7. CONCLUSIONS, RECOMMENDATIONS AND SCOPE FOR FURTHER WORK

7.1 CONCLUSIONS

The following conclusions are made out of the study:

(i) L_{eq} for traffic jam has exceeded the permissible limit of 65 dBA daytime noise level stipulated for the commercial landuse at all 65 legs of 19 intersections covered under the study for all observer distance ranging from 2.40 to 14.99m from the noise source. The highest recorded L_{eq} was 92.0 dBA of on the GF level of Sundarpur leg of Bhikharipur intersection on October 18, 2013, while the lowest value of 66.8 dBA was recorded on the SF of Khajuri leg of Pandeypur intersection on November 23, 2013.

(ii) Variation of L_{eq} was recorded in the range of 92.0 to 70.2 dBA on the GF level; 91.2 to 68.7 dBA on FF level, and 90.4 to 66.8 dBA on SF level. The study reveals a broad range of noise level variation during traffic jam that being 21.8, 22.5, and 23.6 dBA for GF, FF, and SF levels, respectively.

(iii) Knowing that the sustained exposure to the noise level of 90 dB or more may lead to irreversible physiological and psychological damages in human beings including permanent loss of hearing, below mentioned 25 legs of intersections were found to equal or exceed this rider limit at GF level. Together they amount to more than $1/3^{rd}$ of the total legs covered under the study.

a) Towards Ravidas Gate (BHU Gate intersection).

b) Towards BHU (Ravidas Gate intersection).

c) All three legs of Lanka-Sankatmochan intersection.

d) Towards Bhelupur (Durgakund Temple intersection).

e) Towards Kamachcha (Bhelupur intersection).

f) Towards Kamachcha and towards Sigra (Rathyatra intersection).

g) Towards Rathyatra (Sigra intersection).

h) Towards Andhapapul and towards Lahartara (Englishia Line intersection).

i) Towards Englishia Line (Andharapul intersection).

j) Towards Andharapul and towards City Railway Station (Chaukaghat intersection).

k) All three legs of Bhikharipur intersection.

l) Towards Cantt. Railway Station and towards Mohan Sarai (Lahartara-Manduadih intersection).

m) Towards Orderly Bazar (Bhojubir intersection).

n) Towards Paharia (Pandeypur intersection).

o) Towards Kutchhary, towards Maqbool Alam Road and towards Pandeypur (Police Line intersection).

(iv) L_{eq} would reduce at FF and SF level with respect to GF level due to an increase in observer distance. The reduction at FF level was in the range of 4.40 dBA to 0.29 dBA for a corresponding increase in observer distance ranging from 3.92 and 0.97m. Similar reduction at SF level was in the range of 7.51 to 0.60 dBA for an increase in observer distance ranging from 6.76 and 2.38m.

Reduction of L_{eq} at SF level w.r.t. FF level was found in the range of 3.11 to 0.31 dBA for an increase in observer distance ranging from 2.84 and 1.41m.

The highest reduction of L_{eq} of 4.40 dBA at FF level w.r.t. GF level was observed at Manduadih intersection on its leg towards Manduadih Police Station, while the lowest reduction of 0.29 dBA at FF level w.r.t. GF level was observed at Ravidas Gate intersection on its leg towards Lanka Thana.

(v) Reduction of L_{eq} at SF level with respect to GF level was found equaling the numerical summation noise reductions of recorded between GF-FF levels and FF-SF levels. Mathematically,

$$Reduction\ of\ L_{eq}\ at\ topmost\ floor\ w.r.t.GF\ level$$
$$= \sum Reduction\ of\ L_{eq}\ at\ all\ story\ levels\ of\ the\ building$$

Also, the increase in observer distance at SF level with respect to GF level was found equaling the numerical summation of increase in observer distance recorded between GF-FF levels and FF-SF levels. Mathematically,

$$Increase\ of\ observer\ distance\ at\ topmost\ floor\ w.r.t.GF\ level$$
$$= \sum Increase\ of\ observer\ distance\ \ at\ all\ story\ levels\ of\ the\ building$$

(vi) Study on spatial decay rate suggests that the reduction of L_{eq} was < 3 dBA per distance doubling. Considering from the strength of literature that the spatial decay rate for L_{eq} is always 3 dB per distance doubling for all traffic densities under free field conditions, the lowering of the L_{eq} decay rate may be attributed to reflection of noise signals from the façade reaching the microphone of the SLM at the observer position, thereby reinforcing the noise levels during traffic jam.

(vii) Traffic noise index (TNI) and noise pollution level (NPL) were generally exceeding their permissible limit of 74 and 88 dBA, respectively, for the 8 data sets of traffic jam period. They were found to be maintaining their maximum values at similar legs of the intersections where the L_{eq} value was hovering around 90 dBA mark.

(viii) Four types of mathematical models viz. floor-wise leg models, floor-wise intersection models, floor-wise city models, and consolidated city model were developed in the study for estimation of L_{eq} at a confidence level of 95%.

The floor-wise leg model is specific to the leg of an identified intersection in the city of Varanasi and may aid future noise intervention of the city; while other models were cases of subsequent generalization for estimating traffic jam noise for mixed composition and non-lane based movement with the freedom for honking. Accordingly, the following predictive models are recommended.

Floor-wise leg models:

For GF level, $$L_{eq} = 81.14 + 0.03(NR) + 0.58\left(\frac{Q_w}{d}\right) + 0.05(p_2) + 0.07(\%AO)$$

$$R^2 = 1.000, \quad SE = 0.044$$

For FF level, $$L_{eq} = 79.56 + 0.02(NR) + 0.75\left(\frac{Q_w}{d}\right) + 0.06(p_2) + 0.07(\%AO)$$

$$R^2 = 1.000, \quad SE = 0.034$$

For SF level, $$L_{eq} = 80.77 + 0.08(NR) + 0.73\left(\frac{Q_w}{d}\right) + 0.03(p_2) + 0.06(\%AO)$$

$$R^2 = 1.000, \quad SE = 0.043$$

Floor-wise intersection models:

For GF level, $$L_{eq} = 72.37 + 0.66(NR) - 0.22\left(\frac{Q_w}{d}\right) + 0.04(p_2) + 0.15(\%AO)$$

$$R^2 = 0.956, \quad SE = 0.548$$

For FF level, $$L_{eq} = 79.56 + 0.02(NR) + 0.75\left(\frac{Q_w}{d}\right) + 0.06(p_2) + 0.07(\%AO)$$

$$R^2 = 1.000, \quad SE = 0.034$$

For SF level, $$L_{eq} = 80.77 + 0.08(NR) + 0.73\left(\frac{Q_w}{d}\right) + 0.03(p_2) + 0.06(\%AO)$$

$$R^2 = 1.000, \quad SE = 0.043$$

Floor-wise city models:

For GF level, $$L_{eq} = 70.51 + 0.03(NR) + 0.12\left(\frac{Q_w}{d}\right) + 0.01(p_2) + 0.22(\%AO)$$

$$R^2 = 0.396, \quad SE = 3.743$$

For FF level, $$L_{eq} = 69.66 - 0.04(NR) - 0.66\left(\frac{Q_w}{d}\right) + 0.01(p_2) + 0.22(\%AO)$$

$$R^2 = 0.366, \quad SE = 4.127$$

For SF level, $$L_{eq} = 68.97 - 0.17(NR) + 0.59\left(\frac{Q_w}{d}\right) + 0.05(p_2) + 0.20(\%AO)$$

$$R^2 = 0.442, \quad SE = 4.382$$

Consolidated city model:

$$L_{eq} = 69.31 + 0.01(NR) + 0.30\left(\frac{Q_w}{d}\right) + 0.02(p_2) + 0.21(\%AO)$$

$$R^2 = 0.403, \quad SE = 4.030$$

where, 'p_2' is percentage of heavy vehicles in traffic jam; 'd' being observer distance; and '$\%AO$' being %Area-Occupancy for every model.

(ix) It was found that noise range (NR) and weighted flow (Q_w) as new parameters were better than noise climate (NC) and passenger car unit (PCU) for describing noise variability and traffic volume, respectively, in modeling of traffic jam noise.

7.2 RECOMMENDATIONS

(i) For all such locations of a traffic jam where the L_{eq} has exceeded its permissible value, installation of noise reduction measures after due future study may be done.

(ii) GF level being most affected by traffic jam noise, and it reduces with increase in story height of the building, brings forth the fact that habitation story may be shifted upwards by providing soft story or stilt floor in apartment design and creation of basement for parking in commercial building design.

(iii) Lowering of the spatial decay rate of L_{eq} at a distance of 1m in front of the façade vertical recommends the lesser use of balconies facing the roadway during traffic jam period by the children and elderly.

(iv) The floor-wise leg models are more precise by virtue of higher coefficient of determination (R^2) and lower standard error of estimate (SE). Therefore, they are more suited for the identified leg of an intersection in the city of Varanasi to aid future noise intervention. Other models may help researchers and policy makers for estimating traffic jam noise for mixed composition and non-lane based movement with the freedom for honking. The floor-wise city models and the consolidated city model may be used till the time better models are developed.

7.3 SCOPE FOR FURTHER WORK

The present work was concerned with the evaluation of traffic jam noise on the ground as well as different floor levels of buildings for the mid-sized city of Varanasi. Further work may be conducted for improving scientific understanding on traffic jam noise under mixed traffic conditions under the following suggested domains:

(i) It was observed that every intersection experiencing traffic jam in the study area was unique in terms of noise emission profile which is attributable to its physical apparatus, geometry, available carriageway width, type of traffic encountered, traffic control measures in place etc. Therefore, data collection for a sustained period of time covering seasonal variation is necessary since a larger number of data sets would render models with better precision.

(ii) Noise profiling on larger vertical scale to study façade effects with height.

(iii) Selecting more number of mid-sized cities in different geographical areas.

(iv) Selecting large urban metropolitan geographical area.

(v) Consideration of buildings inclination in plan and verticality in assessment and modeling.

(vi) Consideration of different floor levels of GF floor in assessment and modeling.

(vii) Consideration of different façade voids and materials in assessment and modeling.

(viii) Study various noise abatement measures for reducing indoor noise during traffic jam.