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Noise impact assessment of mass rapid transit systems in Delhi city

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Noise and vibration assessments are key elements of the environmental impact assessment studies of mass transit projects. Although the technological innovations associated with operation of mass rapid transit systems (MRTS) play a vital role in improving transport facility in Delhi city, yet to gain complete acceptability among the commuters, their operation should not cause additional noise and vibration problems in immediate vicinity. The present work reviews the international noise standards proposed for transit trains noise and investigates the noise impact assessment of elevated metro rail corridor in Delhi city. The cumulative accentuated ambient noise levels due to operation of elevated metro trains in areas based on their traffic density is analyzed.

Keywords: Metro train, Noise impact, Federal transit Administration

1 Introduction

Environmental noise is recognized as a major health problem. The adverse effects of transportation noise are well documented. In a large number of community attitudinal surveys, transportation noise has been ranked among the most significant causes of community dissatisfaction. Environmental impacts from such mass transit projects is a must and all possible measures for mitigation have to be explored and implemented. Thus, spatial modeling of environmental impact assessment is an indispensable tool for acousticians to quantify the impact and correlate with annoyance caused to residential community. Walters[1] studies on annoyance from rail traffic noise in residential areas had shown that although the rail traffic is less disturbing than road traffic noise, yet there has to be some guidelines formulated for assessing the noise impact of new projects and investigations on community response in immediate vicinity of these mass transit projects so that noise mitigation measures can be applied in the early stages of planning and design. A-weighted L_{Aeq} is considered to be most suitable for predicting general annoyance and most of disturbance reactions observed. The American National Standards Institute[2] and the U.S. National Research Council recommend Day-night average sound level (L_{dn}) for assessment of environmental noise as do most federal agencies and administrations. The relationship between the day-night noise level L_{dn} and percentage of highly annoyed people due to it was initiated by Schultz as shown in Fig. 1. The Schultz curve has been updated[3] and separate relationships are given for aircraft, road and electric rail have been proposed by Miedema [4] according to which, the % highly annoyed is calculated as:

$$\% \text{ HA} = 9.994\times10^{-4}(L_{dn}-42)^3-1.523\times10^{-2}(L_{dn}-42)^2 + 0.538\,(L_{dn}-42) \text{ for road traffic} \quad \ldots(1)$$

$$\% \text{ HA} = 7.158\times10^{-4}(L_{dn}-42)^3-7.774\times10^{-2}(L_{dn}-42)^2 + 0.163\,(L_{dn}-42) \text{ for railways} \quad \ldots(2)$$

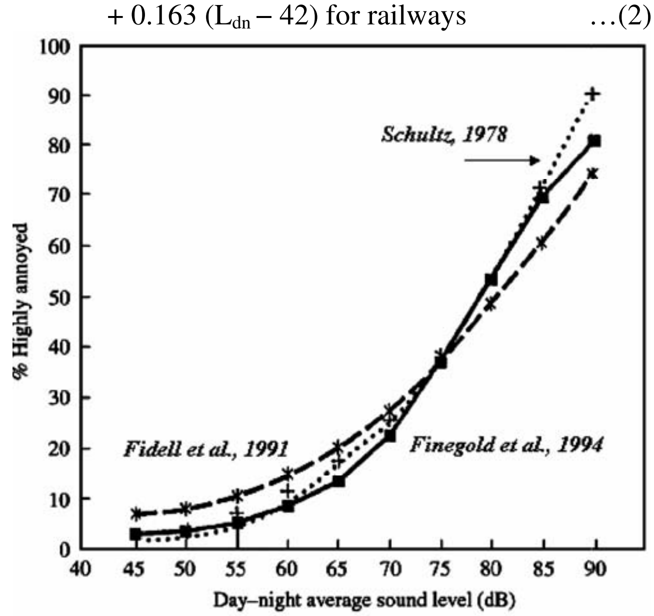

Fig. 1 — Community annoyance due to noise [3]

$$\%HA = -1.395\times10^{-4}(L_{dn}-42)^3 - 4.081\times10^{-2}(L_{dn}-42)^2 + 0.342\,(L_{dn}-42) \text{ for aircraft} \quad \ldots(3)$$

The distribution of the degree of annoyance is shown in Table 1 recommended by position paper of EU according to which, the percentage of persons annoyed [%A], or the percentage of persons highly annoyed [%HA] be used as the descriptor of noise annoyance in a population and relationships for aircraft, road traffic and railways noise are presented in terms of L_{dn}[5]. It can be observed that an L_{dn} of 65 dB [6] is the onset of a normally unacceptable noise zone. Thus, with an alarming increase in vehicular population on roads, noise impact investigations of mass transit projects in integration with a GIS methodology[7] is a necessity for feasibility study and noise abatement procedures to be adopted in future.

The present work analyzes the increase in noise levels due to the elevated metro rail corridor in various places in Delhi city. The assessment of sound exposure level is based on following criteria: (i) long term measurements (for 24 hours) at some representative locations in both exposed and shielded areas, and (ii) short term measurements for 1-hour in a number of complementary positions. The measurements are done with a calibrated precision Sound Level Analyzer Norsonic, Nor 118.

2 Noise Impact Criteria - a literature survey

The Federal transit Administration (FTA), US in 1995 published impact assessment procedures to be used for mass transit projects[8]. These criteria are based upon comparison of the existing outdoor ambient noise to future outdoor sound levels from the proposed project. The noise impact criteria (Fig. 2) are defined by two curves, which allow increasing project noise levels as ambient noise increases up to a point beyond which the impact is determined based on the project noise alone. The land use category 1 relates to areas where quiet is an essential element in their intended purpose and outdoor L_{eq} metric is used. The category 2 relates to residences and buildings where people normally sleep and outdoor L_{dn} metric is prescribed. Category 3 includes institutional land uses with primarily daytime and evening use outdoor L_{eq} metric is used. While no increase in noise is allowed in areas with the existing ambient noise of 75 dB(A) [L_{dn}], an exposure increase of 7 dB(A) is allowed where the ambient noise is currently 45 dB(A) [L_{dn}]. As the existing level of ambient noise increases, the allowable level of transit noise increases, but the total amount that community noise exposure is allowed to increase is reduced.

The criterion for moderate impact allows a noise exposure increase of 10 dB(A) if the existing noise exposure is 42 dB(A) or less but only a 1 dB(A) increase when the existing noise exposure is 70 dB(A) as is evident from Fig. 3.

Table 1 — % A (Annoyed) and % HA (Highly Annoyed) at various noise exposure levels (L_{dn}) for aircraft, road traffic, and rail traffic[5]

L_{dn}	Aircraft		Road traffic		Rail traffic	
	%A	% HA	% A	% HA	% A	% HA
45	11	1	6	1	3	0
50	19	5	11	4	5	1
55	28	10	18	6	10	2
60	38	17	26	10	15	5
65	48	26	35	16	23	9
70	60	37	47	25	34	14
75	73	49	61	37	47	23

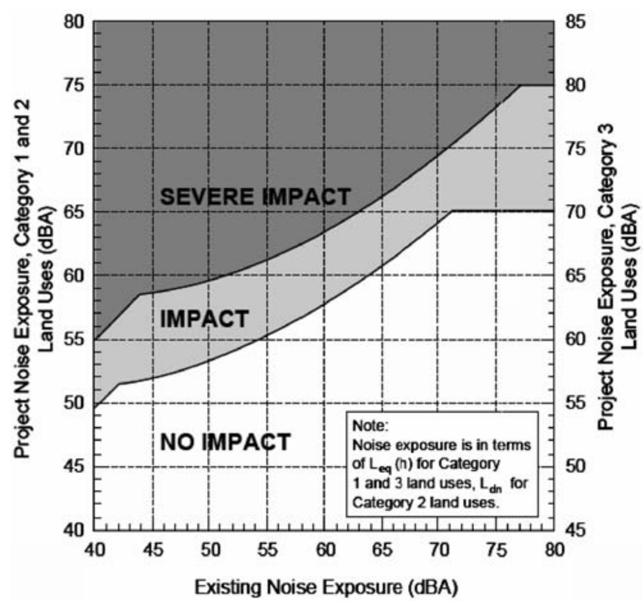

Fig. 2 — Noise Impact criteria [8]

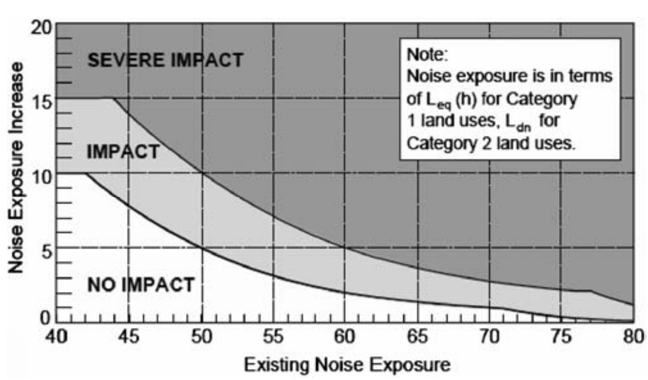

Fig. 3 — Increase in cumulative noise levels allowed by criteria [8]

American Public Transit Association (APTA)[9] proposed noise guidelines based upon the maximum A-weighted sound level (LA_{max}) of a single vehicle pass-by. Table 2 shows the maximum pass by noise level of train operations for distances less than 15 m. The World Health Organization[10] recommended a 16-hour daytime L_{eq} of 55 dB and, approximately, a 45 dB nighttime L_{eq} to prevent "serious annoyance." The Department of Housing and Urban Development term DNL levels from 65 dB to 75 dB as "normally unacceptable" and DNL levels from 60 to 65 dB as "normally acceptable."

All international agencies have cognizance over use of DNL criterion value of 55 dB as the threshold for defining noise impact in urban residential areas. The concern of incremental noise levels in a particular area for the onset of annoyance due to a new project activity is discussed in UK 'Design Manual for Roads and Bridges' (DMRB) as shown in Table 3 according to which if the change is more than 10 dB(A), annoyance is considerable.

Table 4 shows the various railway noise impact criteria followed by different European nations. Specific maximum noise levels (L_{max}) and equivalent noise levels (LA_{eq}) for given periods of the day as related to these noise sensitive areas are specified**.** Majority of federal administrations, agencies, boards, and commissions use DNL 55 dB or lower as a level of significance. Only the FAA, DOD, and HUD use DNL 65 dB as a level of significance. For residential areas and other similarly noise sensitive land uses, noise impact becomes significant in urban areas when the DNL exceeds 55 dB. In suburban areas where the population density is between 1250 and 5000 inhabitants per square mile, noise impact becomes significant when the DNL exceeds 50 dB. And in rural areas where the population density is less than 1250 inhabitants per square mile, noise impact becomes significant when the DNL exceeds 45 dB[12].

Table 2 — APTA guidelines for maximum airborne noise from train operations[9]

Community Area Description	Maximum Pass-by sound level dB(A)		
	Single-family dwellings	Multi-family dwellings	Commercial buildings
Low-density residential	70	75	80
Average residential	75	75	80
High-density residential	75	80	85
Commercial	80	80	85
Industrial/Highway	80	85	85

Table 3 — Noise Impact Assessment Significance Criteria[11]

Noise Change band dB(A)	Descriptor	Significance criteria
< 1	Not discernible	No Impact
1 to < 3 dB(A)	Marginal	Minor
3 to <5 dB(A)	Noticeable	Moderate
5 to 10 dB(A)	Considerable	Major

3 Noise Impact Assessment – Case study

A case study of application of FTA criteria to evaluate the impact of metro trains along elevated corridor in Delhi is presented. The measured daytime ambient noise levels along existing metro corridor at certain locations for peak traffic hours (hourly L_{eq}) is shown in Table 5.

In Delhi city for an average population density of 10,000 people per square mile, the criterion of 55 dB DNL is exceeded at most of the metro stations. However, not many complaints have been reported attributed to the adaptable living style of inhabitants towards noise. The noise due to vehicles is a major culprit in the accentuated ambient noise levels Fig. 4 shows the spectrum of sound radiated by metro on elevated corridor at a distance of 5 m from the source. The measurements were taken with a sound level meter installed on a pneumatic platform moved on

Table 4 — Railway noise impact criteria[13]

Country	Period (T)	$L_{A,max}$ (dBA)	$L_{Aeq,T}$ (dBA)
Australia	06h00-06h00	85	60
Denmark	06h00-06h00	88	60
UK	06h00-24h00	85	68
	24h00-06h00	85	63
USA	06h00-06h00		67, 55 (L_{dn})
Sweden	06h00-06h00		63
Japan	07h00-22h00	70	60
	22h00-07h00	70	55
Germany	06h00-22h00		59
	22h00-06h00		49
France	06h00-22h00		60
	22h00-06h00		55

Table 5 — Measured Day-Time Noise Levels along Metro Corridor

No.	Location	L_{eq} dB(A)
1	Pusa Gate	78.8 ± 1.3
2	Link Road	73.7 ± 1.1
3	Patel Nagar	73.5 ± 2.0
4	Tilak Nagar	73.4 ± 1.0
5	Dwarka	64.3 ± 2.3
6	Jhandewalan	74.2 ± 2.4
7	Shaadipur	75.8 ± 2.7
8	Dwarka Morr	73.4 ± 1.8

either side of the track and in level with the elevated corridor viaduct wall parapet. The noise levels measured for the metro trains at maximum speed at a distance of 5m from track was 75 ±2.3 dB(A) in At - grade and elevated corridor, while in the underground stations e.g. Vidhan Sabha, it was higher by 10 dB(A) due to the reverberant sound field. The braking noise measured was 85.4± 1.5 dB(A) in elevated track and the L_{max} measured for the trains starting from the elevated track was 78.5 ± 1 dB(A).

The ambient noise levels observed at different times of the day have a lot of variability involved due to variability in the traffic density and percentage of heavy vehicles on the road. However, in case, the ambient levels are much higher than source under consideration, its relative contribution in accentuating the overall L_{eq} is minimal. Fig. 5 shows the procedure for noise impact study as per FTA criteria. The overall at-grade noise of metro measured at a distance of 15 m is 69 ± 4.7 dB(A). The L_{eq} due to metro noise at a distance of 15 m is estimated[12] using the following equations:

$$L_{eq}\text{day(h)}=SEL_{ref}+10\log(V_d)+C_s-35.6 \quad \ldots (4)$$

$$L_{eq}\text{night(h)}=SEL_{ref}+10\log(V_N)+C_s-35.6 \quad \ldots (5)$$

where L_{eq}(h) is the average hourly equivalent noise level for selected time period, SEL_{ref} is the reference Sound Exposure Level for source, V_d is the number of trains activity in day time and V_N is number of trains activity in night time and C_s is the shielding correction.

$$V_d=\left[\left(\sum_{7A.M}^{10P.M} N_D\right)/15\right] \; V_N=\left[\left(\sum_{10P.M}^{7A.M} N_N\right)/9\right] \quad \ldots (6)$$

$$L_{eq}(h)@\text{receiver}=L_{eq}(h)-15\times\log_{10}(d/15) \quad \ldots (7)$$

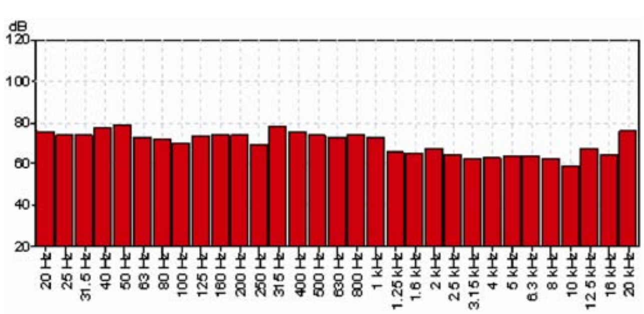

Fig. 4 — Spectrum of sound radiated by metro on elevated corridor at a distance of 5 m from track (L_{eq} = 77.8 dB(A))

where L_{eq}(h) @ receiver is the source noise at receptor level at the reference distance of 15 m and d is the source-receptor distance

The 24 h day-night noise level at receptor is calculated as:

$$L_{dn}=10\log[15\times10^{L_{eq}(\text{day})/10}+9\times10^{L_{eq}(\text{night})+10/10}]-13.8 \quad \ldots (8)$$

where L_{dn} is average 24-h day-night noise level; L_{eq} (day) is average hourly L_{eq} noise level during the daytime (7 am to 10 pm); L_{eq} (night) being the average hourly L_{eq} noise level during the night time (10 pm to 7 am) and 13.8 is the adjustment for the number of hours in a day 10×log(24).

The threshold of moderate impact for land use category 1&2 is calculated in terms of project noise exposure (L_p) which determines impact and existing noise exposure (L_E) as[14]

$$L_p = 71.662 - 1.164\, L_E + 0.018\, L_E^2 - 4.088 \times 10^{-5}\, L_E^3 \text{ for } 42< L_E < 71 \quad \ldots (9)$$

$$L_p = 65 \text{ for } L_E > 71 \quad \ldots (10)$$

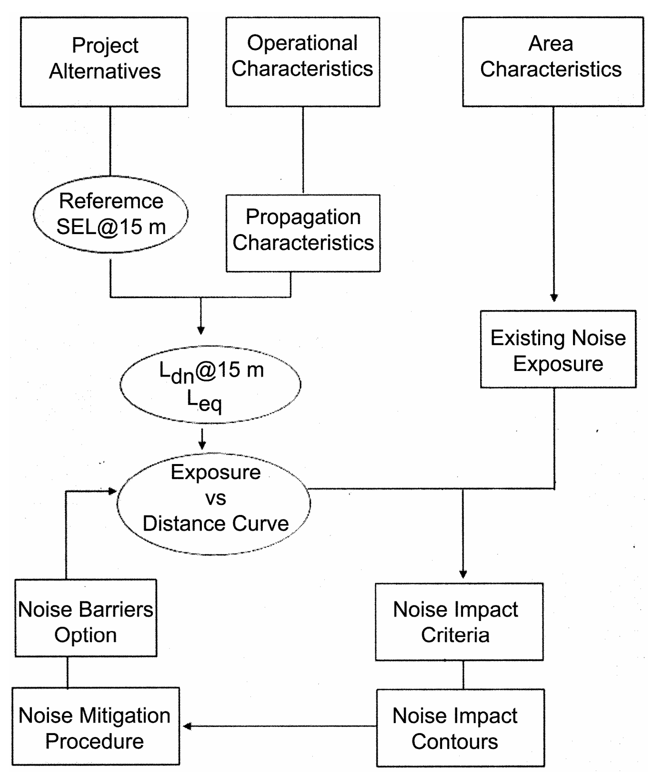

Fig. 5 — Procedure for noise impact assessment and mitigation

The threshold of severe impact for land use category 1 & 2 is estimated as[14]

$$L_p = 96.725 - 1.992\ L_E + 3.02\times 10^{-2}\ L_E^2 - 1.043 \times 10^{-4}\ L_E^3 \text{ for } 44 < L_E < 77 \quad \ldots (11)$$

$$L_p = 75 \text{ for } L_E > 77 \quad \ldots (12)$$

An additional factor of 5 dB is added for both the criteria for moderate and severe impact in case of land use category 3. These equations approximate the curve shown in Fig. 2 and can be used for predicting the onset of moderate and severe impact for a particular area in case the existing noise exposure of that area is known. A case study for Pusa road was done using the above empirical formulations. Fig. 6 shows the ambient noise measurements done at the Pusa road at various distances from the metro corridor. The noise exposure decreases with increasing distance from the metro track as the traffic density is relatively high beneath the track. The noise radiated by metro train could not be differentiated from the traffic noise, although the passage of trains is perceptible while standing beneath the track due to the structural noise radiated by the track elements and pillars.

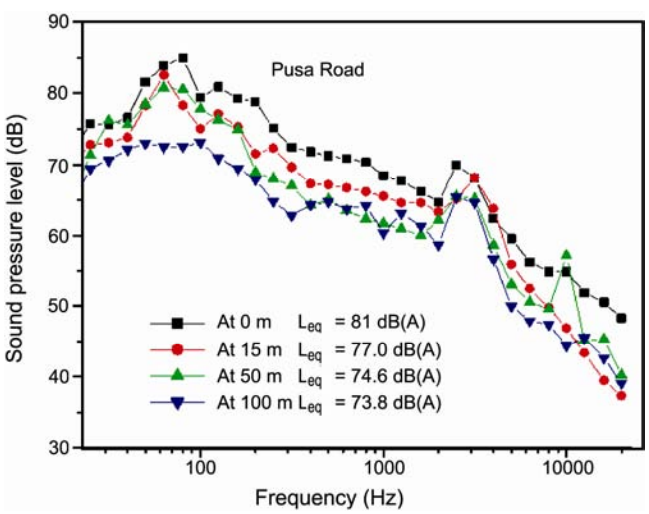

Fig. 6 — Ambient noise due to metro passing by in Pusa Road, Delhi at different distances from metro corridor during peak traffic hour

A noise impact evaluation exercise was done considering both day and night L_{eq} depending upon the operational frequency of the metro trains. Table 6 shows the threshold noise levels based on the existing ambient noise as proposed by FTA for the onset of severe and moderate impact at different distances from elevated metro corridor.

The combined noise exposure computed from the project L_{eq} and existing noise scenario is shown in Table 7. It is observed that the accentuated noise levels amount to be 1.7 dB(A) depending upon the ambient noise conditions at the site.

A similar analysis was conducted for the Tis Hazari metro station followed by round the clock noise monitoring along one side of the road at a distance of approximately 15 m. An L_{eq} level of 72.0 dB(A) was

Table 6 — Predicted maximum levels for onset of moderate and severe impact

Distance from Metro corridor up to (m)	Existing noise L_{eq} dB(A)	Project L_{eq} criteria	
		Onset of moderate impact	Onset of severe impact
10	75.1	65 dB(A)	73 dB(A)
15	73.2	65 dB(A)	72 dB(A)
30	69.5	64 dB(A)	69 dB(A)
60	67.6	62 dB(A)	67 dB(A)
100	63.1	60 dB(A)	65 dB(A)

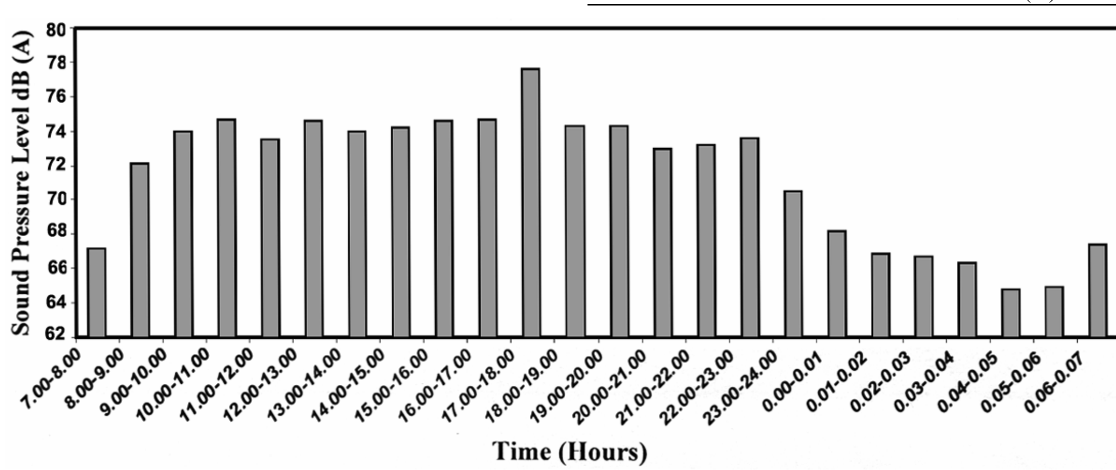

Fig. 7 — Traffic noise measurement at Tis Hazari station, Delhi

Table 7 — Predicted increase in noise exposure due to elevated metro corridor at Pusa road

Distance from metro corridor up to (m)	Existing Noise L_{eq} dB(A)	Project L_{eq} dB(A)	Combined Total Noise Exposure dB(A)	Increase in Noise Exposure dB(A)
10	75.1	72	76.8	1.7
15	73.2	69	74.6	1.4
30	69.5	64.5	70.7	1.2
60	67.6	60	68.3	0.7
100	63.1	56.6	64.0	0.9

Table 8 — Predicted increase in noise exposure due to elevated metro corridor at Tis Hazari station

Distance from metro corridor up to (m)	Existing Noise L_{eq} dB(A)	Project L_{eq} dB(A)	Combine d Total Noise Exposure dB(A)	Increase in Noise Exposure dB(A)
10	74.8	72	76.6	1.8
15	72.3	69	74.0	1.7
30	68.5	64.5	70.0	1.5
60	65.4	60	66.5	1.1
100	62.2	56.6	63.3	1.1

observed at the site due to an adjoining road having medium traffic density as shown in Fig. 7. Table 8 summarizes the predicted increase in noise exposure due to elevated metro corridor at Tis Hazari station. It can be predicted that for a receiver located within 5 m from the metro corridor, the cumulative increase in noise exposure shall be up to 3 dB(A).

4 Conclusions

The operation of metro trains can cause a cumulative increase in ambient noise level by maximum 2 to 3 dB (A) in medium and high traffic density areas. An incremental exposure of 2 dB for areas having ambient noise levels of 70 dB due to a new project will create relatively more impact than in areas of lower and medium traffic density. As the prevailing ambient noise levels of 65-75 dB(A) can cause annoyance in 25-50 % of the population, the operation of metro trains along new elevated corridors may at the most cause an additional 6.5 % increase in the affected population. The people who are residing in those buildings overlooking the metro routes are the ones mostly affected by metro trains. Thus, the sound insulation of the building elements facing the metro tracks should be increased by providing double glazed windows, heavy doors of high transmission loss values. So, the design target for noise reduction for future metro alignments should be increased at the façade by 5-10 dB (A), which can be achieved by installing suitable environmental friendly noise barriers.

References

1 Walters D, *Architektur-Psychologie*, (1989).
2 American National Standards Institute (ANSI), Acoustical Society of America, (1996).
3 Ouis D, *J of Environmental Psychology*, 21 (2001) 101.
4 Miedema H M E & Vos H, *J of Acoustical Society of America,* 104 (6) (1998) 3432.
5 Position paper, WG2 – dose/effect, (2002).
6 U.S Department of Housing & Urban Development, The Noise Guidebook, HUD 953-DPC, (1985).
7 Hamed M, Effat W, *J of Environmental Management*, 84 (2007) 305
8 Federal Transit Administration, Transit Noise and Vibration Impact Assessment, DOT-T-95-16, (1995).
9 APTA, Guidelines for Design of Rail Transit Facilities, Noise and Vibration, (1979).
10 WHO, Guidelines for Community Noise, Geneva, (1999).
11 http://www.standardsforhighways.co.uk/dmrb/vol11/section3/ha21308.pdf
12 Schomer P, A *White paper: Assessment of noise annoyance*, (2001)
13 http://www.tshwane.gov.za/documents/noise/NoiseAppendixG.pdf
14 http://www.hmmh.com/cmsdocuments/FTA_ Appendix_B.pdf