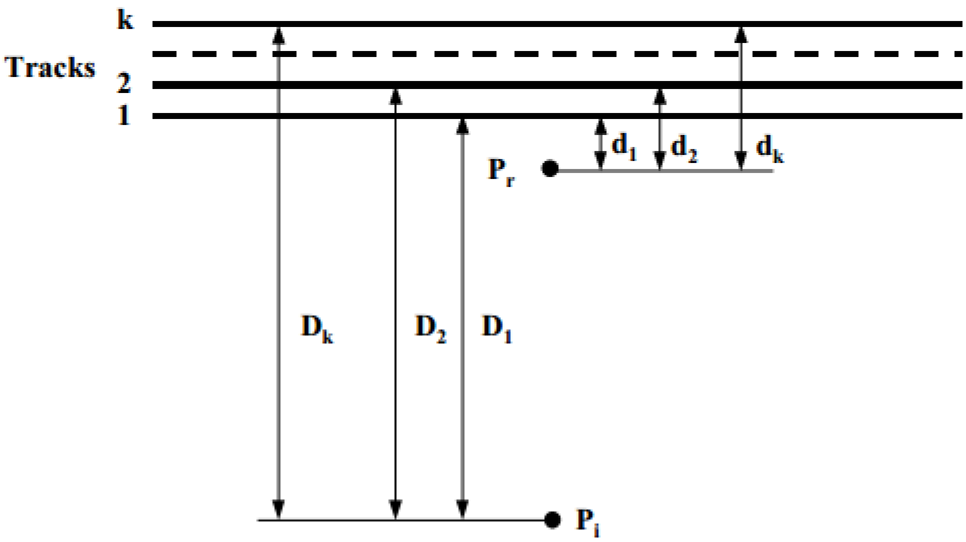
According to The State of Queensland 2013, Environmental Performance and Coordination Branch, Department of Environment and Heritage Protection, A noise measurement should be taken on a day with calm to gentle breeze and without rain. Some conditions to avoid are high wind (generally, do not conduct the assessment if the wind is higher than 5 meters/second (m/s)), or rain. If it is necessary to measure in a wind-affected position, at this time the manufacturer's specification for the microphone has to be checked and confirm that the windshield can be used in these conditions. The Time Weighting (Fast, Slow or Impulse) will be specified by the noise standard, guideline or license condition. Fast is the default unless otherwise specified. The noise under investigation should be measured for sufficient time to establish that the measured value adequately represents the subject source noise. The source noise is measured over a time interval of at least 15 minutes or, if the noise continues for less than 15 minutes, the duration of the source noise. When an investigating officer is undertaking a noise assessment it is essential to make note of the following on a site map. (11)

- Location of noise source
- Background noise measurement location
- Source noise measurement location
- Topography between noise source and sensitive receivers

It is well known that railway noise is composed of generally easily identifiable sound events generated by single train transits. Thus it is simple to measure the sound energy value (LAE)i or (LAeq)i related to the i-th single event. Eq. (1) gives the values of the equivalent sound level LAeq,TR calculated on the two reference periods TR: day-time (06-22) and night-time (22-06):

$$L_{Aeq\,,}\ T_R = 10\log\left[\frac{1}{T_R}\sum_{i=1}^{n} 10^{0.1(L_{AE})i}\right] d_{BA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 2.1$$

Where n is the number of transits during the TR period. In case of spurious events, that is to say events that could not be clearly associated to a train pass-by; the inspection of their time-history usually makes a decision possible. If there is still a residual doubt or if some events show evident anomaly due to, for example, the overlap with noise generated by other sources, then those events have to be rejected from the calculation. The rejection procedure could introduce some approximations but these can be minimized. In fact it is possible replace the rejected values with the arithmetic mean value obtained by the (LAE) i values definitely associated with the train transits. On the other hand, if there are relatively few uncertain spurious events, for example 5% of the total trains transits, and then they can be left out of the account. The calculation error is small. The outlined measurement procedure can be applied straightforwardly in those situations where the railway noise source is the only one or it is decidedly prevalent in comparison with other ones. But very often there is a multiplicity of almost equivalent noise sources. Urban areas where a railway and roads can be very close to each other represent typical cases. It becomes difficult to discriminate the single source contribution in the total environmental noise. In spite of the complexity, in many situations it is still possible to measure only the railway noise. The measuring geometry is schematically represented in Figure below. There are at least two measurement points Pr and Pi. The first one (reference point) is close to the railway tracks; the second one (noise emission point) is on the facade of a building which is usually far from the railway. Otherwise the simplified procedure above could obviously be applied. (12)



D1 D2 … Dk

d1 < d2 < … < dk

Figure 2: Geometry of the system tracks - Pr – P.

$$[(L_{Aeq}, T_R)j]p_i = [(L_{Aeq}, T_R)j]p_r - \triangle j \quad d_{BA} \ldots \ldots \mathbf{2.2}$$

$$L_{Aeq}, \; T_R = 10 \log \left[\sum_{j=1}^{n} 10^{0.1(L_{Aeq}, T_R)j} \right] d_{BA} \ldots \ldots \mathbf{2.3}$$

The term on the left in Eq. (2) is the sound equivalent level at Pi due to trains passing on the j-th track. It is given by the value of the same acoustic magnitude measured at Pr, taking into account the attenuation △ j due to the noise propagation effects between the two considered points. It can be calculated as the average of the differences between LAE values measured at Pi and Pr for a few train transits. Eq. (3) gives the whole sound equivalent level at Pi as a sum of contributions of the k sources (k tracks). Some conditions have to be in place so that the procedure can give reliable results: Pr has to be in an acoustic free-field as much as possible.

Simultaneous measurements have to be carried out at Pr and Pi points for at least a few transits (see below); the duration of the measurement at Pr must be at least24 hours; the transit tracks must be distinguished exactly in order to proceed to a correct calculation of △ j values (see the conditions on the distances below the drawing of Fig above); well identified railway noise events have to be measured only at the Pi point (at Pr there is no problem of this kind) for a statistically Significant number of passenger and freight train transits on every track. (12)

2.1.1. Noise measuring equipment

Other important information can be obtained by the measurement at Pr point: the acoustic behavior of the railway sources described by the noise spectrum in octave or 1/3 octave band. It is also necessary to measure the speed and length of the trains. The measuring equipment used is partially shown in Figure below. There is also a video camera triggered by a signal generated by the approaching train and an electronic system for measuring train speed and length (start and stop clock signals are given by two pairs of IR cells fixed at a well-defined distance). (12)

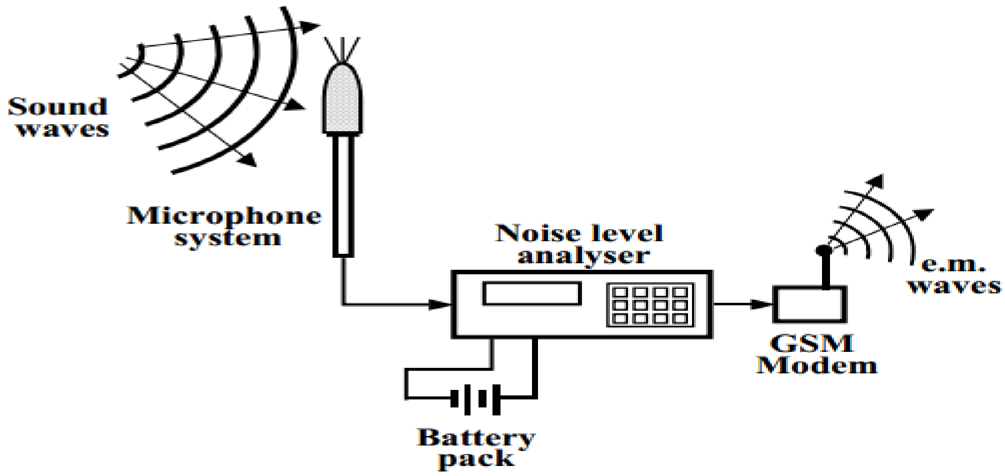


Figure 3: Noise measuring and data transmitting system (12)

A GSM modem links the remote measuring system to a computer. The data recorded by the sound analyzer is periodically transmitted to the computer, which can also send setting up, and controlling signals.

A great deal of study has been done on the effect of noise caused by rail transportation and a criterion for acceptable noise has been established.

In this study, the noise environment of the rail coaches is assessed not only by the results of questionnaires but also by the measured spectra.

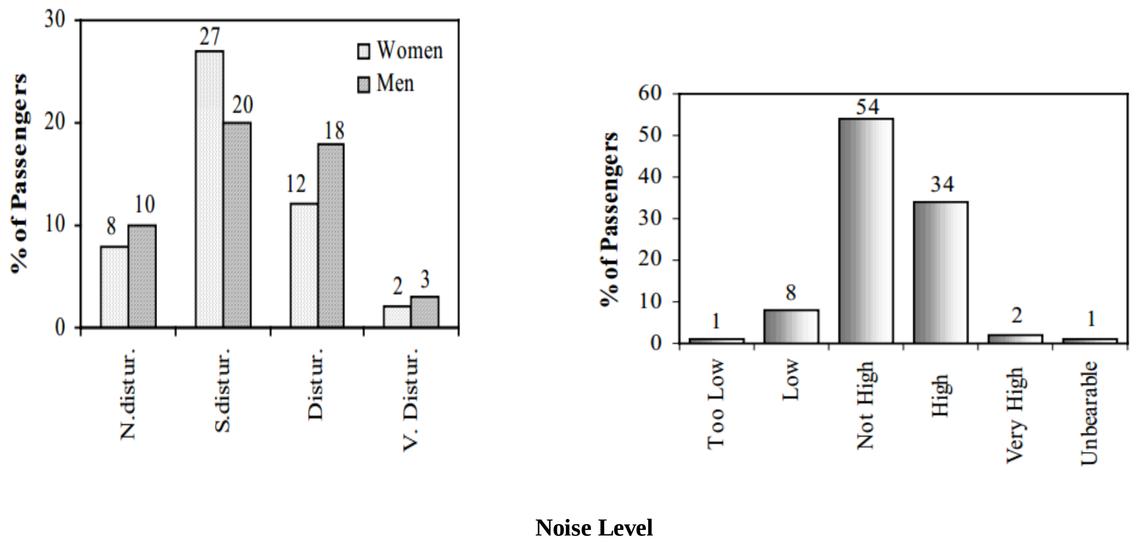


Figure 4: Passenger Ratings and The degree of disturbance of the passenger

The questionnaires (having 24 questions) are distributed and collected during a 4.5 hr. voyage in an intercity train. 48% (52%) of the passengers were women (men). They were mostly young (36% at 20-29 yrs.). 54% of the travellers have assessed the interior noise as "not high", but 30% were disturbed. The passengers seemed to prefer "Reading" to "Talking with their neighbors". 31% of them were disturbed, while reading, by the noise level in the coach.

The noise level in the coach was measured at, at least, 3 points. Seat 1 was on the bogies and just in front of the door. Whereas seat 34 was at the middle of the coach. As can be seen the SPL level at $f \geq 25$Hz is above the threshold level and the slopes of the spectrum, at $16 \text{ Hz} \leq f \leq 200$ Hz, are steep for both seats. Independent of the seat location the turning, in this low frequency range is at 40 Hz. the turning point.

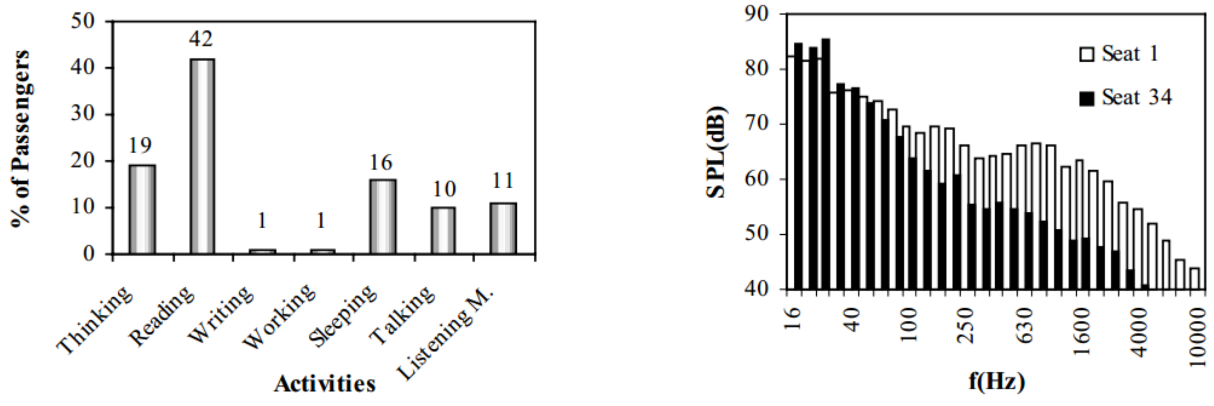


Figure 5: Distribution of first priority activities (13)

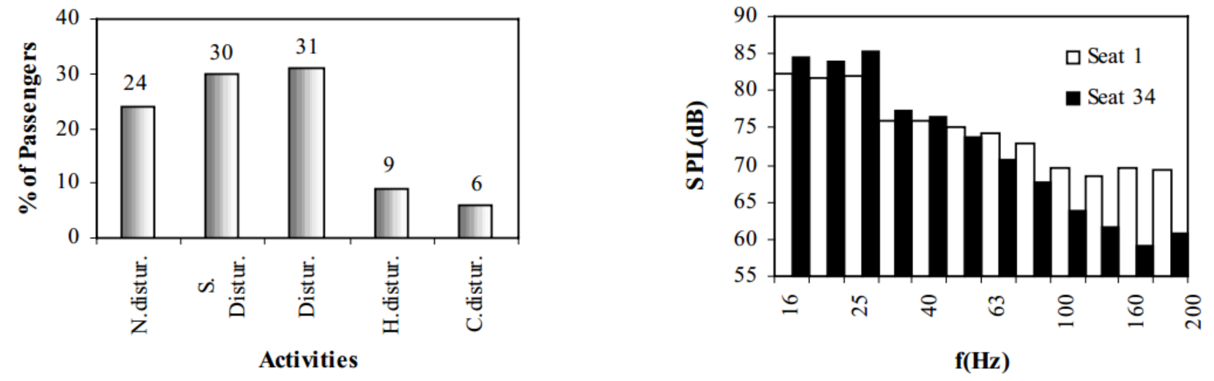


Figure 6: Disturbance of "Reading" and comparison of seats (13)

In 200 Hz ≤ f ≤10000 Hz is location dependent. It is at f=1000 Hz for Seat 1 and f=500 Hz for Seat 34. The spectrum slope of the seats, however, does not differ significantly. It is worth noting that, independent of "where they sit", 54% of the passengers have rated this noise level (72 dB (A) for Seat 1 and 61.6 dB (A) for Seat 34) as "not high" As whole this paper assess the impact of passenger activity inside the train.

A sensitivity analysis to changes in receptor and noise barrier locations, track length, and train characteristics was conducted. In all scenarios receptors were located midway along the track, at different distances along the track's perpendicular bisector to obtain a noise profile up to 1,000 ft. (305 m) away from the railway running surface. Average A weighted noise levels were then obtained in terms of Leq1 and Lmax2 for each receptor point by simulating train pass by incidents. Other noise sources, such as motor vehicles, aircraft, and other point sources, were assumed to be accounted for in the background level which means that the simulated values above background reflect the contribution of the transit system to ambient noise levels. (13)

For the base case with a downtown background noise level of 70 dB(A), predicted average noise levels ranged from about 75 dB(A) at 20 ft. (6 m) away from the railway to 70 dB(A) at 1,000 ft. (305 m), with maximum noise levels reaching 101.1 dB(A) close to the track (Figure 8). Average and maximum noise levels stabilize at 70 dB(A) and 100 dB(A), respectively, at receptors located further than 500 ft. (152 m) away from the track, implying that the noise emitted by a train pass by incident converges to the background noise level. The result distribution is displayed in the figure below.

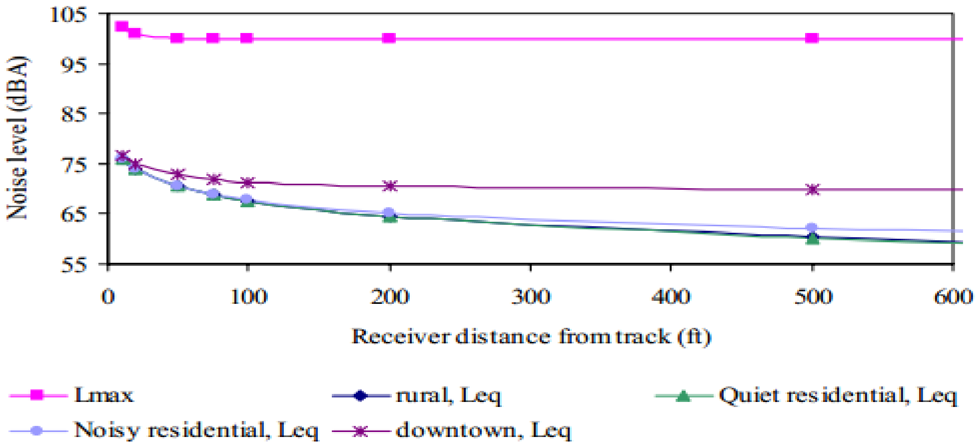


Figure 7: Base case average noise levels (5)

In addition that by the year 2012 there were three lines of about 96.9 km with more than 60,000 trains passing annually(Haydarpaşa-Gebze, Alsancak-Cumaovası, BasmaneMenemen) and three lines of about 120.5 km with 30,000-60,000 trains passing annually (Sirkeci-Halkalı, Menemen-Aliağa, Adana-Mersin), which corresponds to approximately 82-165 trains per day. The rest of the lines had less than 30,000 trains passing in a year. According to Ahrlin (1988), approximately 13% of the people are very annoyed, 45% complained from speech interference, 35% complained from rest/sleep interference and 25% complained from awakening, which are living in the areas exposed to a maximum train noise level of 80±3 dB(A) where 80-100 expected to be completed in 2013. (8)

Sometimes it is impossible to use the whole data or in Questionnaire to ask all peoples it is better to use sample size. So In statistics, the standard deviation (SD, also represented by the Greek letter sigma σ or the Latin letter s) is a measure that is used to quantify the amount of variation or dispersion of a set of data values. A low standard deviation indicates that the data points tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

The standard deviation of a random variable, statistical population, data set, or probability distribution is the square root of its variance. It is algebraically simpler, though in practice less robust, than the average absolute deviation. A useful property of the standard deviation is that, unlike the variance, it is expressed in the same units as the data. There are also other measures of deviation from the norm, including average absolute deviation, which provide different mathematical properties from standard deviation.

In addition to standard deviation in probability and statistics mean and expected value are used synonymously to refer to one measure of the central tendency either of a probability distribution or of the random variable characterized by that distribution. In the case of a discrete probability distribution of a random variable X, the mean is equal to the sum over every possible value weighted by the probability of that value; that is, it is computed by taking the product of each possible value x of X and its probability P(x), and then adding all these products together, giving. An analogous formula applies to the case of a continuous probability distribution. Not every probability distribution has a defined mean; see the Cauchy distribution for an example. Moreover, for some distributions the mean is infinite: for example, when the probability of the value is for n = 1, 2, 3, (14)

$$\sigma = \frac{1}{N-1}\sum_{i=1}^{N}(xi - \bar{x})^{2} \quad \text{------} 2.4$$

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} xi \quad \text{------} 2.5$$

From the above review it understands that using the direct measurement of noise and to see the feeling of the peoples living and working around rail way additionally using Questionnaire is the best methods.

2.2. In terms of area of study and conditions

Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects discussed that some sections of rail corridor might be shared usages (i.e. passengers and freight) and some have shared ownership. In some cases there are dedicated freight lines, but in most cases these are the same tracks with shared usage. For this case considering all the line type is the basic criteria for the area of study and route selection. (6)

According to EPA VICTORIA (A guide to the measurement and analysis of noise) the Policies normally specify noise limits for outdoor areas of noise sensitive areas. It is therefore preferable to choose a point outdoors to take measurements. It should be chosen so a maximum level of the noise source is obtained.

In some cases it is difficult to measure the noise outdoors, and an indoor measurement may be necessary. This situation is most likely to occur when an outdoor area, such as a front or back yard, doesn't exist such as where the noise sensitive area is an apartment in a high-rise building. An indoor measurement is not preferred; it may be possible to use a microphone attached to a boom protruding from the window of the affected room instead of measuring indoors. The Policies specify the circumstances in which measurements should be taken indoors. (16)

For practical reasons it may not be possible to take measurements in a noise sensitive area. In such cases an alternative point is chosen, called a derived point. A derived point will normally be located out of doors and the general requirements of microphone placement are as follows.

The Policies allow a derived point to be set at any point outside a noise sensitive area. They also specify under what circumstances a derived point may be used. These are discussed below. (a) Multiple industries a derived point may be appropriate when more than one premise contributes to the noise received at the noise sensitive area. In this case derived points should be selected so that the noise of an individual premise is measured at each point. Care should be taken in selecting a derived point so that the distance from the premises is sufficient for it to appear as a point source. Where there are a number of noise sources in the premises, it may be necessary to set multiple derived points to control individual pieces of equipment.

(b) Atmospheric effects Weather conditions can markedly affect the noise level received at a noise sensitive area. This is particularly important when the level is low and the distance between the noise sensitive area and the source exceeds 200 meter. When it is believed that the noise received at the noise sensitive area is affected by weather conditions, then a derived point may be used. It is advisable to use this point in all cases where the noise source is more than 500 meter from the noise sensitive area because weather conditions are likely to be the major source of variability in the noise level at this distance. (16)

Where a suitable derived point is not available, three measurements to be taken within a 30 day period at the noise sensitive area; this is used as an alternative to the derived point method to account for the variability in received noise caused by weather conditions.

Difficulties can arise in the measurement of noise due to the placement of microphone and tripod. For example, if a microphone is located too close to an acoustically reflecting surface, then reflections from that surface may artificially increase the noise level. Also, if the tripod is placed on a rigid surface then vibration through the legs of the tripod may affect the measured level. Noise levels can vary from place to place because of shielding by buildings or other structures and also because of the presence of nodes and anti-nodes (especially indoors) resulting from tonal noises. The microphone should be located so reflections from nearby surfaces are minimized and where a maximum noise level (unaffected by reflections) is obtained. (16)

In order to see the effect and correlate to the standard the noise measurements were undertaken at three different offset distances from the track centerline (1 m, 7.5 m and 15 m). (16)

The following procedure is suggested.

(a) To be consistent with the procedures recommended in Australian and international standards, a microphone height of from 1.2 to 1.5 meters above the ground or floor should be used. The microphone may be located at a height greater than 1.5 meters in exceptional circumstances, such as when a measurement is made on a boom outside the window of a building to avoid making an indoor measurement.

(b) To avoid reflections from nearby acoustically reflecting surfaces, the microphone is best located at least 3.5 meters from such surfaces when located outdoors. (16)

The Policies allow measurements to be taken closer than 3.5 meter from reflecting surfaces. Such measurements would only be made in exceptional circumstances, such as when a microphone is located outside a window to avoid an indoor measurement. In such cases a negative adjustment is made to the measured level as specified in the Policies.

(c) To avoid reflections affecting the measured level indoors, the microphone should be located at least 1.2 meters from any acoustically reflecting surface. A reflection adjustment is not made for indoor measurements;

(d) To avoid reflections from the body of a person when making direct reading measurements from the meter scale, the meter should be held at arm's length or placed on a tripod with the person taking the measurement at a suitable distance; and Use of equipment should be generally in accordance with the manufacturer's recommendations.

In particular, the following points are important. (16)

(a) Some pieces of equipment require a minimum 'warm-up' time before their performance is optimum. The manufacturers' recommendations are the best guide.

(b) A battery check should be done on each piece of equipment used in the field before and after it is used.

(c) A calibration check should be made both before and after the measurement. Where a tape recorder is used, a calibration tone should be recorded at the start and end of the tape. Calibration checks may vary slightly, and may cause the measurement to be invalid if the difference is significant. The magnitude of the noise excess above the noise limit will play a part in this judgment.

(d) Residual equipment noise can be a source of measurement error; all equipment including tape recorders and sound level meters have internally generated electrical noise. It is important that the signal being measured is significantly higher than this equipment noise. The margin will depend on the sound level meter range being used and the VU level recorded on a tape recorder. If the measurement signal is 10 dB above the residual noise, then an error of approximately 0.4 dB will result. This is insignificant, and a margin of at least 10 dB is recommended. The residual noise may be estimated by placing a calibrator on the microphone of the sound level meter and observing the sound level indicated by the meter, without turning the calibrator on.

(e) The heads of a tape recorder should be kept clean using a suitable cleaning fluid.

The time for which a measurement of the effective noise level is made will depend to a large degree on the variability of the noise source. The following points should be noted when determining an appropriate measurement time.

(a) Some policy does not specify a measurement time, but it is recommended that the L_{Aeq} be measured so it represents the L_{Aeq} over a 30 minute period. Noise emissions need to be observed for at least 30 minutes for the purpose of assessing a duration adjustment; if the noise is steady over this period (that is, there is no observed rising or falling trend in the noise level either audibly or by sound-level meter inspection), a short measurement (say five minutes) should be adequate to represent the 30 minute L_{Aeq}.

(b) If the noise varies in a cyclic or regular manner then the L_{Aeq} should be measured over a number of periods of the cycle. If the level fluctuates in a random manner, then a short measurement may be used as long as the measurement is carried out in an appropriate manner. (16)

(c) Some policy also requires the measurement to be taken over at least fifteen cumulative minutes of audible music. (16)

The method to determine noise limits is clearly set out in the Policies. The following additional points should be noted.

Some specifies a requirement to determine a zoning level. This level is based on the land-use zoning of the area as specified by the appropriate planning scheme. The Policy classifies land as Type 1, 2 or 3 depending on the zoning. Where a zone or reservation is undefined by the Policy then the Authority will designate the Type taking into consideration the nature of the uses permitted in the area. In most cases the Type given will be based on a similar land use. There may be cases where the uses permitted will have to be determined from the planning scheme ordinance before a suitable Type can be allocated. (16)

Some require a derived noise limit to be determined for a derived point. The derived noise limit is set so when the industrial or entertainment noise complies with this level, the noise limit at the noise sensitive area is not exceeded. To determine the derived noise limit, an adjustment must be made to noise limit conditions to allow for attenuation due to distance, weather conditions, barriers, etc. Standard methods are available to determine the attenuation of noise over distance. If a derived point is used as an alternative point when the noise received at a noise sensitive area is affected by weather conditions, it is recommended that the derived noise limit calculation be based on weather conditions favoring propagation that occur for 20 per cent of the time. (16)

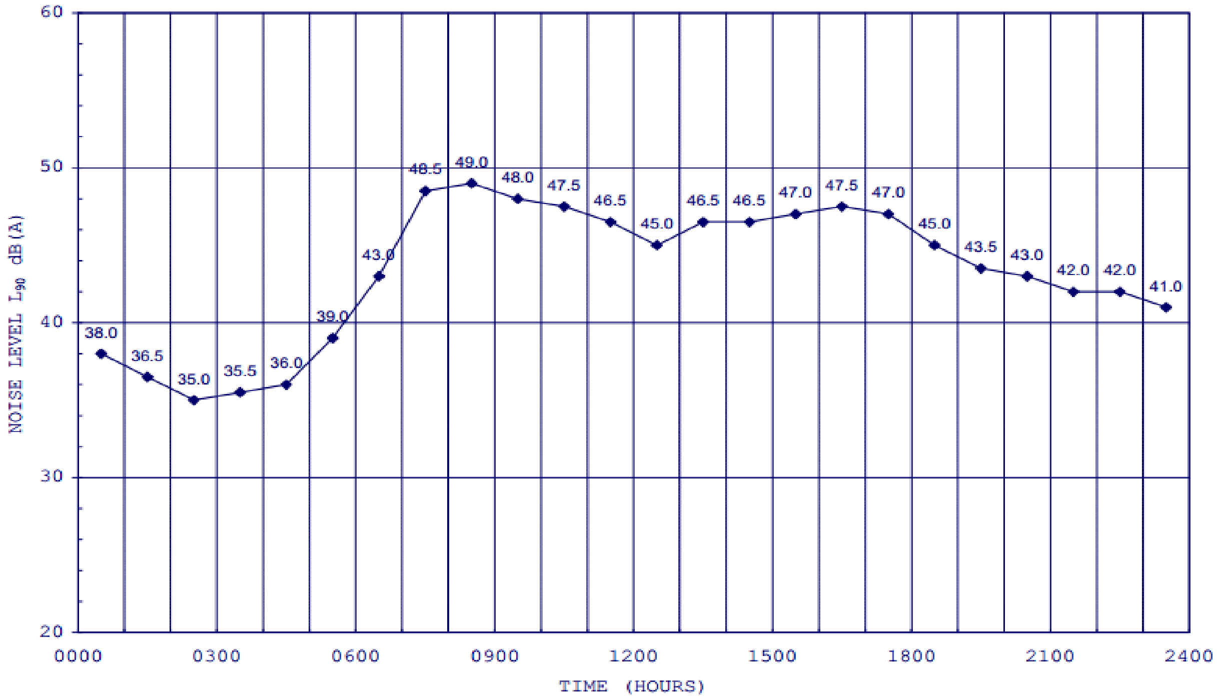


Figure 8: Average of 40 sites - Melbourne noise survey (16)

The condition also varying in accordance with the nature of the selected route and the country even if it is conditions like the weather, speed, wear rate and the vehicle track geometrical speciation has to be listed in detail the measurement has to be taken at different speed and load level in order to see the relationship of noise and speed and load.

2.3. In terms of standard and guide line

Operational noise limits for light rail transit cars running on the surface are set under the MOE/TTC “Protocols for Noise and Vibration Assessment” which were developed in 1993. The “Protocol for Noise and Vibration Assessment for the Proposed Eglinton West Rapid Transit Line” sets out the following limits for noise (MOE/TTC 1993).

Points of reception for noise include existing and approved residential development, nursing homes, group homes, hospitals, and other such institutional land uses where people reside. It does not apply to commercial or industrial land uses. Daytime points of reception are any outdoor area where noise from the light rail transit system may be received, 15 m or more from the track centerline. Night-time points of reception are in the plane of any bedroom window where the noise is received, more than 15 m from the track centerline. (17)

Table 1: Noise Limits for LRT Surface Operations (17)

Time Period	Guideline Limit
Daytime (07:00-23:00h)	55 dB(A) Leq(Day), or existing ambient, whichever is higher
Night time (23:00-07:00h)	50 dB(A) Leq(Night), or existing ambient, whichever is higher
Pass by	80 dB(A) Lmax during the pass-by
Mitigation Required:	If above limits are exceeded by > 5 dB(A)

Where required, all mitigation measures must ensure that the predicted sound levels are as close to or lower than the above limits as is technologically, economically, and administratively feasible.

The Maintenance and Storage Facility, stations, and associated ventilation shafts are considered to be “Ancillary Facilities” under the Ministry of the Environment (MOE) and Toronto Transit Commission (TTC) guidelines. The Mount Dennis Station will have an HVAC system for station comfort ventilation, and an emergency fire ventilation system, which will be used to supply air to the stations and tunnel system. Noise from the Bus Station will be dominated by bus activity. Noise from the Maintenance and Storage Facility will include heating ventilation air conditioning and cooling and also light rail transit activity. Toronto Transit Commission Design Manual DM-0403-00 (TTC 1994) sets out requirements for station ventilation fans. Noise from station ventilation fans (excluding emergency ventilation fans) should not exceed 60 dB (A) on enclosed platforms. Noise from “Ancillary Equipment” should not exceed 60 dB (A) at 1 m distance in all public areas. In addition, for these facilities, MOE Publication NPC-205 noise guidelines apply. These guidelines state that the 1-hour average sound level from the equipment (Leq (1-hr) values measured in dB (A)), must meet the following limits at all off-site noise sensitive points of reception: March 19, 2013. (17)

Table 2: Noise Limits for LRT Ancillary Operations (Stations, Vent Shafts) (17)

Time Period	Guideline Limit
Daytime (07:00 to 19:00h)	50 dB(A) Leq(1hr), or existing ambient, whichever is higher
Evening (19:00 to 23”00h)	47 dB(A) Leq(1hr), or existing ambient, whichever is higher
Night-time (23:00 to 07:00h)	45 dB(A)Leq(1hr), or existing ambient, whichever is

	higher

Notes:

• Limits for Class 1 Urban area are shown Noise sensitive points of reception include but are not limited to: Permanent and seasonal residences, Hotels, motels and campgrounds, Noise sensitive institutional uses such as hospitals, daycares, nursing homes, and schools and also Places of worship.

The MOE guidelines require that impacts be assessed for predictable worst-case operating scenario. The four tunnel ventilation fans are the dominant noise sources, and will be used in one of three modes:

a) Regular Operations

During regular operations of the LRT system, the fans operate on half (½) speed on a continuous basis during warm days.

b) Emergency Operation

In emergency operation, all fans will operate at full speed. As an emergency, this situation is excluded from the MOE’s noise guidelines.

c) Track Maintenance

During overnight track maintenance, the fans will be operated at three-quarter (¾) speed. The fans could run for extended periods of time between 0200 – 0600h.

d) Testing

Full speed testing of the fans occurs on a weekly basis. The fans are operated in both directions (supply and discharge) at full speed for up to 60 seconds for each direction (2 minute total test times).From the above, the “predictable worst-case scenario” is the track maintenance operations, which occurs for extended periods of time, during the over-night period. Despite the 2-minute long higher sound level during full speed testing, average hourly sound levels will still be higher for maintenance operations. The noise guidelines also provide for procedures and adjustments for addressing noise of especially annoying character, such as tonal noise, beats, impulsive noise and quasi-steady impulsive noise (MOE 1977 a,b). Based on the generic sound data provided for the tunnel ventilation fans sound from the ventilation fans will likely be tonal in nature. In accordance with Publication NPC-104 guidelines, a + 5 dB penalty has been applied in predicting noise impacts from these sources (MOE 1978). (17)

Reports from the city government of Addis Ababa environmental protection authority shows that in 2003 detail study in the area of noise pollution where done. In this study about 90% of the stations are more than the standard when it compares with the night time standard decibel which is 55 dB (A) and about 50% of the stations are more than the standard when it compares with the day time standard decibel which is 65 dB (A).

From South Australia, Guidelines for the assessment of noise from rail infrastructure to assess rail noise, criteria are provided for:

- LAeq, 15h and LAeq,9h equivalent noise levels, addressing the average noise exposure of a sensitive land use across the day or night period respectively
- LAmax levels, addressing the maximum noise levels at a sensitive land use due to individual pass-by events.
- LAeq, 1h equivalent noise levels, addressing the worst-case average noise exposure of nonresidential sensitive receivers during their hours of operation.

Separate LAeq criteria are provided for the day and night periods with more stringent criteria applied for the night period. This reflects the increased effect of rail noise during night-time. The 15-hour day period is defined from 7 am to 10 pm and the nine-hour night period from 10 pm to 7 am.

Table 3 outlines the noise criteria at noise sensitive receivers for new railway lines and upgraded existing lines, and for new residential development adjacent to existing rail corridors. The noise criteria represent external noise levels at the most exposed sensitive façade at the ground level. The aim of the Guidelines is to protect internal living areas and external recreation areas.

Table 3: Noise criteria for residential receivers. (18)

Period	Noise criteria, dB(A)		
	Rail infrastructure developments		New sensitive developments near existing railway line
	New railway line	Upgraded existing railway line	
Day,7 am to 10 pm	60 LAeq,15h 80 LAmax	65 LAeq,15h 85 LAmax	60 LAeq,15h 80 LAmax
Night, 10 pm	55 LAeq,9h 80	60 LAeq,9h 85 LAmax	55 LAeq,9h 80 LAmax

to 7 am	LAmax		

The criteria outlined in Table 3 are also applicable for nursing homes, aged care facilities and for caravan parks accommodating long-term residential use. If private or community outdoor recreation areas associated with the sensitive noise receiver are provided, the residential noise criteria in Table above should be met in at least one of these locations to enable residents to enjoy a place of quiet amenity.

Table 4 outlines the noise criteria for non-residential sensitive receivers near proposed new railway lines and upgraded existing lines, and for new sensitive development adjacent to existing rail corridors. The noise criteria represent external *LAeq* noise levels at the most exposed sensitive façade for the hours of operation of the land use unless otherwise stated. Noise assessment in recreational areas should be conducted at the most exposed boundary of the area.

For new noise sensitive developments, it is advisable to refer to the relevant Development Plan applicable to the locality of interest. The development plan may indicate that special provisions regarding protection from rail noise apply in the development zone, or that the subject site lies within the Noise and Air Emissions overlay. In such cases, the provisions of the Minister's Specification are mandatory for building rules approval to be granted for certain classes of buildings on the land.

Table 4: Noise criteria for non-residential sensitive receivers during hours of operation. (18)

Land use	Noise criteria, dB(A)		
	Rail infrastructure developments		New sensitive developments near existing railway line
	New railway line	Upgraded existing railway line	
Educational institutions	65 LAeq,1h	65 LAeq,1h	65 LAeq,1h
Hospitals	60 LAeq,1h	60 LAeq,1h	60 LAeq,1h
Places of worship	60 LAeq,1h	60 LAeq,1h	60 LAeq,1h
Passive recreation areas	60 LAeq,15h	65 LAeq,15h	60 LAeq,15h
Active recreation areas such as sporting fields*	65 LAeq,15h	65 LAeq,15h	65 LAeq,15h

LAmax noise criteria have not been specified for the sensitive receivers in above Table as the focus for these receivers is considered to be speech interference and interference with general activities. (18)

In 2004 also detail study in the area of noise pollution around mixed use buildings where done. In this study the recorded value is 38% increment to the day time standard and 17% increment to the night time noise standard. In addition to the planting the trees around the noise source contribute minimizing about 5 dB of noise. (19)

The generation of excessive noise in the community can have undesirable effects on the population. It can cause annoyance and disturbance to people at work or during leisure activities, disturbance to sleep and possibly a deleterious effect on general physical and mental well-being. All people are not equally sensitive to the disturbing aspects of noise. There is a small but significant minority which is more sensitive than others.

The objective of these guidelines is to minimize the amount of noise to which people, living or working in sensitive locations, are exposed. Examples of such areas include domestic dwellings, hospitals, schools, places of worship, or areas of high amenity. The sensitivity to noise is usually greater at night-time than it is during the day, by about 10dB (A). Ideally, if the total noise level from all sources is taken into account, the noise level at sensitive locations should be kept within the following values:

Table 5: Noise Standard for Ethiopia (20)

		Limits in dB(A) L_{eq}	
Area code	Category of area	$Day\ time^{Noise\ 1}$	$Night\ time^{Noise\ 2}$
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45

Note-1: Day time reckoned in between 6.00 am to 9.00p.m

Note 2: Night time reckoned in between 9.00 pm to 6.00am

In some particularly quiet areas, such as pastoral, rural settings, where the background noise levels are very low, lower noise limits may be more appropriate. Audible tones and impulsive noise at sensitive locations at night should be avoided, irrespective of the noise level. Because of the variability in sensitivity to noise from one area to the next, it may be desirable to establish formal noise zoning criteria under the planning code. (20)

Table 6: motor vehicle noise standards for Ethiopia **(20)**

Vehicle Type	Maximum Permissible Noise Levels, dB(A) at 7.5 meters from the source
Two wheelers (petrol-driven)	80
All passenger cars, all petrol-driven three-wheelers and diesel driven two wheelers	82
Passenger or light commercial vehicles into three-wheeled vehicles fitted with diesel engine with gross vehicle weight up to 4000 Kg.	85
Passenger or commercial vehicles with gross vehicle weight above 4000 Kg and up to 12000 Kg.	89
Passenger or commercial vehicles with gross vehicle weight above 12000 Kg.	91

The vibration of a source causes pressure changes in air which result in pressure wave. Perceived sound is comprised of numerous pressure waves of varying characteristics

There are three Pressure wave characteristics

Amplitude—the amount of sound pressure measured in decibels (dB)
Frequency—the rate of vibration per unit time measured in cycles per second, more commonly known as hertz (Hz); range of normal perception for young person is 20– 20,000 Hz

In most scholars the Human hearing covers a wide range of sound pressures

- Threshold of hearing (the minimum pressure vale that human ear senses) 0.00002 Pa
- Loud noise (the maximum pressure value that human ear senses) 200 Pa

Decibel (dB) scale is a log-based scale developed to quantify sound Compresses range to 0–140 dB the Scale starts at zero when sound pressure equals the threshold of human hearing.

$$\mathbf{Decibel = 10Log\left(\frac{acoustic\ energy}{reference\ energy}\right) ------------------------2.6}$$

Reference energy is the threshold of human hearing that means 0.00002 Pa, 10*Bel = decibel (dB)

Acoustic energy cannot be readily measured Acoustic energy is proportional to the square of the sound pressure

$$\mathbf{dB = 10log(\frac{P^2}{P_O{}^2})}$$ --2.7

Which is the same as $dB = 10\log(\frac{P^2}{P_O{}^2}) = 10\log(\frac{P}{P_O})$

Where p is the sound pressure and p_o is the reference which is equal to the threshold of human hearing (i.e., 0.00002 Pa or 20 μPa) Since Sound pressure levels are based on a log scale, they cannot be added directly I.e., 80 dB + 80 dB ≠ 160 dB

$$\mathbf{SPL = 10Log(\sum_{i=1}^{n} 10^{\frac{spl\,i}{10}})}$$ ---Equation 1

Where: SPL T is the total sound pressure level, and SPLi is the ith sound pressure level to be summed. In practical case 95 dB (A) for 4 hours is as bad as 90 dB (A) for 8 hours the table below shows about maximum standard exposed time for each noise recorded (21)

Table 7: Maximum exposed time for each noise recorded (21)

Exposure Time, Hrs.	PEL, dB(A)
No time limit	<90
8	90
4	95
2	100
1	105
0.5	110

2.4. In terms of controlling mechanism

This gives a broad overview of ways to mitigate noise from rail operations. Measures for reducing noise impacts from railway operations follow three main control strategies:

- Controlling noise at the source
- Controlling the transmission of noise
- Controlling noise at the receiver.

2.4.1. Controlling noise at the source

For new rail line developments it is important that the route is carefully selected to avoid creating noise impacts. In particular, attention should be paid to the location of the proposed rail line in relation to existing and planned residential areas and the possibility of using existing topographical features to mitigate noise. Keeping rail vehicles and tracks well maintained is important (Hemsworth and Hubner 1999) and this should be given high priority in any mitigation strategy. Other types of sources that should be given high priority are those with annoying characteristics (e.g. tonality, impulsiveness), such as wheel squeal, brake squeal, and the noise from track joints and turnouts as they generally evoke a strong community reaction. Noise mitigation that reduces these annoying characteristics would provide a benefit to the community, even where there may be no measurable changes in measured noise levels. Examples of mitigation measures at the source include. (6)

- Track measures: rail grinding, welding to smooth discontinuities, lubrication, use of soft rail pads, and relocation of signals or turnouts.
- rolling stock measures: effective muffling of diesel locomotive exhaust noise, wheel truing, onboard wheel lubrication, use of disc brakes, dampening of wheels, and use of resilient wheels, wheel vibration absorbers and low-squeal brake blocks.

In applying mitigation measures at the source it is recommended that the principles of 'best management practice' (BMP) and 'best available technology economically achievable' (BATEA) be followed. Best management practice is the adoption of particular operational procedures that minimize noise while retaining efficient operations. When a mitigation strategy that incorporates expensive engineering solutions is being considered, the extent to which cheaper, non-engineering-oriented best management practice can contribute to the required reduction of noise should be taken into account. Application of best management practice includes the scheduling of noisy operations at least-sensitive times, selective use of certain tracks, keeping equipment well maintained, siting noisy operations behind structures, employing 'quiet' practices when operating equipment, and running staff-education programs.

Best available technology economically achievable this involves ensuring operations incorporate the most advanced and affordable technology to minimize noise output. Affordability is not necessarily determined by the price of technology alone. Increased productivity may also result from using more advanced technology offsetting the initial outlay: for example, 'quieter' trains can be operated over extended hours without causing impact. (6)

Where best management practice fails to achieve the required noise reduction by itself, the best available technology economically achievable approach should then be considered. As both track and rolling stock factors contribute to rolling noise, mitigation needs to address both to be effective. For example, the noise control achieved by just applying track mitigation measures is only as effective as the condition of the rolling stock that is using the track. Vincent (2000) provides a useful analysis on the differing contributions of track and rolling stock measures in reducing overall emissions.

Reducing ground-borne noise can be achieved by including resilient elements in the tracks, such as rail pads or rubber mats inserted between the ballast and tunnel floor, or on other types of sufficiently rigid supporting structures, such as steel bridges. (6)

2.4.2. Controlling of transmission noise

This involves restricting the propagation of noise. Such measures include the use of noise barriers, installation of resilient baseplates and ballast mats, and noise treatment of bridges. Barriers should be used selectively. They are a high-cost approach, and their effectiveness in controlling impacts will depend on the situation. Barriers are more effective if they are near the source or the receiver. Their effectiveness is also determined by their height, the material used (absorptive or reflective), and their density. The relationship of these design features to attenuation is well documented.

Barriers can take a number of forms, including freestanding walls, grass or earth mounds or bunds, and trenches or cuttings within which noise sources are sited. (6)

2.4.3. Controlling noise at the receiver

Rail lines are an essential part of our urban infrastructure. Even after the application of best management practice and best available technology economically achievable, the closeness of affected premises and the physical, operational and economic constraints may be such that measures to manage the problems at source or to intercept noise in transmission may need to be complemented by management at the point of impact. Where new residential development is planned to occur around a rail line, appropriate building design, layout and construction techniques should be applied to minimize noise intrusion and provide suitable internal noise levels for sleeping and external areas shielded from high levels of noise.

Where a proposed rail development will affect an existing development, acoustic treatment of buildings (e.g. insulation, double-glazing, and upgrading construction) can be considered as an option to mitigate noise. For this to be effective, an appropriate ventilation system that does not compromise the effect of noise insulation, such as air conditioning, often needs to be incorporated into the design. (6)

2.4.3.1. Sound Absorbers material

There are three main categories of sound absorbing materials: porous materials, panel absorbers, and resonators. The mounting of the absorber has a large bearing on the effectiveness. Each one acts through a different mechanism of sound absorption or dampening. Below are brief descriptions of each method. (15)

- Porous materials - These materials contain voids that convert acoustic energy to heat, dissipating the sound that goes through them. Thickness of the coating plays an important part in how effective the sound dampening is. Thicker configurations of porous materials increase low frequency absorption.
- Panel Absorbers - These structures have membranes that respond to sound pressure exerted by adjacent air molecules by flexing. Panels are most efficient at absorbing low frequencies. Due to the requirements of the project, this technique is not likely to be utilized.
- Resonators - These are structures with holes or slots connected to a trapped quantity of air. Resonators act on a narrow band of frequency. What frequency is absorbed depends on the shape of the cavity. The resonant frequency is governed by the size of the opening, the length of the neck, and the volume of air trapped in the chamber. Typically, perforated materials only absorb the mid-frequency range. Due to the part geometries for this project, this technique will most likely not be utilized.

Based on this research, porous materials appear to be the best candidate for a sound absorption coating to be incorporated in the sponsor’s impact stop. Several types of porous materials were looked into, such as polyurethane based foams, fiber glass, activated carbon fiber, and spray cellulose. (15)

From the above controlling mechanism each noise controlling strategy has its own future. The first method controlling noise at the source is basically before the railways are constructed based on careful selection of the rout selection and materials used. The second one controlling the transmission of noise is used to decrease the propagation of the noise to the receiver. The last one which is controlling noise at the receiver is basically used to decrease the noise by considering appropriate design of receiver like considering noise barrier materials. From the three controlling mechanisms using the second one controlling the transmission of noise is best feet for constructed railways.

CHAPTER THREE: EXPERIMENTAL METHODOLOGIES AND CONDITIONS

3.1. Area of study

In order to select the area of the study the following criteria's has been considered.

- Location of noise source
- Background noise measurement location
- Source noise measurement location
- Topography between noise source and sensitive receivers

Based on the above criteria curves which has a minimum radius(from 50 m to 100 m) for south north line like kality near the station ,Stadium before the station, Lideta station, Autobus tera station and the Tunnel and also for East west line near Ayat station are the serious selected. Which the detail analysis has to be done but for the purpose of getting full information the rest stations also selected.

It is the total map which the assessment covers and also the specific location or distance for which the measurement taken.

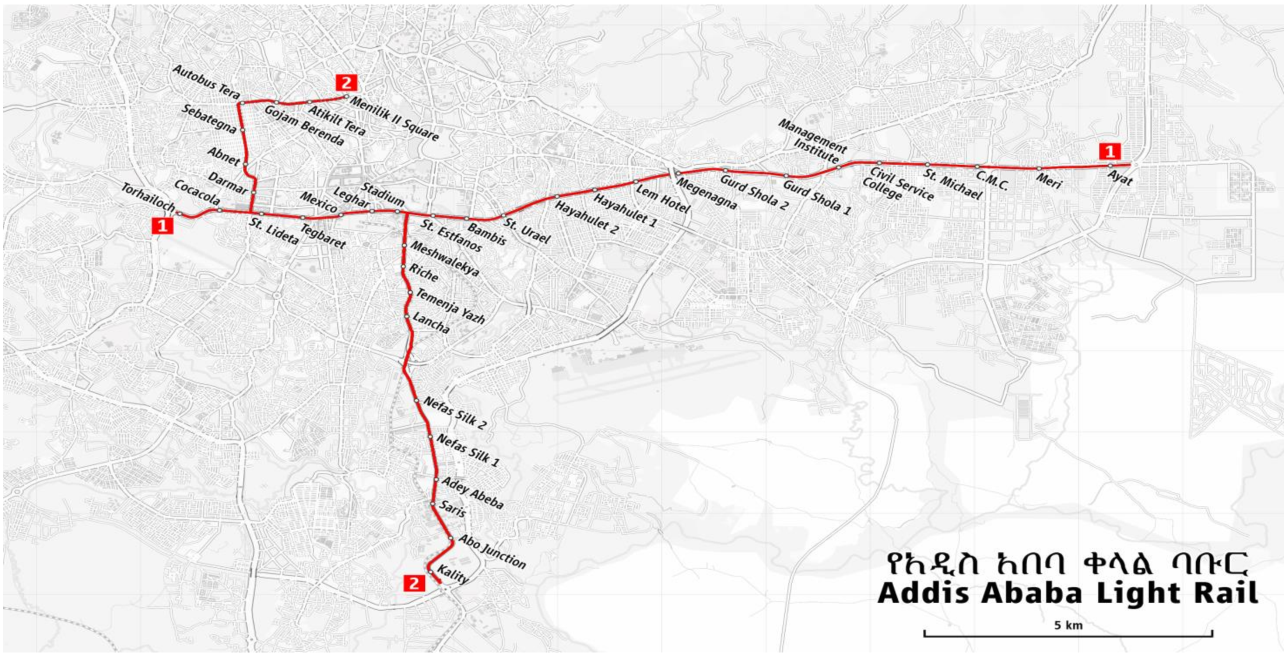


Figure 9: Site selection and area of study (3)

Noise varies with distance. For example, railway traffic 50 feet away from a receptor (such as a person listening to the noise) typically produces sound levels of approximately 70 dB (A). The same railway noise measures 66 dB (A) at a distance of 100 feet, assuming soft ground conditions. This decrease is known as "drop-off." The outdoor drop-off rate for line sources, such as traffic, is a decrease of approximately 4.5 dB (A) (for soft ground) for every doubling of distance between the noise source and receptor (for hard ground the outdoor drop-off rate is 3 dB (A) for line sources). Assuming soft ground, for point sources, such as amplified rock music, the outdoor drop-off rate is a decrease of approximately 7.5 dB(A) for every doubling of distance between the noise source and receptor (for hard ground the outdoor drop-off rate is 6 dB(A) for point sources). So the data collection area is based on the above statement.

3.2. Methodologies

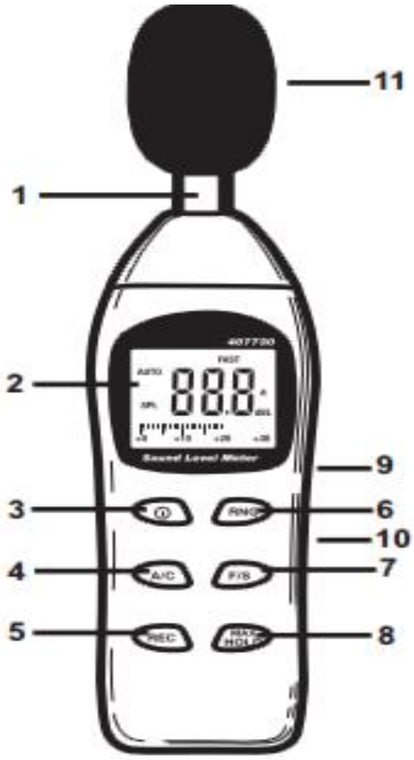
3.2.1. Using sound level meter

The first method is by measuring the noise using Sound level meter. A sound level meter is used to measure sound that travels through air.

It is commonly a hand-held instrument with a microphone. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. That is why the instrument is sometimes referred to as a Sound Pressure Level (SPL) Meter.

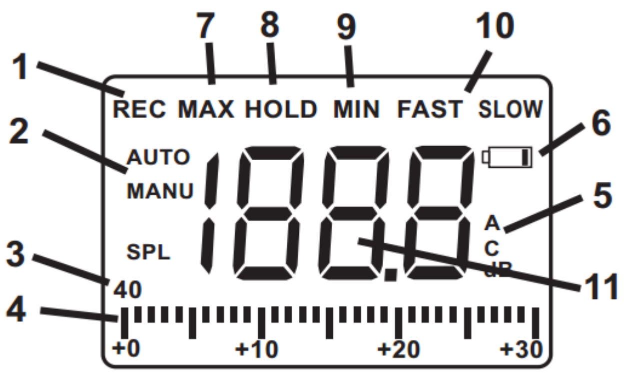
This movement of the diaphragm, i.e. the sound pressure deviation (Pascal Pa), is converted into an electrical signal (volts V).

A microphone is distinguishable by the voltage value produced when a known, constant sound pressure is applied. This is known as the microphone sensitivity. The instrument needs to know the sensitivity of the particular microphone being used. Using this information, the instrument is able to accurately convert the electrical signal back to a sound pressure, and display the resulting sound pressure level (decibel dB)



1. Microphone
2. LCD Display
3. ON-OFF button
4. A/C weighting selection button
5. Min/Max Record button
6. Range selector button
7. F/S response selection button
8. Max Hold selector button
9. Calibration adjustment
10. AC analog output jack
11. Windscreen

Figure 10: Sound level meter part name



1. Record icon
2. Auto or Manual range
3. Range indicator
4. Barograph
5. A or C weighting
6. Low bat icon
7. Max level indicator
8. Hold indicator
9. Min indicator
10. Fast or slow weighting
11. dB display

Figure 11: Sound level meter digital display indication

During the operation of the Extech 407730 instrument the following must be considered:

- ‘A’ and ‘C’ Frequency Weighting Use the ‘A/C’ button to select ‘A’ or ‘C’ frequency weighting. With ‘A’ weighting selected, the frequency response of the meter is similar to the response of the human ear. ‘A’ weighting is commonly used for environmental or hearing conservation programs. ‘C’ weighting is a much flatter response and is suitable for the sound level analysis of machines, engines, etc. “A” or “C” icons will appear in the display. Most noise measurements are performed using 'A' Weighting and SLOW Response. So that for this assessment A’ Frequency Weighting method is used.
- ‘FAST’ and ‘SLOW’ Response Time Use the ‘F/S’ button to select FAST (125 ms) or SLOW (1 second) response time. Select FAST to capture noise peaks and noises that occur very quickly. Select the SLOW response to monitor a sound source that has a consistent noise level or to average quickly changing levels. “FAST” or “SLOW” icons will appear in the display. Select slow response for most applications. So that for this assessment FAST response method is used.
- Wind blowing across the microphone increases the noise measurement. Use the supplied windscreen to cover the microphone when applicable.
- Calibrate the instrument before each use if possible. Especially if the meter has not been used for a long period of time.
- Do not store or operate the instrument in areas of high temperature or humidity.
- Keep meter and microphone dry.
- Avoid severe vibration.
- Remove the battery when the meter is to be stored for long periods of time

Table 8: Technical specification of sound level meter (22)

Par No.	Parameter	Specification
1.	Display	LCD with barograph
2.	Microphone	10mm (0.5”) Electret condenser
3.	Measurement Bandwidth	300Hz to 8KHz
4.	Measurement Range	40 to 130dB (A wtg), 45 to 130dB (C wtg)
5.	Frequency weighting	‘A’ and ‘C’ (selectable)
6.	Accuracy / Resolution	± 2dB @1kHz (under reference conditions) / 0.1dB
7.	Response time	Fast: 125 milliseconds / Slow: 1 second
8.	Calibration source	1KHz sine wave @ 94 or 114dB

Par No.	Parameter	Specification
9.	AC output	0.707Vrms full scale
10.	Power	4 AAA Batteries
11.	Battery life	30 hours (typical); low battery indicator alerts user
12.	Automatic power off	After approx. 20 minutes
13.	Operating temperature	0 to 50oC (32 to 122oF)
14.	Operating humidity	10 to 90% RH
15.	Storage temperature	-20 to 60oC (-4 to 140oF)
16.	Dimensions/weight	230 x 57 x 44mm (9 x 2.3 x 1.7") / 172g (6oz)

The noise measurements are taken at 7.5 m offset distance from the horizontal track center line and 1.5m offset distance from the vertical side. The measurement includes outdoor and indoor measurements. This measuring coordinates are selected for the reasons: to follow similar procedure with noise standard of Ethiopia and feasibility study of Addis Ababa light rail transit, and, in turn, for making a one to one correlation with their standard.

The indoor noise was measured inside the rail vehicle at each station on different locations; 39 different data's are taken. In the other hand, the outdoor noise values are taken from outside the vehicle with offset distance in 100m interval throughout AALRT line; around 340 data's are taken.

Figure 12: Site measurement using sound level meter.

But while measuring the noise inside the tunnel it is impossible to keep 7.5 m offset distance from the center track because of envelops constraint, the gap between the wall and the center track line is as small as around 3.2 m.

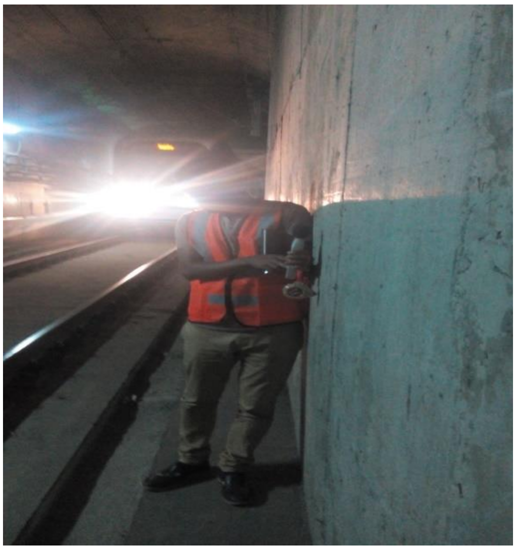


Figure 13: Site noise measurement using sound level meter inside the tunnel

3.2.2. Using Questionnaire

The second methodology is using questionnaire. It helps to collect data from the user and people living around, additionally it helps to understand the community thought on the transit service. 200 people are covered by the questionnaire in different age group and sex composition. During the interview some of the respondent where not willing to fill the questioner and the feeling from one person to the other is not consistence. To alleviate this problem during the interview awareness and the reason behind questionnaire and how they fill it is presented to the participant.

A standard questionnaire and other adopted questionnaire from same study were used for measuring occupational hearing capacity in the interview. The questionnaire was designed to obtain a complete history relevant to hearing, including demographic data and duration of occupational exposure. The questionnaire was being pre-tested to identify potential problem areas; unanticipated interpretations and cultural objections to any of questions.

The developed questionnaire includes the following information:

- **General information**
  - Age, Gender, Occupation, Job location, Resident location and Date
- **Noise level**
  - No, Some, Much and Too much
- Annoyance time (peak time): Listed 1 to 24 hr.
- **Additional information**

In general based on the above two methods detail analysis has done.

3.3. Software packages

For this assessment software versions are used

Microsoft excel 2010

It is used to draw the noise model and to show the impact distance from the rail and it has its own formula to drown out the graph.

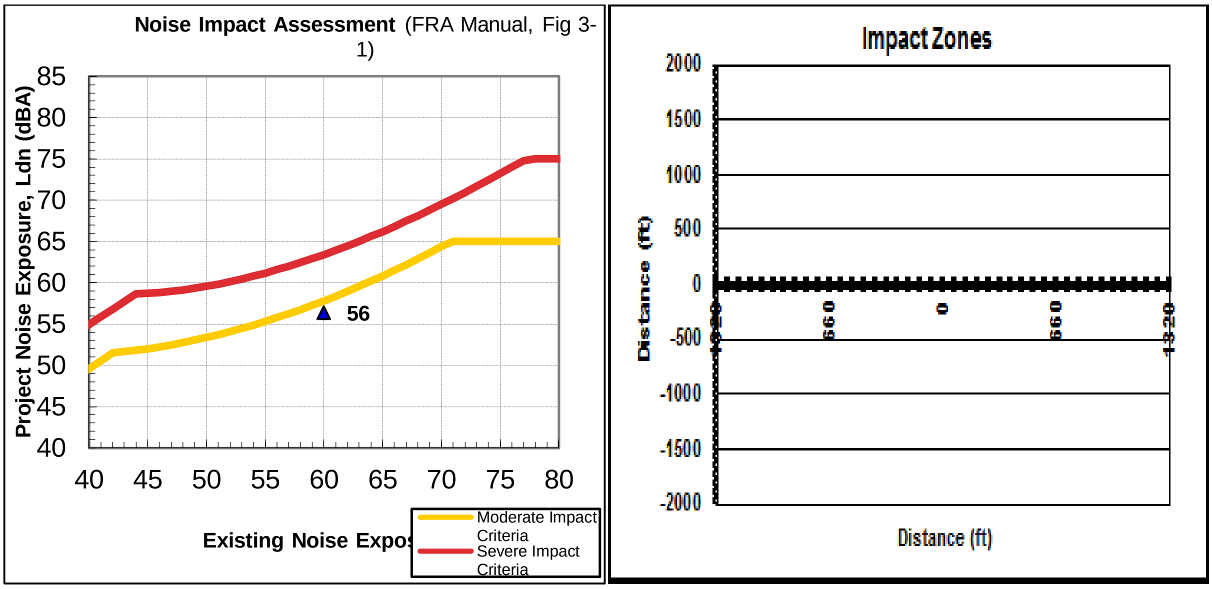


Figure 14: Microsoft excel 2010 noise mapping

3.4. Conditions

3.4.1. Basic technical conditions of vehicles and the track of AALRT

3.4.1.1. Vehicle type and train formation

The vehicles shall be 70% low-floor articulated 6-axle modern trams, consisting of three modules, bi-directional driving. Two tramcars shall be able to operate with double heading.

Train formation: –Mc+Tp+Mc–

Where: Mc module: motor car with driver's cab

Tp module: trailer without driver's cab and with pantograph

+: articulation device

-: Hidden folding coupler

3.4.1.2. Main dimensions of vehicle

Table 9: Main dimensions of the rail vehicle (23)

No.	Parameter	Value	Remark
1.	Length of car body:	30000 mm	
2.	Height of vehicle roof from top of rail (excluding	3700 mm	

No.	Parameter	Value	Remark
	pantograph):		
3.	Maximum width of car body:	2650mm	
4.	Height of vehicle floor from top of rail (low floor area, new wheels and empty load)	380 mm	
5.	Height of vehicle floor from top of rail (exit and entry areas, new wheels and empty load)	350 mm	
6.	Height of vehicle floor from top of rail (raised floor area, new wheels and empty load)	900 mm	
7.	Wheelbase (power bogie)	1900 mm	
8.	Wheelbase (unpowered bogie)	1800 mm	
9.	Clear height of passenger compartment	1980 mm	
10.	Wheel diameter (new wheel)	660 mm	
11.	Wheel diameter (Max. wear)	600 mm	
12.	Side doors of passenger	four pairs per side	

No.	Parameter	Value	Remark
	compartment		
13.	Clear opening of passenger compartment door (width x height):	1300×1860 mm	

3.4.1.3. SEATING CAPACITY OF VEHICLES

Table 10: Seating capacity of the rail vehicle (23)

Number of passengers (persons)	Seated	Standing	Total
Seats (AW_1)	65	0	65
Seating capacity (AW_2) (standing: 6 persons/m^2)	65	189	254
Overload capacity (AW_3) (standing: 8 persons/m^2)	65	252	317

3.4.1.4. VEHICLE WEIGHT

Table 11: Weights of the rail vehicle

Loads	Car body weight	Passenger weight	Total weight
Empty vehicle (t)	44	0	44
Seating capacity (t)	44	15.24	59.24
Overload capacity (t)	44	19.02	63.02
Axle load	≤11（1+3%）t		

Note: Take 60kg as average weight of each passenger. (23)

3.4.2. Main technical indicators

3.4.2.1. Speed

At the time of measuring the noise value using sound level meter the following speed conditions will be taken

Speed 1- initial speed before the starts the normal operation between 1to 5 km/hr.

Speed 2- normal operation speed 20 to 40km/hr.

Speed 3 - designed speed which is 80km/hr.

Speed 4 - maximum operation speed which is **70** km/hr.

Speed 5- Operation speed during car wash: 3~4 km/h

In order to predict the exact effect of speed on noise, the train speed was being recorded by the train master (driver) at a time the noise had been measured on the selected track stations so as to illustrate their relation graphically.

3.4.2.2. Average acceleration

Under rated load and rated voltage on straight and dry track, with half-worn wheels, average acceleration is as below:

Vehicle speed from 0km/h to 40 km/h ≥1m/s^2

Vehicle speed from 0km/h to 70 km/h ≥0.5m/s^2

3.4.2.3. Average braking deceleration

Under rated load on straight and dry track, with half-worn wheels, average deceleration from maximum vehicle operation speed of 70 km/h until stop is as below:

Maximum service brake deceleration: ≥1.1m/s^2

Emergency brake deceleration: ≥2.0m/s^2

Longitudinal vehicle jerk rate: ≤1.0 m/s^3

3.4.2.4. Fault operation and rescue capability

Within range of permissible adhesion, under seating capacity and working conditions, with loss of 1/4 power, vehicles should be able to complete a round trip as normal and return to depot.

With loss of 1/2 of traction power, empty vehicle should be able to continue the operation until it reaches deport in case of failure.

One empty vehicle should be able to bring another empty vehicle, stopping on a maximum slope (uphill) with failure, to depot.

3.4.2.5. Noise standard for AALRT

1）Indoor noise

Noise level at the center inside of a vehicle, measured where it is 1.5m above floor, with the vehicle operating at a speed of 52.5km/h on straight tracks: ≤75dB(A)

2）outdoor noise

Equivalent noise level outside the vehicle, measured where it is 7.5m from centerline of track and 1.5m from top of rail, when vehicle is running at 52.5km/h in open area above the ground along long seamless rails on gravel ballast through free sound field within horizontal and straight sections: ≤80dB(A)

Equivalent noise level outside the vehicle, measured where it is 7.5m from centerline of track and 1.5m from top of rail, when vehicle is parked on horizontal and straight line with gravel ballast in free sound field while auxiliary equipment is working normal: ≤69dB(A) (23)

3.4.3. Wear rate

Rail wear and the battering of rail ends are the two major defects in rails. Due to the passage of moving loads and friction between the wheel and the rail, the rail head gets worn-out in the course of service. The impact of moving loads, the effect of the forces of acceleration, deceleration, and breaking of wheels, the abrasion due to rail-wheel interaction, the effect of weather conditions such as changes in temperature, snow, and rains, the presence of materials such as sand, the standard of maintenance of the track, and such allied factors causes considerable wear and tear of vertical and lateral planes of the rail head. Lateral wear occurs more on curves because of the lateral thrust exerted on the outer rail by centrifugal force. A lot of the mental of the rail head gets worn out; causing the weight of the rail to decrease .this loss of weight of the rail section should not be such that the stresses exceed their permissible values.

The railway noise has been a serious problem not only on narrow gauge lines but also standard lines in Addis Ababa light rail transit. The rolling noise between wheel and rail becomes remarkable of the whole noise from a running train. It has been said that the roughness of both wheel and rail affects rolling noise. The methods to prevent the increase of roughness and to remove it are required. (24)

The rolling noise occurs by the collision between both roughness's of wheel and rail when wheels roll on rails. Therefore, it can be thought that the wavelength of roughness on wheel and rail relates with the frequency of rolling noise.

This paper also intended to relate the noise with wear rate, to do that, the wear rate of the line also measured as the noise done. According to wear rate measurement, the maximum wear rate which measured on Addis Ababa Light Rail Transit line is around 0.8mm (mostly at sharp curves) this is minimal when it is compared to the standard (i.e. 8mm wear rate is acceptable based on track condition).

The wear rate is measured by the abrasion measuring tape.

Figure 15: Wear measurement on site

3.4.4. Weather condition

Whether condition has a great effect on the transmission of sound so that the measurement had been performed by considering a clear weather condition. The followings are the Addis Ababa whether conditions while the measurement where taken.

- Altitude: ≤2500m
- Ambient temperature: 0℃～+29.7℃
- Average daily highest temperature in years: 25.5℃
- Average daily lowest temperature in years: 6.1℃
- Average relative humidity in years: 95%
- Normal pressure of Addis Ababa 101600 pas

In addition to the above conditions the measurement is taken at the day and night time in order to correlate the difference.

CHAPTER FOUR: RESULT, DISCUSSION AND REMEDIAL ACTION OVER THE ASSESSMENT

4.1. Result

4.1.1. Sound level meter measurement result

The measurements were taken to see the comfort of the passengers inside which is indoor noise measurement and the outdoor measurement.

4.1.1.1.Indoor noise measurement result

The measurement covers all station around 39 selected sites in each location and taking the average of each location. In addition to that inside the vehicle the measurements are taken at three different locations and taken the average that means at the two powered bogie and one none powered bogie.

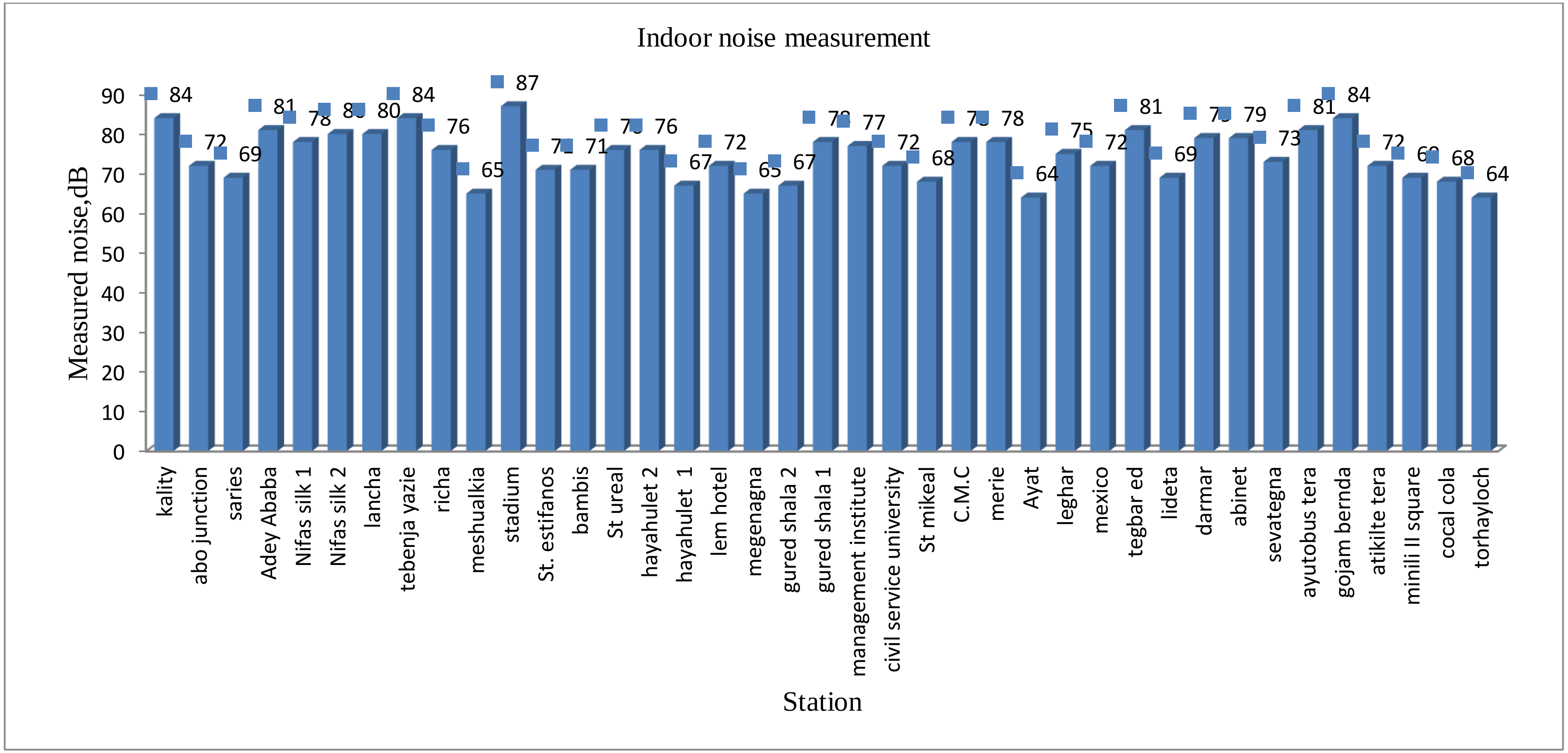


Figure 16: Indoor noise measurement noise value

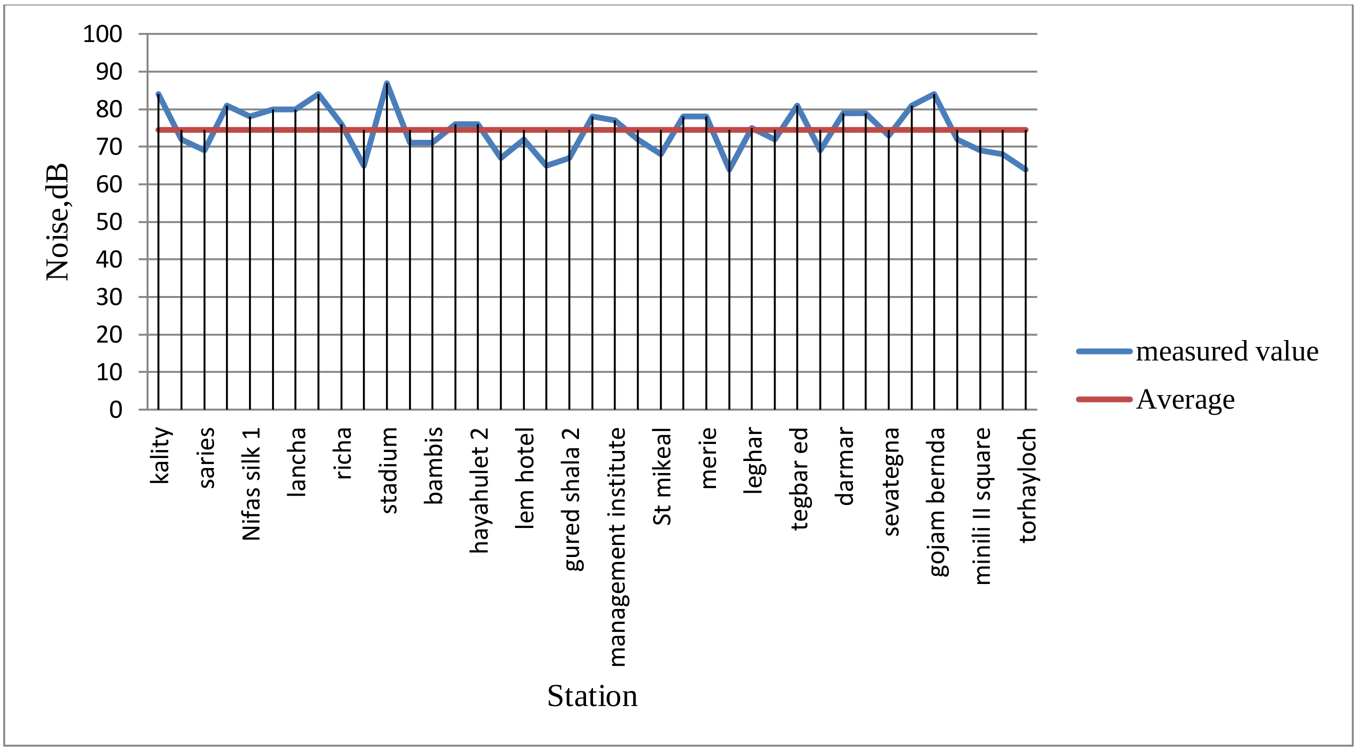


Figure 17: Comparison of each measured noise value at each station with the average

Average value, $\bar{x}=\frac{1}{N}\sum_{i=1}^{N} xi$ = **74.41025641 dB**

Max value which is the maximum reading **87 dB**

Min value which is the mean reading **64dB**

The standard deviation, $\sigma = \frac{1}{N-1}\sum_{i=1}^{N}(xi - \bar{x})^{2}$= **6.125683421** which shows that it debates **6.12** from the average

4.1.1.2. Outdoor noise measurement result

The measurement covers all the two lines which is the North-south lines covers around 17.4 Km and the East-west lines covers around 16.9 Km. In addition to that the outdoor noise measurement taken at three different vehicle types and taken the average of the three different vehicle types having the following specification.

Vehicle No	No of passengers per coach (including standing and seated)	No of coaches	Remark
Vehicle 1	300	2	

Vehicle 1	317	2	
Vehicle 1	341	1	

During the overall site measurement the above parameters are not keeping equally but somehow those are similar to the rest locations.

The day (1-12) sound level measurement value

Average value, $\bar{x}=\frac{1}{N}\sum_{i=1}^{N} xi$ = **84.18824 dB**

Max value which is the maximum reading **104 dB**

Min value which is the mean reading **74 dB**

The standard deviation, $\sigma = \frac{1}{N-1}\sum_{i=1}^{N}(xi-\bar{x})^{2}$= **5.866644** which shows that it debates **5.86** from the average

The night (13-24) sound level measurement value

Average value, $\bar{x}=\frac{1}{N}\sum_{i=1}^{N} xi$ = **57.18824**

Max value which is the maximum reading **77 dB**

Min value which is the mean reading **47 dB**

The standard deviation, $\sigma = \frac{1}{N-1}\sum_{i=1}^{N}(xi-\bar{x})^{2}$= **5.7** which shows that it debates **5.7** from the average

4.1.2. Questionnaire result

The 200 peoples' are covered by the Questionnaire in selected sites are grouped in Questionnaire type (No, Some, Much, Too much) results are correlated as follows.

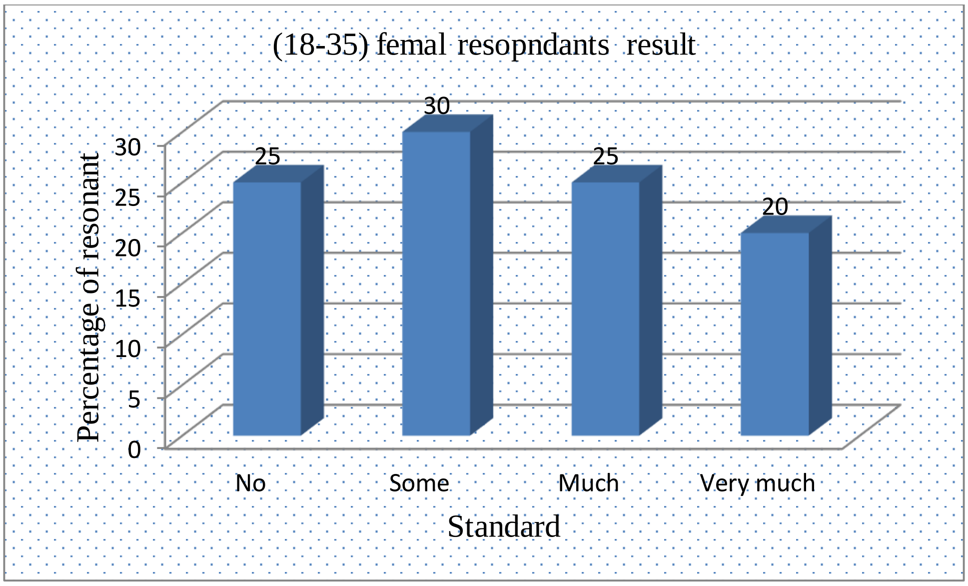


Figure 18: Percentage of female respondent in the range of age 18-35

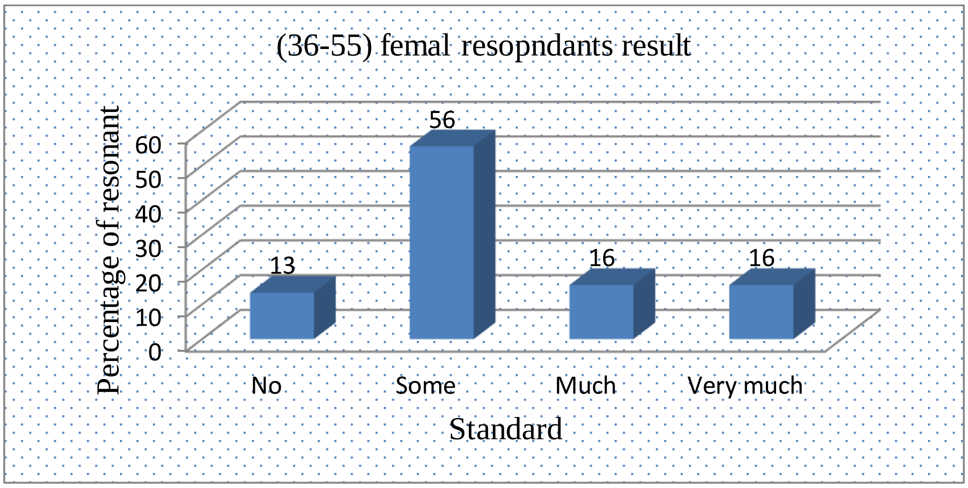


Figure 19: Percentage of female respondent in the range of age 35-55

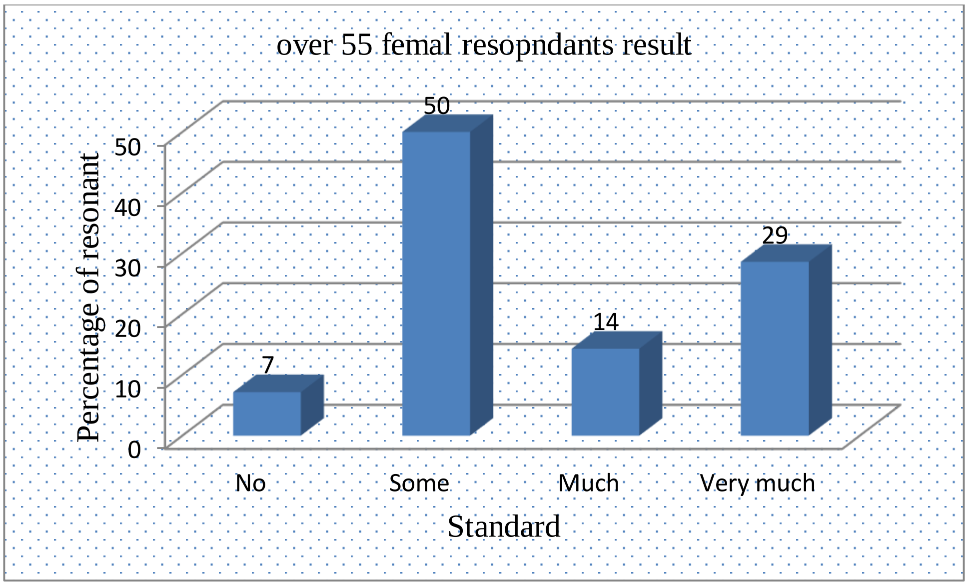


Figure 20: Percentage of female respondent in the range of age over 55

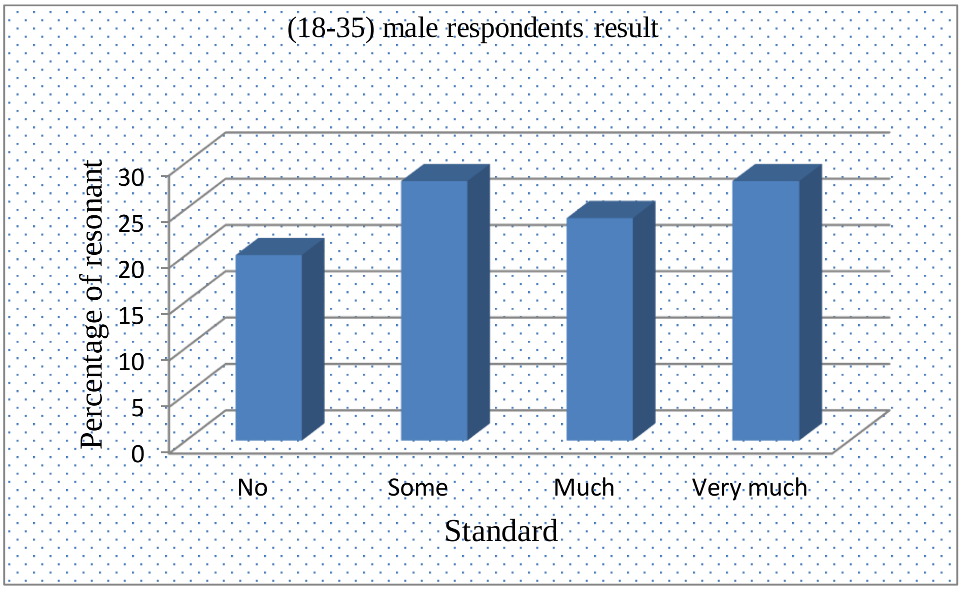


Figure 21: Percentage of male respondent in the range of age 18-35

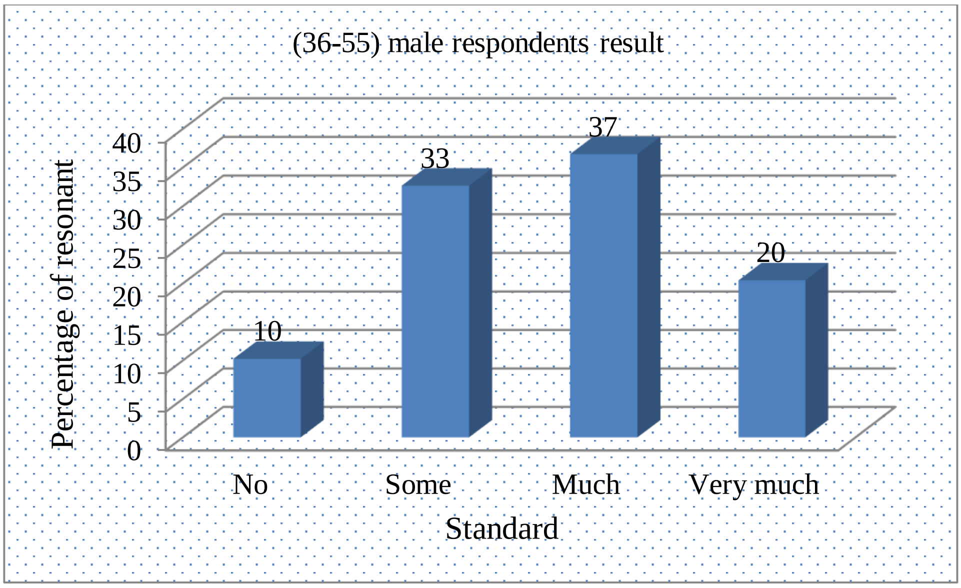


Figure 22: Percentage of male respondent in the range of age 35-55

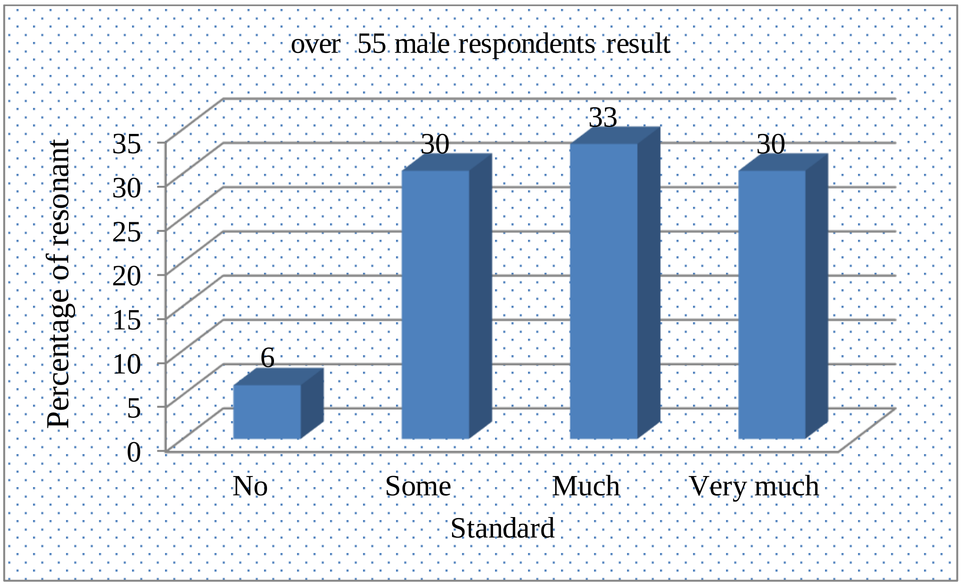


Figure 23: Percentage of male respondent in the range of age over 55

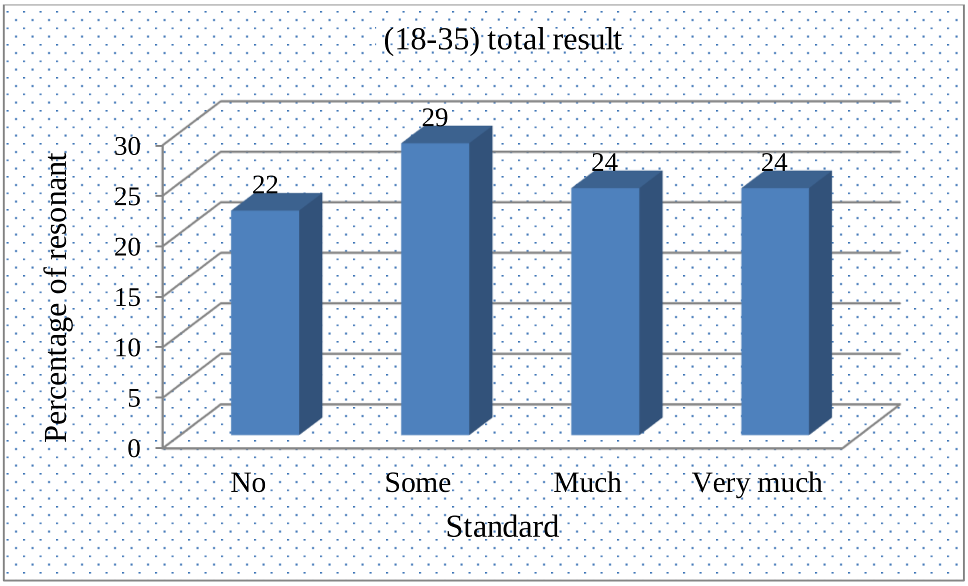


Figure 24: Percentage of total respondent in the range of age 18-35

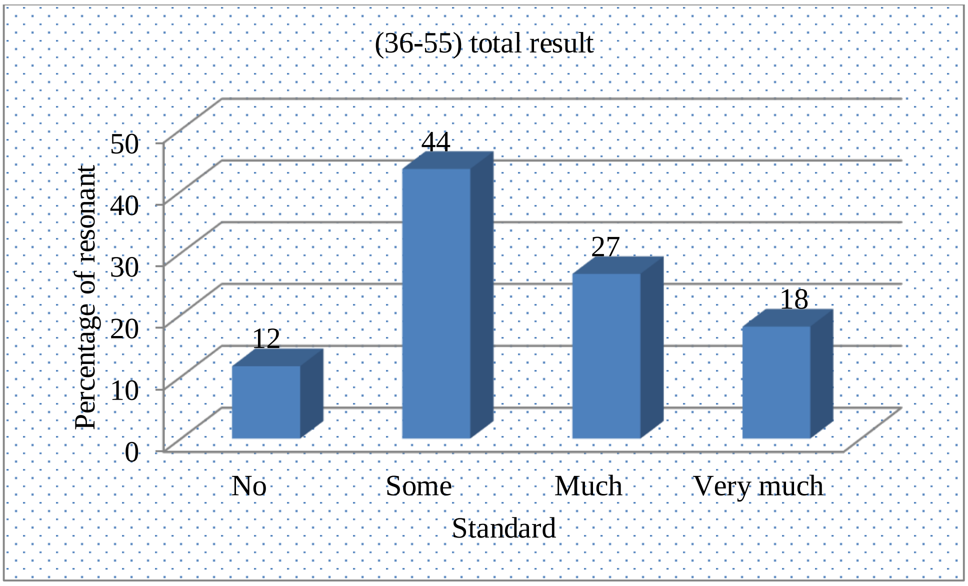


Figure 25: Percentage of total respondent in the range of age 35-55

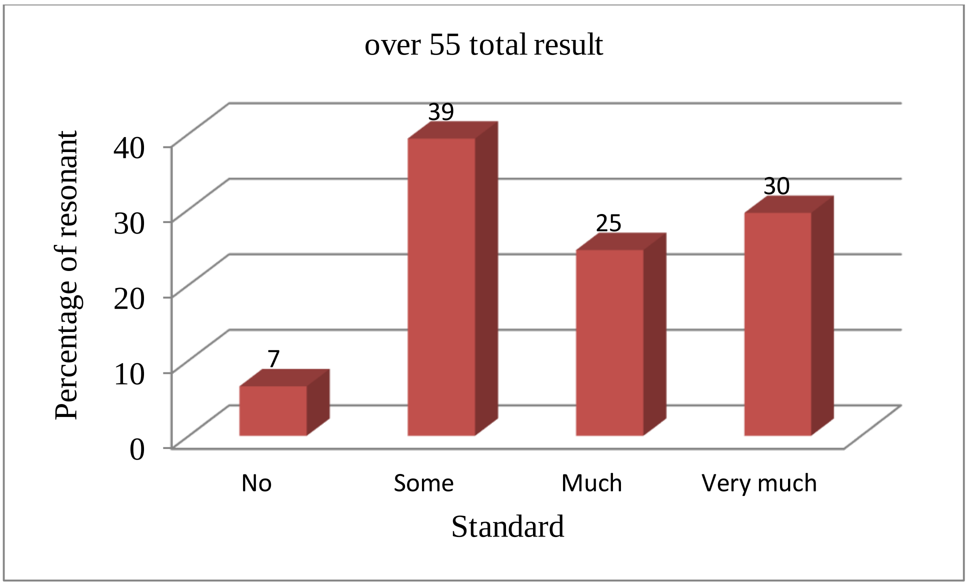


Figure 26: Percentage of total respondent in the range of age over 55

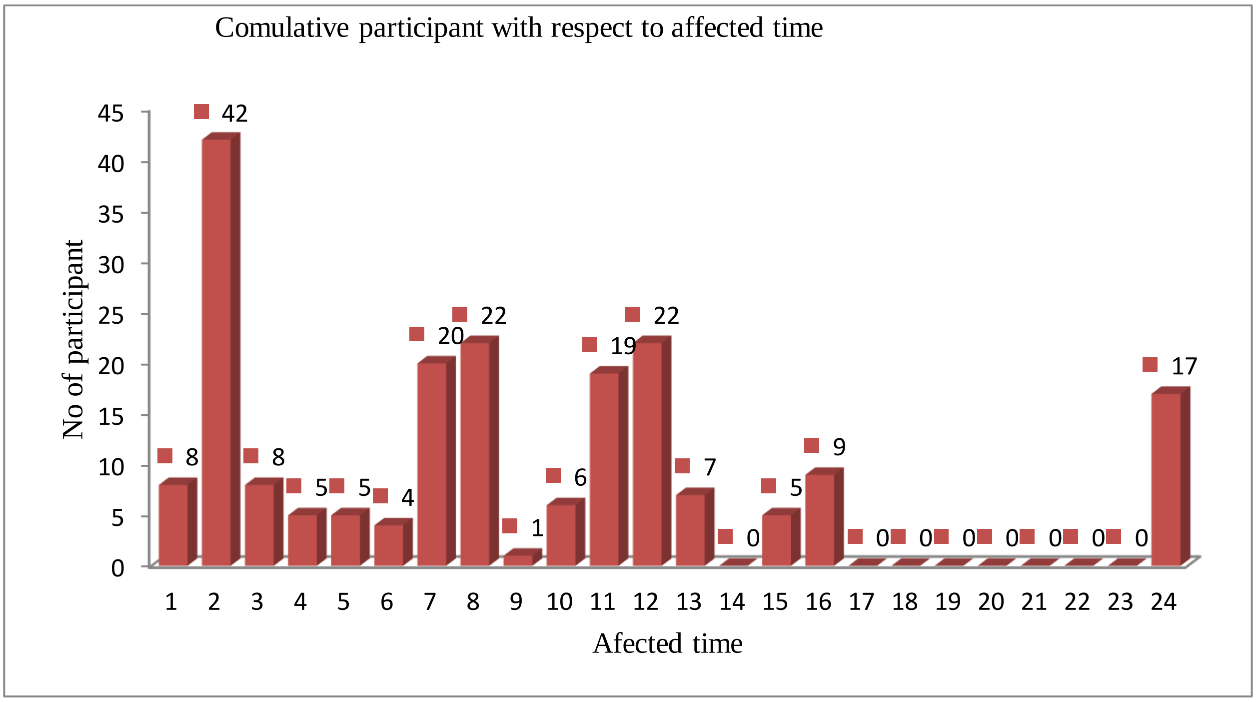


Figure 27: The cumulative total respondent in there time distribution within 24 hours

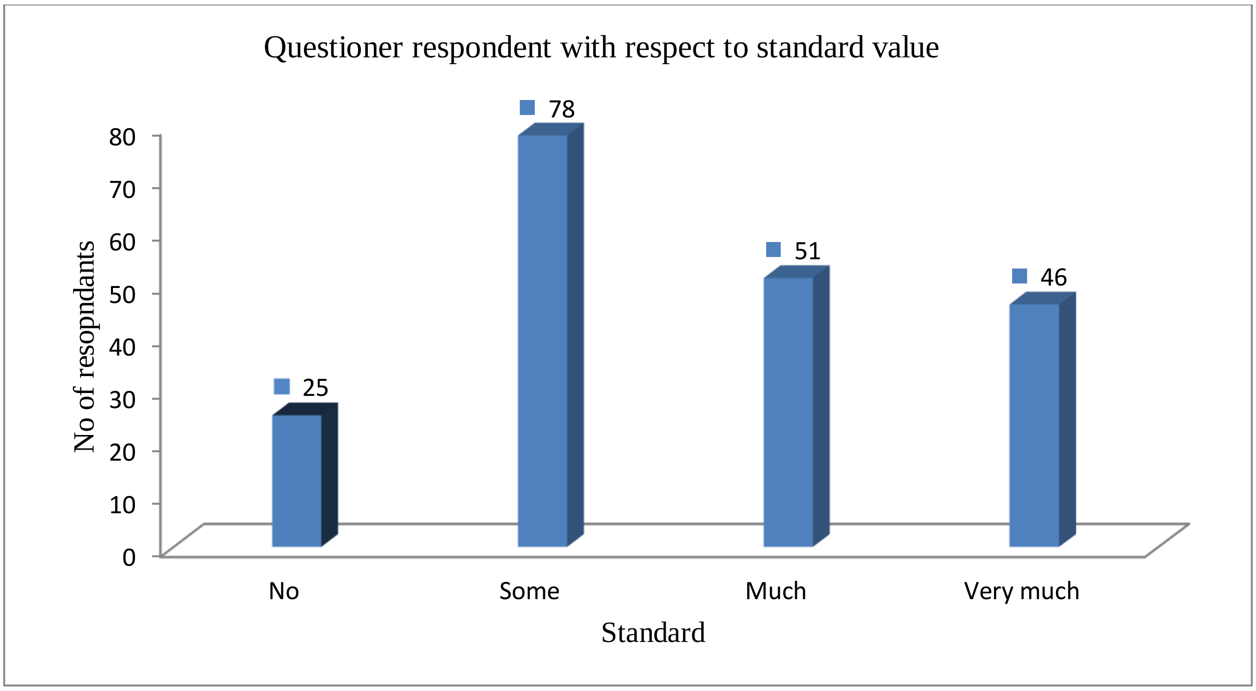


Figure 28: The total 200 respondents in there affected level distribution

Table 12: Sound level meter measurement and questionnaire result summery

No	Methodologies	Parameters	Value	Comparison 1 (feasibility study of Addis Ababa Light Rail Transit 80dB(A) for outdoor and 75dB(A) for indoor)	Comparison 2 (Ethiopian noise standard for commercial area,65dB(A) for day and 55dB(A) for night)
1.	Sound level meter measurement	Indoor noise	74.4dB(A)	Normal	Maximum
		Outdoor noise (day)	84.18dB(A)	Maximum	Maximum
		Outdoor noise (night)	57.18dB(A)	Normal	Normal (considering the instrument accuracy which is 2dB)

4.1.3. Wear rate vs. noise results

From the measured speed and measured noise value relation the following result is presented (this is done in collaboration with Addis Ababa Light Rail Transit maintenance division)

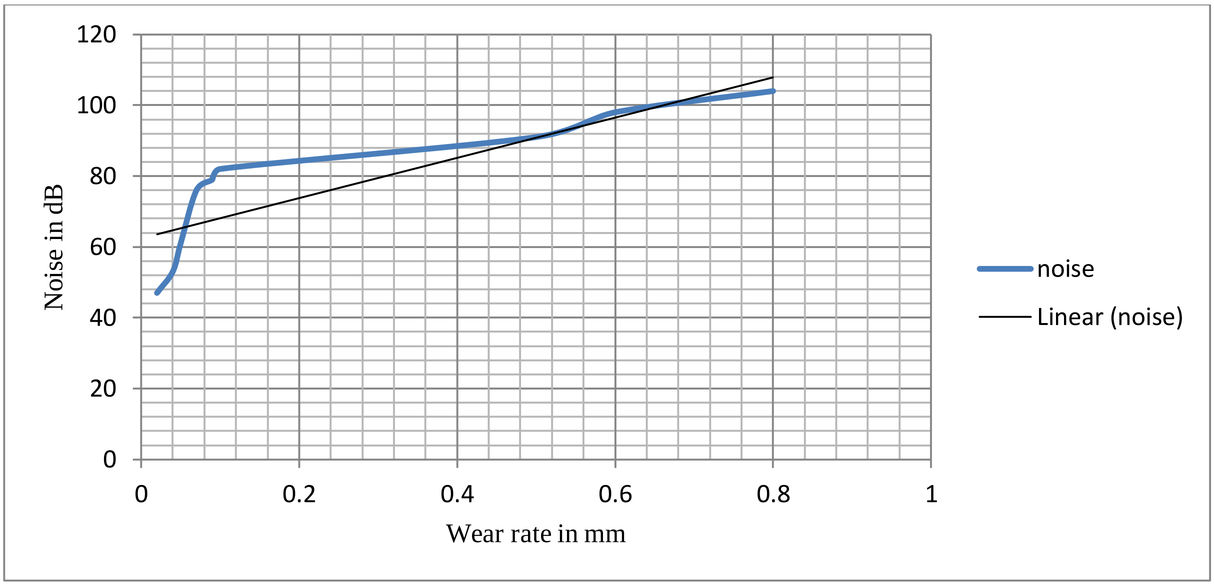


Figure 29: Noise vs. wear rate

4.1.4. Speed vs. Noise results

From the recorded speed and measured noise value relation the following result is presented

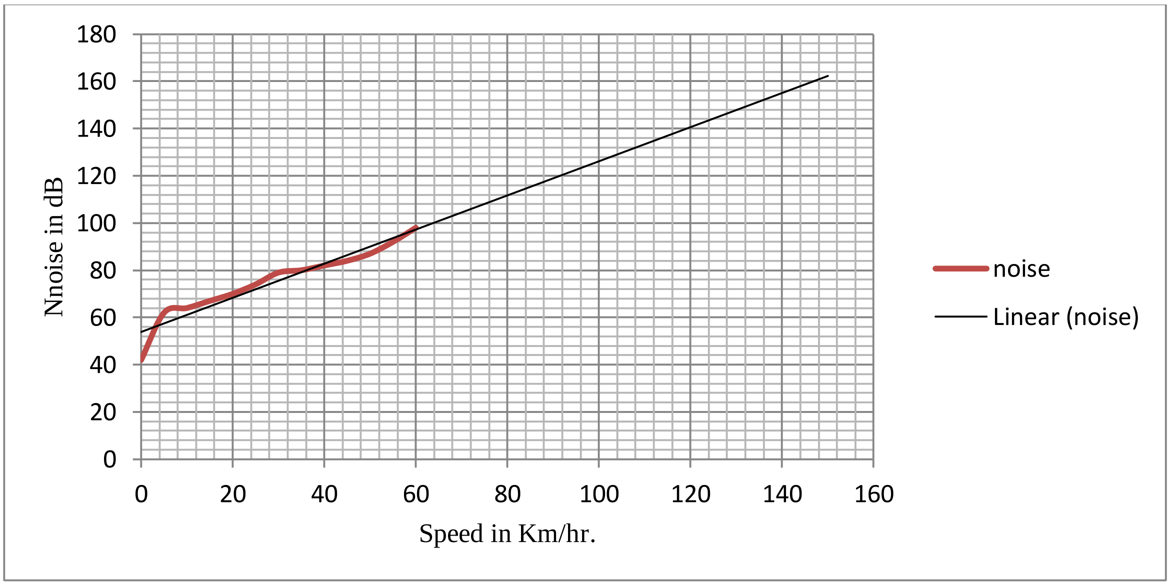


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Figure 30: Speed vs. Noise relation

4.1.5. Measured nose value for bolted and welded joint

From the recorded speed and measured bolted and welded joint noise value relation the following result is presented

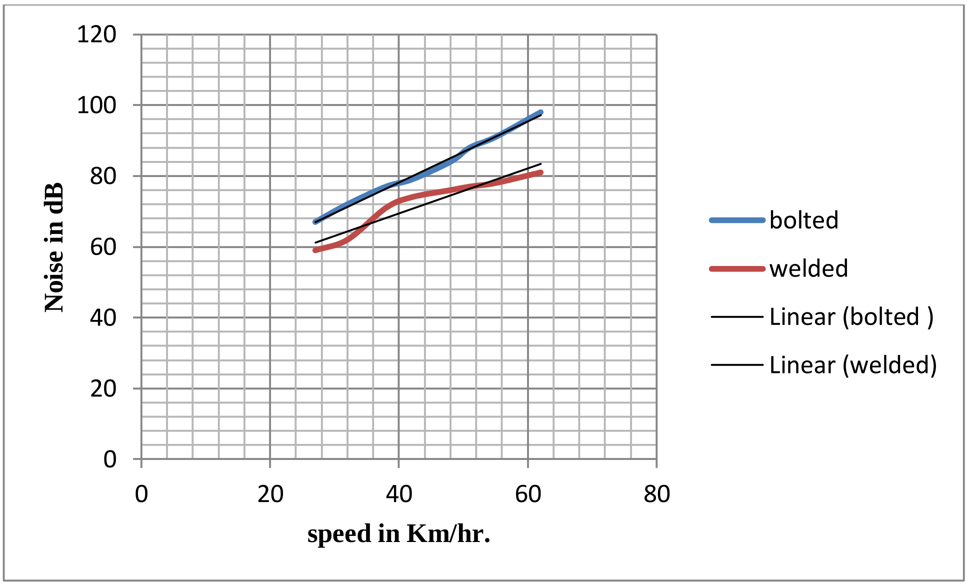

Figure 31: Speed vs noise

4.2. Discussion

From the above result, the maximum of indoor measurement is 87 dB (A); which is a reading around stadium because of the number of passengers when it is compared with the rest stations. The average indoor measurement is 74.4.dB (A), it is below the value on the feasibility study of Addis Ababa light rail transit, which is 75 dB (A). However, when comes to the Ethiopian national noise pollution standard, the result is way higher, the standard is 65 dB (A) (for commercial areas).

From the day outdoor measurement, the maximum value is 104 dB (A) which is a reading around tunnel (*Minlik II square*) because it is somehow enclosed area and there a minimal noise dissipation when it compared to the rest stations. The average outdoor measurement is 84.12 dB (A); it is above the value on the feasibility study of Addis Ababa light rail transit, which is 75 dB (A), however, it is larger than Ethiopian national noise pollution standard commercial area, 65 dB (A). The standard deviation is 5.86 dB (A).

From the night outdoor measurement the maximum value is 77 dB (A) which is a reading around tunnel (Minlik II square). The average outdoor measurement (night) is 57.18 dB (A) . The feasibility study of Addis Ababa Light Rail Transit in this regard is 75 dB (A), so it is in the range, and also below Ethiopian national noise pollution standard for commercial area. The standard deviation is 5.7 dB (A).

According to the questionnaire result, out of 200 respondents 25 of them answered as not affected by noise of light rail transit, 78 of them answered as some affected, 51 of them answered as much affected, and the rest 46 of them answered as too much affected. And also according to the affected time 38 of them are being affected at the night time and the rest 162 of 200 respondents answered as they are being affected at the day time.

From the female respondent over the age range of 18-35 25% answered as no affected, 30% answered as some affected, 25% answered as much affected and 20% answered very much affected. Over the age range of 36-55 13% answered as no affected, 56% answered as some affected, 16% answered as much affected, 16% answered very much affected. over the age range of above 55 7% answered as no affected, 50% answered as some affected, 14% answered as much affected, 29% answered very much affected.

From the male respondent over the age range of 18-35 20% answered as no affected, 28% answered as some affected, 24% answered as much affected and 28% answered very much affected. Over the age range of 36-55 10% answered as no affected, 33% answered as some affected, 37% answered as much affected, 20% answered very much affected. over the age range of above 55 6% answered as no affected, 30% answered as some affected, 33% answered as much affected, 30% answered very much affected.

From the total respondent over the age range of 18-35 22% answered as no affected, 29% answered as some affected, 24% answered as much affected and 24% answered very much affected. Over the age range of 36-55 12% answered as no affected, 44% answered as some affected, 27% answered as much affected, 18% answered very much affected. over the age range of above 55 7% answered as no affected, 39% answered as some affected, 25% answered as much affected, 30% answered very much affected.

From the wear perspective as the graph shows as the wear rate increase the resulting noise also increase.

Since speed is one factor of noise, from the noise vs. speed graph, it shows that as the speed of the train increase the noise also increases to some level. Again, as wear also another factor for noise, based on the graph, they have a direct relationship.

As it shows from result different sound level values were observed during measurement on the selected site track continuity disposition, i.e. welded and bolted. On the bolted joints the sound level is relatively higher than that the welded one.

4.3. Remedial action over the assessment

Based on the result around *stadium* station, *Lideta* station, *Ayat* station, *Autobus Tera* and *kality* station, the recorded noise results are greater when it compares with the Ethiopian commercial area noise standard. In order to protect the environment from noise pollution noise mitigation has to be done.

Since the fact that public health has been matter of great concern for us, control of noise pollution is necessary. The remedial measure for noise pollution can be broadly classified as follows:

- Controlling noise at the source: it is controlling noise at the time of construction and rout selection
- Controlling the transmission of noise: it is controlling the transmission of noise using noise barriers and dampers which is installed in web and foot part of the track
- Controlling noise at the receiver: is controlling the noise by using alterative design noise receiver.

Specifically for Addis Ababa Light Rail Transit the second method of mitigation, controlling the transmission of noise, is recommended because of so many reasons (like investment cost and situation). There are a lot of mechanisms to control the transmission of noise like using rail dampers, noise barriers, planting trees, etc. Among the above mechanisms, rail dampers and planting trees are around the line are economical and seems feasible for cities light rail like Addis Ababa as a remedial action. Essentially, using noise barriers is recommended to block severe noise level.

Rail damping is an emerging technology for mitigating airborne railway noise during the transmission. Rail dampers may be described as pre-formed or adjustable elements that are attached to the sides of the rails. These pre-formed elements improve the rail's ability to decay noise-inducing vibrations resulting from the rolling contact between the wheel and rail. The implementation of transmission controls such as rail dampers can potentially avoid or reduce the need to consider further mitigation options such as noise barriers and building treatments. The rail dampers can minimize the noise from 3 - 6 dB.

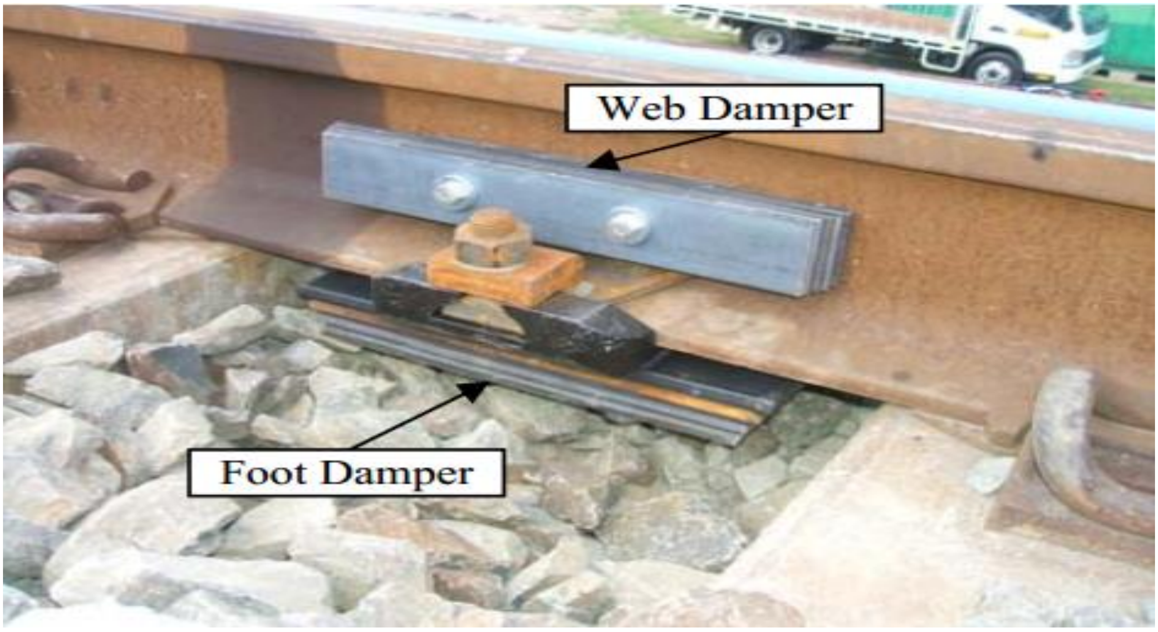

Figure 32: Rail dampers

The second remedial is using planting trees. Planting trees can minimize the transmission of noise by 5dB. (23) (19) (24)

CHAPTER FIVE : CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. Conclusion

The purpose of this paper is to assess the noise impact of Addis Ababa Light Rail Transit based on the measurement using the sound level meter and the questionnaire results. Addis Ababa transient rail transport is becoming one of the major modes of transportation in Addis Ababa, and on the other hand, it is a source of ambient noises which causes an uncomfortable environment for the people living around railway track. In order to ascertain the effect of Addis Ababa Light Rail Transit on the community and nearby infrastructures, detail analysis of noise impact has been performed.

Based on the data taken on site and questionnaires, the results are correlated as day time noise and night time noise with the Ethiopian noise standard, which are 65dB (A) for day time and 55dB (A) for night time. When the measured results are compared, the day time noise is 84.18dB (A) and it is above the range. The night time noise is 57.18dB (A) and it is normal (considering the instrument accuracy which is 2dB).

The analysis also includes questionnaires. Based on that the result, out of 200 respondents 25 of them answered as not affected by noise of light rail transit, 78 of them answered as some affected, 51 of them answered as much affected, and the rest 46 of them answered as too much affected. And also according to the affected time 38 of them are being affected at the night time and the rest 162 of 200 respondents answered as they are being affected at the day time. On the other hand, over the age range of 18-35 22% answered as no affected, 29% answered as some affected, 24% answered as much affected and 24% answered very much affected. Over the age range of 36-55 12% answered as no affected, 44% answered as some affected, 27% answered as much affected, 18% answered very much affected. over the age range of above 55 7% answered as no affected, 39% answered as some affected, 25% answered as much affected, 30% answered very much affected. From this result, as the age increases the noise sensitivity will also increases. The correlation on different scenarios reveal that the noise level of Addis Ababa Light Rail Transit is beyond the range on some aspects and within or on the margin on the others.

From the graphical relation between wear versus noise, and speed versus noise show a direct relationship.

These situations are explaining that the Addis Ababa Light Rail Transit noise pollution level is not that much severe. However, it is a sufficient remark which shows that this system needs somehow a suggested remedial action and prompts follows up in this regard.

5.2. Recommendation

This paper recommends the following to alleviate the impact of Addis Ababa Light Rail Transit noise:

- Since the measured value is maximum at the most sharp curves around *Stadium*, *Lideta*, *kalitie*, *Ayat* and inside the tunnel, therefore feasible controlling mechanism has to be used in order to preserve the community, i.e. using rail damper and planting trees.
- From the result, as the wear rate of the rail increases the noise increases. So that the wear has to be checked periodically for repair or replacement.
- Addis Ababa Light Rail Transit noise impact is not much severe, as a matter of fact, among the other, it is due to the limited speed (up to 60 km). But if the speed of the train would be high speed on this designed rail, the impact might have been severe. Therefore, it is recommended that the noise effect of the system has to be considered when high speed rail transits are planned to be constructed in the future.
- Maximum value of noise was recorded where the radius of curvature is minimum. Hence during design and/or construction railways, it is better to eliminate sharp curves as much as possible.
- Long welded rails significantly reduce the formation of noise. Therefore, it is recommended that using weld joint could reduce noise at possible locations and situations.

5.3. Future work

Doing an assessment of noise is not a one time job for a specific line; it has to be periodically analyzed. This paper is the first paper in the area of Addis Ababa light railway interaction with the environment and singled out the concerns, on which the government has to be alert in order to preserve the environment and human beings from the noise pollution.

Finally, in order to do more detailed analysis of the noise, some suggestions are listed below for future work as extension and continuity of this paper.

- As long as the noise is resulted from vibration, it is better to include vibration in the future noise study.
- Using the sound plan software package, draw the noise map of Addis Ababa light rail transit.
- Assess the noise using the digital recorder noise versus the frequency of the sound.
- Assess the noise effects of Addis Ababa Light Rail Transit using the software which helps to show only the effect of rail noise to the environment.

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APPENDIX

Appendix 1. Sample Questionnaire

General information

Age	
Gender	
Occupation	
Job location	
Resident location	
Date	

Annoyance type from rail way (thick appropriate cell)

	No	Some	Much	Too much
Noise				

In which time you are disturbed? (Thick appropriate cell)

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

Health problem in less than one year due to noise (thick appropriate cell)

Yes (specify the health problem)	
No	

Appendix 2. Measured noise values of the line (North South and East West) per 100 meter interval

NS SLM reading per 100m			EW SLM reading per 100m		
NO.	Area code	SLM reading	NO.	Area code	SLM reading
1	**NS1**	**104**	1	EW1	102
2	**NS2**	**102**	2	EW2	98
3	**NS3**	**99**	3	EW3	82
4	NS4	87	4	EW4	74
5	NS5	81	5	EW5	78
6	NS6	84	6	EW6	77
7	NS7	90	7	EW7	90
8	NS8	82	8	EW8	82
9	NS9	82	9	EW9	82
10	NS10	84	10	EW10	84
11	NS11	82	11	EW11	82
12	NS12	79	12	EW12	78
13	NS13	88	13	EW13	88
14	NS14	78	14	EW14	88
15	NS15	79	15	EW15	88
16	NS16	87	16	EW16	87
17	NS17	86	17	EW17	86
18	NS18	86	18	EW18	86
19	**NS19**	**99**	19	EW19	84
20	NS20	84	20	EW20	84
21	NS21	89	21	EW21	89
22	NS22	84	22	EW22	84
23	NS23	78	23	EW23	78
24	NS24	79	24	EW24	79
25	NS25	79	25	EW25	79
26	NS26	79	26	EW26	79
27	NS27	78	27	EW27	78
28	NS28	75	28	EW28	75
29	**NS29**	**98**	29	EW29	78
30	NS30	87	30	EW30	74
31	NS31	99	31	EW31	74
32	NS32	82	32	EW32	74
33	NS33	87	33	EW33	74
34	NS34	81	34	EW34	74
35	NS35	84	35	EW35	78
36	NS36	90	36	EW36	79
37	NS37	82	37	EW37	82
38	NS38	82	38	EW38	89
39	NS39	84	39	EW39	89
40	NS40	82	40	EW40	78

NS SLM reading per 100m			EW SLM reading per 100m		
NO.	Area code	SLM reading	NO.	Area code	SLM reading
41	NS41	78	41	EW41	86
42	NS42	88	42	EW42	86
43	NS43	78	43	EW43	86
44	NS44	79	44	EW44	79
45	NS45	87	45	EW45	89
46	NS46	86	46	EW46	89
47	NS47	86	47	EW47	89
48	NS48	84	48	EW48	87
49	NS49	84	49	EW49	89
50	NS50	89	50	EW50	88
51	NS51	84	51	EW51	89
52	NS52	78	52	EW52	89
53	NS53	79	53	EW53	87
54	NS54	79	54	EW54	89
55	NS55	79	55	EW55	89
56	NS56	78	56	EW56	88
57	NS57	75	57	EW57	88
58	NS58	78	58	EW58	87
59	NS59	87	59	EW59	87
60	**NS60**	**99**	60	EW60	87
61	NS61	82	61	EW61	87
62	NS62	87	62	EW62	89
63	NS63	81	63	EW63	98
64	NS64	84	64	EW64	98
65	NS65	90	65	EW65	96
66	NS66	82	66	EW66	92
67	NS67	82	67	EW67	92
68	NS68	84	68	EW68	91
69	NS69	82	69	EW69	89
70	NS70	78	70	EW70	89
71	NS71	88	71	EW71	87
72	NS72	78	72	EW72	98
73	NS73	79	73	EW73	97
74	NS74	87	74	EW74	82
75	NS75	86	75	EW75	74
76	NS76	86	76	EW76	78
77	NS77	84	77	EW77	78
78	NS78	84	78	EW78	90
79	NS79	89	79	EW79	82
80	NS80	84	80	EW80	82
81	NS81	78	81	EW81	84

NS SLM reading per 100m			EW SLM reading per 100m		
NO.	Area code	SLM reading	NO.	Area code	SLM reading
82	NS82	79	82	EW82	82
83	NS83	79	83	EW83	78
84	NS84	79	84	EW84	88
85	NS85	78	85	EW85	88
86	NS86	75	86	EW86	88
87	NS87	78	87	EW87	87
88	NS88	87	88	EW88	86
89	NS89	92	89	EW89	86
90	NS90	82	90	EW90	84
91	NS91	87	91	EW91	86
92	NS92	81	92	EW92	89
93	NS93	84	93	EW93	84
94	NS94	90	94	EW94	78
95	NS95	82	95	EW95	79
96	NS96	82	96	EW96	79
97	NS97	84	97	EW97	79
98	NS98	82	98	EW98	78
99	NS99	78	99	EW99	80
100	NS100	88	100	EW100	78
101	NS101	78	101	EW101	74
102	NS102	79	102	EW102	74
103	NS103	87	103	EW103	74
104	NS104	86	104	EW104	74
105	NS105	86	105	EW105	74
106	NS106	84	106	EW106	78
107	NS107	84	107	EW107	79
108	NS108	89	108	EW108	82
109	NS109	84	109	EW109	89
110	NS110	78	110	EW110	89
111	NS111	79	111	EW111	78
112	NS112	79	112	EW112	86
113	NS113	79	113	EW113	86
114	NS114	78	114	EW114	86
115	NS115	75	115	EW115	79
116	NS116	78	116	EW116	89
117	NS117	87	117	EW117	89
118	NS118	99	118	EW118	89
119	NS119	82	119	EW119	87
120	NS120	87	120	EW120	89
121	NS121	81	121	EW121	88
122	NS122	84	122	EW122	89

NS SLM reading per 100m			EW SLM reading per 100m		
NO.	Area code	SLM reading	NO.	Area code	SLM reading
123	NS123	90	123	EW123	89
124	NS124	82	124	EW124	87
125	NS125	82	125	EW125	89
126	NS126	84	126	EW126	89
127	NS127	82	127	EW127	88
128	NS128	78	128	EW128	88
129	NS129	88	129	EW129	87
130	NS130	78	130	EW130	87
131	NS131	79	131	EW131	87
132	NS132	87	132	EW132	87
133	NS133	86	133	EW133	89
134	NS134	86	134	EW134	98
135	NS135	84	135	EW135	98
136	NS136	84	136	EW136	96
137	NS137	89	137	EW137	92
138	NS138	84	138	EW138	92
139	NS139	78	139	EW139	91
140	NS140	79	140	EW140	89
141	NS141	79	141	EW141	89
142	NS142	79	142	EW142	87
143	NS143	78	143	EW143	98
144	NS144	75	144	EW144	92
145	NS145	78	145	EW145	82
146	NS146	74	146	EW146	74
147	NS147	78	147	EW147	78
148	NS148	77	148	EW148	77
149	NS149	90	149	EW149	90
150	NS150	82	150	EW150	82
151	NS151	82	151	EW151	82
152	NS152	84	152	EW152	84
153	NS153	82	153	EW153	82
154	NS154	78	154	EW154	78
155	NS155	88	155	EW155	88
156	NS156	89	156	EW156	89
157	NS157	88	157	EW157	88
158	NS158	87	158	EW158	87
159	NS159	90	159	EW159	90
160	NS160	86	160	EW160	86
161	NS161	84	161	EW161	84
162	NS162	84	162	EW162	84
163	NS163	89	163	EW163	89

NS SLM reading per 100m			EW SLM reading per 100m		
NO.	Area code	SLM reading	NO.	Area code	SLM reading
164	NS164	84	164	EW164	84
165	NS165	78	165	EW165	78
166	NS166	79	166	EW166	79
167	NS167	80	167	EW167	80
168	NS168	79	168	EW168	79
169	NS169	81	169	EW169	81
170	**NS170**	**97**	170	EW170	75

Appendix 3. East west curves and their parameters

CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPERR ELEVATI ON	CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPER RELEV ATION
ZJD1	5+260.543	5+339.913	79.37	**65**	30	YJD1	5+254.845	5+339.166	84.321	**70**	30
ZJD2	5+378.696	5+481.727	103.031	450	50	YJD2	5+378.988	5+482.886	103.898	455	50
ZJD3	5+652.031	5+926.5	274.469	**190**	120	YJD3	5+659.246	5+923.125	263.879	**194**	100
ZJD4	6+003.957	6+239.37	235.413	240	120	YJD4	5+997.05	6+249.54	252.49	236	120
ZJD5	6+752.288	6+845.805	93.517	2504	0	YJD5	6+752.438	6+845.806	93.368	2500	0
ZJD6	7+829.135	8+043.597	214.462	600	120	YJD6	7+846.665	8+026.99	180.325	604	100
ZJD7	8+304.553	8+454.19	149.637	**200**	0	YJD7	8+312.68	8+444.11	131.43	**204**	0
ZJD8	8+474.521	8+600.02	125.499	**204**	0	YJD8	8+459.923	8+610.706	150.783	**200**	0
ZJD9	8+762.119	8+782.901	20.782	5004	0	YJD9	8+760.207	8+780.973	20.766	5000	0
ZJD10	8+862.279	8+923.725	61.446	2004	0	YJD10	8+860.35	8+921.673	61.323	2000	0
ZJD11	8+985.862	9+042.93	57.068	2000	0	YJD11	8+985.796	9+042.978	57.182	2004	0
ZJD12	9+132.706	9+239.884	107.178	1300	50	YJD12	9+139.086	9+246.517	107.431	1304	50
ZJD13	9+263.225	9+390.255	127.03	254	80	YJD13	9+263.024	9+403.684	140.66	250	80
ZJD14	9+947.631	10+088.141	140.51	1000	60	YJD14	9+962.306	10+073.138	110.832	1004	60
ZJD15	10+203.714	10+272.894	69.18	500	40	YJD15	10+175.104	10+293.956	118.852	700	80
ZJD16	10+289.361	10+407.661	118.3	700	80	YJD16	10+310.314	10+379.099	68.785	500	40

CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPERR ELEVATI ON	CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPER RELEV ATION
ZJD17	10+888.321	11+018.903	130.582	1400	30	YJD17	10+885.561	11+016.474	130.913	1404	30
ZJD18	11+035.408	11+298.841	263.433	350	120	YJD18	11+049.086	11+269.442	220.356	354	120
ZJD19	11+364.395	11+444.696	80.301	1200	0	YJD19	11+302.757	11+378.934	76.177	1200	0
ZJD20	11+460.797	11+541.228	80.431	1200	50	YJD20	12+031.509	12+241.873	210.364	800	80
ZJD21	12+046.597	12+227.663	181.066	804	80	YJD21	12+328.45	12+478.433	149.983	1300	0
ZJD22	12+328.249	12+478.616	150.367	1304	0	YJD22	12+505.374	12+553.044	47.67	2004	0
ZJD23	12+505.559	12+553.134	47.575	2000	0	YJD23	12+806.951	12+867.595	60.644	2500	0
ZJD24	12+807.04	12+867.781	60.741	2504	0	YJD24	13+037.356	13+067.416	30.06	2504	0
ZJD25	13+037.404	13+067.416	30.012	2500	0	YJD25	13+495.101	13+627.212	132.111	1304	50
ZJD26	13+495.101	13+626.884	131.783	1300	50	YJD26	13+738.847	13+788.366	49.519	2504	0
ZJD27	13+738.926	13+788.366	49.44	2500	0	YJD27	13+967.249	13+989.383	22.134	3000	0
ZJD28	13+967.249	13+989.412	22.163	3004	0	YJD28	14+096.815	14+256.695	159.88	1300	50
ZJD29	14+096.844	14+257.139	160.295	1304	0	YJD29	14+317.138	14+417.645	100.507	1500	40
ZJD30	14+316.91	14+410.589	93.679	1000	60	YJD30	14+433.79	14+517.593	83.803	2000	0
ZJD31	14+424.33	14+558.014	133.684	500	90	YJD31	14+535.163	14+600.165	65.002	2000	0
ZJD32	14+573.257	14+657.669	84.412	1000	0	YJD32	14+707.965	14+767.549	59.584	1500	40
ZJD33	14+707.989	14+767.573	59.584	1500	40	YJD33	14+790.203	14+849.787	59.584	1500	40
ZJD34	14+790.203	14+849.787	59.584	1500	40	YJD34	15+097.244	15+380.79	283.546	550	110

CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPERR ELEVATI ON	CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPER RELEV ATION
ZJD35	15+114.805	15+364.758	249.953	554	110	YJD35	15+540.282	15+691.385	151.103	1004	60
ZJD36	15+525.276	15+705.896	180.62	1000	60	YJD36	16+153.554	16+342.69	189.136	1320	50
ZJD37	16+153.554	16+343.188	189.634	1324	50	YJD37	16+578.561	17+085.632	507.071	814	70
ZJD38	16+563.512	17+098.288	534.776	810	70	YJD38	17+658.017	17+947.319	289.302	466	120
ZJD39	17+671.229	17+932.241	261.012	470	120	YJD39	18+835.634	18+860.897	25.263	3004	0
ZJD40	18+835.634	18+860.864	25.23	3000	0	YJD40	19+205.391	19+282.315	76.924	3000	0
ZJD41	19+205.391	19+282.418	77.027	3004	0	YJD41	19+659.416	19+690.976	31.56	3004	0
ZJD42	19+659.519	19+691.037	31.518	3000	0	YJD42	20+825.384	21+081.742	256.358	1904	40
ZJD43	20+825.814	21+081.676	255.862	1900	0	YJD43	21+395.528	21+574.736	179.208	2500	0
ZJD44	21+395.462	21+574.947	179.485	2504	0	YJD44	21+712.005	21+855.508	143.503	2504	0
ZJD45	21+712.234	21+855.507	143.273	2500	0						

Appendix 4. North West curves and their parameters

CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPERR ELEVATI ON	CURVE NAME	CURVE STARTING MILAGE	CURVE ENDING MILAGE	CURVE LENGTH	CURVE RADIUS	SUPER RELEV ATION
ZJD2	1+662.599	1+787.949	125.35	1400	40	YJD2	1+661.755	1+787.443	125.688	1405	40
ZJD3	1+885.812	1+984.273	98.461	300	0	YJD3	1+885.307	1+985.02	99.713	305	0
ZJD4	2+010.207	2+139.37	129.163	**70**	50	YJD4	2+000.729	2+142.095	141.366	**65**	80
ZJD5	2+154.415	2+372.798	218.383	300	120	YJD5	2+159.398	2+355.004	195.606	305	120
ZJD6	2+391.893	2+552.414	160.521	404	120	YJD6	2+379.522	2+558.048	178.526	400	120
ZJD7	2+598.425	2+722.256	123.831	804	0	YJD7	2+598.731	2+722.046	123.315	800	0
ZJD8	2+851.263	2+984.333	133.07	2000	0	YJD8	2+851.053	2+984.389	133.336	2004	0
ZJD9	2+320.091	3+544.619	1224.528	404	120	YJD9	3+305.063	3+557.962	252.899	400	120
ZJD10	3+680.443	3+884.024	203.581	300	120	YJD10	3+693.027	3+873.188	180.161	304	120
ZJD11	4+026.364	4+137.575	111.211	1300	50	YJD11	4+026.099	4+137.575	111.476	1304	50
ZJD12	4+250.778	4+367.071	116.293	**50**	80	YJD12	4+258.053	4+366.976	108.923	**55**	40
ZJD13	4+776.372	4+881.827	105.455	2000	0	YJD13	4+776.161	4+881.827	105.666	2004	0
ZJD14	4+898.839	5+079.745	180.906	1304	50	YJD14	4+898.839	5+079.267	180.428	1300	50
ZJD15	5+100.624	5+208.708	108.084	2000	0	YJD15	5+100.146	5+208.446	108.3	2004	0
ZJD16	5+275.891	5+583.072	307.181	1204	50	YJD16	5+264.336	5+595.58	331.244	1200	50

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ZJD17	5+798.028	5+971.193	173.165	**100**	110	YJD17	5+805.23	5+969.303	164.073	**105**	80
ZJD18	6+013.904	6+180.238	166.334	**105**	80	YJD18	6+012.02	6+187.338	175.318	**100**	110
ZJD19	6+734.529	6+755.806	21.277	2000	0	YJD19	6+726.744	6+748.021	21.277	2000	0
ZJD20	6+772.128	6+793.405	21.277	2000	0	YJD20	6+764.343	6+785.62	21.277	2000	0
ZJD21	6+810.653	6+905.155	94.502	**50**	40	YJD21	6+802.89	6+901.073	98.183	**55**	40
ZJD22	6+946.631	6+967.194	20.563	300	0						
						YJD30	9+533.698	9+553.519	19.821	300	0
ZJD31	9+599.367	9+696.561	97.194	**55**	40	YJD31	9+595.426	9+688.906	93.48	**50**	40
ZJD32	9+714.106	9+735.383	21.277	2000	0	YJD32	9+706.267	9+727.544	21.277	2000	0
ZJD33	9+751.706	9+772.983	21.277	2000	0	YJD33	9+743.866	9+765.143	21.277	2000	0
ZJD34	9+783.886	9+950.583	166.697	1300	50	YJD34	9+783.435	9+950.568	167.133	1304	50
ZJD35	+966.824	10+045.628	9078.804	1000	60	YJD35	9+971.608	10+052.052	80.444	1000	60
ZJD36	10+061.165	10+170.218	109.053	650	0	YJD36	10+068.253	10+178.999	110.746	650	0
ZJD37	10+185.729	10+260.469	74.74	1000	50	YJD37	10+194.5	10+275.203	80.703	1000	60
ZJD38	10+911.782	11+131.77	219.988	286	120	YJD38	10+922.721	11+124.667	201.946	290	120
ZJD39	11+158.095	11+302.928	144.833	350	120	YJD39	11+159.793	11+304.636	144.843	350	120
ZJD40	11+402.223	11+623.159	220.936	294	0	YJD40	11+393.045	11+631.791	238.746	290	0
ZJD41	11+718.809	11+913.973	195.164	236	120	YJD41	11+726.734	11+903.85	177.116	240	120

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ZJD42	11+980.881	12+167.071	186.19	1300	0	YJD42	11+981.669	12+168.355	186.686	1304	0
ZJD43	12+225.381	12+317.088	91.707	1000	60	YJD43	12+225.989	12+317.696	91.707	1000	60
ZJD44	12+342.592	12+467.643	125.051	**204**	80	YJD44	12+333.479	12+476.862	143.383	**200**	120
ZJD45	12+610.775	12+790.051	179.276	504	120	YJD45	12+594.638	12+802.967	208.329	500	120
ZJD46	12+816.503	12+973.918	157.415	1000	60	YJD46	12+829.388	12+957.193	127.805	1004	60
ZJD47	13+097.281	13+368.026	270.745	350	120	YJD47	13+106.416	13+359.341	252.925	354	120
ZJD48	13+467.861	13+553.657	85.796	350	60	YJD48	13+468.632	13+555.066	86.434	354	60
ZJD49	13+569.869	13+676.076	106.207	304	70	YJD49	13+571.263	13+676.534	105.271	300	75
ZJD50	13+732.604	13+775.914	43.31	2000	0	YJD50	13+732.604	13+776.001	43.397	2004	0
ZJD51	14+136.76	14+315.869	179.109	460	120	YJD51	14+150.457	14+303.102	152.645	430	120
ZJD52	14+401.47	14+578.221	176.751	354	120	YJD52	14+389.809	14+590.24	200.431	350	120
ZJD53	15+535.078	15+694.973	159.895	410	120	YJD53	15+521.955	15+709.159	187.204	440	120
ZJD54	16+333.318	16+533.747	200.429	230	0	YJD54	16+343.394	16+525.918	182.524	234	0
ZJD55	17+237.494	17+459.928	222.434	**150**	80	YJD55	17+227.12	17+464.689	237.569	**146**	120
ZJD56	17+898.577	18+155.513	256.936	**146**	0	YJD56	17+900.409	18+147.877	247.468	**150**	0