ICA 2013 Montreal
Montreal, Canada
2 - 7 June 2013

Noise
Session 2pNSb: Soundscape and its Application

2pNSb7. Evaluation of noise climate in a campus environment using geospatial technology
Rajasekar Elangovan*, Puri Yadava Mudaliar, Khaleelur Rahaman, Ravi Muttavarapu and Venkateswaran Rajan

*Corresponding author's address: Center for Excellence and Futuristic Developments, L&T Construction, Chennai, 600089, TamilNadu, India, erajas@gmail.com

This study focuses on experimental evaluation of outdoor noise climate in an office campus which is spread across 27 acres and investigation of its impact on the adjoining office buildings. For this purpose, a base map of the campus was prepared from the recent high spatial resolution satellite image using ESRI ArcGIS and the same was used for planning appropriate locations for capturing noise levels and its spectral characteristics. Mapping grade Trimble GPS was used to stake out the measurement locations and noise levels were recorded using 01 dB solo and Norsonic type 118 sound level meters. Captured noise levels were plotted in GIS environment and appropriate spatial interpolation was carried out in order to give a continuous graphical representation of sound levels. A wide variation of noise levels was observed across the campus with LAeq ranging from 50 dB(A) to 80 dB(A). Low frequency noise was found to be predominant compared to mid and high frequency noise. Major noise sources and the propagation pattern were determined through the mapping. The data thus obtained is used to investigate the noise impact on the office buildings. The measurements were also accompanied by a subjective evaluation of the outdoor noise annoyance.

Published by the Acoustical Society of America through the American Institute of Physics
INTRODUCTION

In office campuses, especially those located in urban areas, excessive noise levels arise from both within the campus (through mechanical equipment and internal vehicular movement) as well from outside sources like neighbouring sites and abutting traffic corridors. Excessive noise is one of the primary sources of disturbance in office spaces which is found to reduce the efficiency of the employees in the work environment [1,2]. In the Indian context, there has been an increase in awareness about environmental noise control in the last decade and studies pertaining to monitoring and mapping of urban noise climate has been widely reported [3,4, 5, 6]. Given the multitude of noise sources with diverse spectral characteristics, it has become increasingly difficult to model the spatial pattern of noise propagation through conventional methods.

Use of newer technologies like Geographic Information System (GIS) for noise mapping and analysis is gaining momentum. Once of the recent studies [7] involved an extensive evaluation of traffic noise incorporating the geometrical features of the roads and varying heights of the buildings, heterogeneity, and prominent honking conditions for the city of Chennai (the city in which the present study is being reported). Internationally, several such studies [8, 9, 10, 11] have been reported for urban noise evaluation. Application of such mapping and modelling techniques for larger campus will be beneficial for evaluating and visualizing the noise climate and for proposing appropriate mitigation measures. GIS provides a powerful set of tools for storing and retrieving, transforming and displaying spatial data from the real world for a particular set purpose [8]. This method serves three primary purposes i.e. (i) it provides specific information about a particular location (ii) it provide general information about spatial patterns and (iii) it can be used to compare patterns on two or more maps that are prepared at various time periods/scenarios. Apart from this, GIS based approach facilitates the visual presentation of the noise effects and it is an additional tool for analysing the results.

This article presents an application research that was initiated to experimentally monitor and model the noise levels in an office campus spread across 27 acres. This study was envisaged as a pilot project which is now planned to be extended for other such campus environments that are being developed by the company.

DETAILS OF THE STUDY

The office campus under investigation which is located at Chennai (13.1°N; 80.3°E) spreads across 27 acres of land. It encompasses dense vegetation and houses eight office buildings (three of which are LEED Green Rated), associated service buildings and has around 6800 employees.

FIGURE. 1: A snapshot of some of the prominent buildings in the campus

Noise Scenario of the Campus

The north east side of the campus is abutted by state highway - 55 which is one of the arterial corridors feeding the city. Given the increasing gap between power supply and demand, Diesel Generator (DG) sets have become integral parts of the campus in order to operate the HVAC systems as well as other equipment. There are 2 numbers of 1450 kVA DG sets, four numbers of 1500 kVA, two numbers of 1500 kVA, One number of 1010kVA, 1000 kVA, and 500 kVA. These are operated between 3 to 5 hours daily and form one of the predominant noise sources in the campus. The campus has a total HVAC load of 5126 TR and is catered through 21 numbers of air cooled chillers. The chillers together with the HVAC exhausts elevate the background noise levels significantly. There are three numbers of cafeterias apart from these operations and associated exhausts form some of the predominant noise sources.
Noise regulations and requirements

Central Pollution Control Board (CPCB) standard for ambient noise level recommends the ambient noise levels inside the commercial zone to be below 65 dB(A) in the day time and 55 dB(A) in night time. The maximum permissible sound pressure level for new diesel generator (DG) sets with rated capacity up to 1000 kVA, manufactured on or after 1st January, 2005 shall be 75 dB(A) at 1 meter from the enclosure surface.

NEED FOR THE STUDY AND OBJECTIVES

With the presence of vivid noise sources that exhibit widely different spectral characteristics, it becomes highly essential to measure and determine the resultant ambient noise characteristics. This helps to evaluate the compliance with noise regulations and to decide on appropriate noise control measures wherever required. The campus houses predominantly open plan office spaces which require a background noise level of NC (Noise Criteria) 40 to be maintained. It hence becomes essential to evaluate the influence of the outdoor noise climate on the office buildings. The objectives of the study thus are

1) To map the noise levels of the campus in a GIS based environment
2) To evaluate the noise climate and analyze its influence on the office buildings

MEASUREMENT PROCEDURE

In order to bring the sound level data into GIS framework, a dual frequency GPS (Trimble 5700) survey was executed to capture the Ground Control Points (GCP) in and around the Campus. These Ground Controls Points are used to rectify the Satellite images that are extracted from the Google Earth Professional software. Image processing software (ERDAS 8.2) was used for rectification of the satellite image and its spectral/spatial enchantments. Same Ground Control Points along with co-ordinates of the rectified satellite image was used to convert the local co-ordinate of the as built engineering design drawing of the campus to global co-ordinate system. Thus a layer based approach with common co-ordinate system was added to all the required thematic layers of the as built (Office & Administrative Buildings, Diesel Generator rooms, Major Roads, Car/two wheeler sheds etc.,). This enables the decision maker to superimpose the results of various spatially analysed data on a common platform.

A base map was prepared from the rectified satellite image along with other relevant as built layers. Arc/GIS Arc/Info software with Spatial & 3D extension developed by Environmental Science and Research institute (ESRI) was used to prepare the base map and for further spatial analysis. This bas map was used to plan the appropriate locations for sound level survey. Extent of campus area along with planned survey locations are showed in figure 2. A mapping grade GPS (Trimble Geo XT) was used to stake all the predetermined 100 points planned using GIS base maps. Planned co-ordinates were located at ground using GPS and sound level in various spectrums was logged using Norsonic NOR 118 Sound Level Meter. Spectral characteristics of noise were recorded in these locations. This method enables the surveyor to conduct the repeated survey at same locations without much difficulty. It also facilitates the decision maker to ensure executed survey reflects the effect of temporal changes (peak and non-peak traffic hours, day and night time, office working and non-working days) on spectrums of various sound levels.

Based on the location of noise sources and noise ambience the campus has segmented into seven zones for the present study as shown in fig. 2. Zone 1A houses Energy Center, (the predominant noise sources due to chillers and DGs), Zone 1B houses service building, (the predominant noise sources due to chillers and DG-3), Zone 2A houses main cafeteria, (predominant noise source is kitchen exhaust fans), Zone 2B houses TC2 cafeteria, (predominant noise source is kitchen exhaust fans and DG-2), Zone 2C houses TC3 Cafeteria, Zone 3 houses medical center and Zone 4 abutting the traffic corridor. Surveyed sound levels in various spectrums were analysed in histograms and outliers of the same are removed. As interpolation is an effective technique used by various researchers for the purposes of noise mapping [9] using the X and Y co-ordinates of surveyed locations sound levels are brought into GIS environment for their interpolation and further spatial analysis.
Since noise changes logarithmically with distance, initial noise generated at source will be high and reduces quadratically as it moves away from the source. The interpolation method that is being used in present study also has the same algorithm that was developed based on the principle that closer points to the predicted location would have greater influence in the interpolation. As there are no standard interpolation methods for this kind of Noise mapping studies[10], considering the nature and distribution pattern of the surveyed data various authors have used various interpolation methods like TIN, IDWA, Kriging and Natural Neighbourhood etc., [11, 12, 13].

Interpolation methods like TIN, IDWA, Kriging and Natural Neighbourhood are subject to edge effect problems and hence additional data collection around the area of interest is required to avoid extrapolation. But due to some practical difficulties like inaccessibility and administrative restrictions etc., sound level at edges and all-around of the campus was not captured. Therefore, according to the nature, distribution pattern and characteristics of the existing survey data set, “Spline with Barriers” interpolation method was used for the present study. This interpolation method is best for generating gently varying surfaces such as elevation, water table heights, or pollution concentrations. It uses a method similar to the technique used in the Spline interpolation method, with the major difference being that this tool honors discontinuities encoded in both the input barriers and the input point data (ESRI technical document). The Spline with Barriers interpolation method applies a minimum curvature method, as implemented through a one-directional multigrid technique that moves from an initial coarse grid, initialized in this case to the average of the input data, through a series of finer grids until an approximation of a minimum curvature surface is produced at the desired row and column spacing. By keeping boundary of the campus as barrier “Spline with Barriers” interpolation method was applied on survey points that are collected in various time periods. Contour with the interval of 5 dBA was created and superimposed on top of the spatial models for better visualisation of noise levels and results of the same are discussed in below sub headings.

**FIGURE 2**: Planned survey locations along with various theme layers
NOISE CLIMATE OF THE CAMPUS MAPPED USING GIS

Spectral characteristics of the ambient noise levels at octave band frequencies were measured during non-office hours (4:00 AM to 7:00 AM) and office hours (8:30 AM to 7:00 PM). Fig. 3 (a) and (b) show the spatial variation of A-weighted sound pressure levels (SPL) during non-office and office hours respectively. Fig. 4 (a) and (b) show the corresponding variation of linear sound pressure levels in the campus.

FIGURE 3: A-weighted SPL in the campus (a) Non-office hours (b) Office hours

FIGURE 4: Linear SPL in the campus (a) Non-office hours (b) Office hours

It was found that the campus experiences a quieter noise ambience during the non-office hours (fig. 3(a), 4(a)) except for the noise prevalent from the canteen block which becomes operational from around 6:00 AM. The noise emission from kitchen exhausts lie in the range of 65 dB(A) to 70 dB(A) and the corresponding variation in linear SPL ranges from 75 dB to 80 dB. The noise levels along the traffic corridor were also found to be slightly higher compared to ambient levels in the campus. In general, during non-office hours the noise levels in the campus lie within the CPCB regulatory limits. During office hours, zones 2A, 2C and 3 are found to be quieter and the noise levels lie within the recommended standard limits. Zone 1 B which houses an energy center shows a slightly elevated noise level and zone 1A and 2B experience higher noise levels and indicates an exceedence from the CPCB regulatory limits of 65 dB(A).

Figs. 5 show the variation of noise levels in the low (63 Hz), mid (1000 Hz) and high (8000 Hz) frequency bands. It can be seen from fig. 8 that during office hours, zone 2B and zone 4 which house the mechanical equipment like Chillers and DGs experience predominance of low frequency noise. Zone 2A which covers mostly public gathering areas, experiences the predominance of high frequency noise.
The impact of the noise levels on the abutting built spaces can be well established through this approach. For instance, from Figs. 3 and 4 it can be seen that the noise levels arising from the mechanical equipment in zone 1A and 2B are found to have a greater impact on the Technology Center II building, especially on the north and eastern facades. Given the facts that the main entrance of this building opens out to the east and there are no special noise control treatment provided for these orientations, the higher noise levels are bound to have a disturbing effect on the quieter office spaces of this building. From fig. 8 it is evident that the disturbance to this building is predominantly due to the low frequency noise. Though the noise levels in the mid and high frequency ranges that are impinging on this building are higher, they are not found to be alarming as compared to the low frequency levels.

Similarly, figs. 3 and 4 show the impact of traffic noise on the CRR center, Technology center I and the north and western facades of EDRC buildings. Traffic noise is found to be alarmingly high near the main entrance of the campus where a traffic signal is been located. The CRR center is found to be more vulnerable especially on the north-eastern facades due to the noise arising from the traffic signal. The noise contours clearly indicate the propagation pattern of the traffic noise inside the campus irrespective of the thick vegetative cover that has been provided. It can be found from fig. 5 that the noise impinging on CRR center and Technology Center I are predominant in the low frequency range compared to mid and high frequency range.

**Noise from Traffic Corridor**

Fig. 6 shows the impact of the traffic noise on the camps measured during non-office and office hours which was assessed through measurements taken at eight different points located inside the campus along the traffic corridor.

The peak traffic and resultant peak in noise levels is found to occur between 8am to 9.30am, 12.15pm to 1.30pm and 5.30pm to 7.00pm on the weekdays. It was identified from the study that, the vehicle exhaust and honking noise generated at traffic signal and bus stop abutting the campus are more intense as compared to the free flowing traffic.
Out of the two buildings which are exposed to higher traffic noise levels, the façade of CRR center which was originally constructed with conventional brick masonry and deep overhangs (fig. 7(a)) was retrofitted recently by adding an additional structural glass façade to its exterior (fig. 7(b)). The outer glazing layer has been fixed at a distance of 900 mm from the existing façade. The horizontal overhangs have been retained in place. The space between the two facades forms a shaft which is intercepted by horizontal overhangs at each floor level.

EVALUATION OF INDOOR ACOUSTICAL CHARACTERISTICS

In order to study the influence of outdoor noise climate on the office spaces, an experimental evaluation of indoor noise characteristics is carried out in these two buildings accompanied by a subjective investigation of noise climate. The survey questionnaire contained 10 questions covering a subjective rating of the noise levels, rating of the acoustical comfort, rating of acceptability towards the acoustic environment and rating of the overall indoor environmental quality. The survey is administered with 120 employees seated in two buildings (CRR center and Technology Center I). The distribution of the samples are as follows – 70% male and 30% female, 48% between the age group of 21-30, 22% between the age group of 31-40 and 30% in the age group above 40.

In both these buildings, the open-plan office spaces occupy the central core of the building and are surrounded by private offices which are distributed along the periphery. It was found that the noise levels in CRR building during non-office hours lie between NC 35 and 40. Due to the façade retrofit, the traffic noise ingress in the work areas is found to be minimal in this building. During office hours the indoor noise ambience is predominantly characterized by indoor noise sources and is found to be similar to the open-plan office spaces of Technology center I building. Fig. 8(a) and (b) show the noise criteria measured at Technology center I in open-plan office and private office spaces respectively. In Technology center I, the peripheral areas are dominated by traffic noise while the core areas are dominated by indoor noise sources. The NC levels in the open-plan office areas were NC 38 and 53 during non-office and office hours respectively. Similarly, the NC levels in private office areas (located predominantly in the peripheral areas and experience the impact of outdoor traffic noise) were NC 40 and 45 during non-office and office hours.
hours respectively. The study shows that the office spaces are dominated by internal noise sources generated from conversations, telephone rings and printer equipment as compared to outdoor noise ingress (Table 1).

<table>
<thead>
<tr>
<th>Source Type</th>
<th>CRR Center</th>
<th>Technology Center I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Outdoor traffic noise</td>
<td>0%</td>
<td>9%</td>
</tr>
<tr>
<td>Mechanical system noise</td>
<td>19%</td>
<td>51%</td>
</tr>
<tr>
<td>Indoor Noise sources</td>
<td>35%</td>
<td>46%</td>
</tr>
</tbody>
</table>

It was found from this study that 60% of the respondents at CRR building rated the noise ambience to be moderately noisy while 13% of the respondents rated it as too noisy. On the other hand 65% of the respondents at Technology center I building rated the noise ambience to be moderately noisy while 15% of the respondents rated it as too noisy. However 84% of respondents in both these buildings rated the noise levels to be acceptable. When asked ‘whether the acoustical quality at your work place enhances or interferes with your productivity’, 69% of respondents in CRR center and 78% in Technology center I felt that they are not concerned about this fact. It was observed from the study that 73% of the respondents in CRR center and 64% of the respondents in Technology center I expressed their satisfaction with the overall indoor environmental quality at their work place.

![FIGURE 9: Background noise levels vs. subjective comfort](image)

There is found to be a wide variation in the perception of the employees towards acoustical comfort. This is evident from fig. 9 which shows a relationship between the background noise levels in different zones of the open-plan office spaces and the respective subjective acoustical comfort registered by the employees in that zone. The comfort votes are registered in a 5-point double-likert scale which ranges from very uncomfortable (-2) to very comfortable (+2) while ‘0’ represents a neutral state. It was found that though the open office spaces experienced fairly high background noise levels, associated discomfort is registered only above 57.5 dB(A). A linear relationship thus established ($r^2=0.61$) shows that the subjective perception of acoustical discomfort exhibits an unit increase for every 5 dB(A) increase in the background noise levels.

**SCOPE FOR FUTURE WORK**

This study helps as a step forward in outdoor environmental noise evaluation and mitigation in larger campus settings. It helps as a tool for the facility managers to understand the complex noise scenario and the spatial propagation pattern and paves a way for effective noise mitigation and control. Further studies need to be carried out in the following two aspects – (i) to evaluate the 3-dimensional noise propagation pattern and (ii) to derive effective and standardized ways of linking such micro-level studies to macro-level urban sound scape studies.

**CONCLUSIONS**

A comprehensive method to experimentally monitor and model the noise levels in an office campus using GIS technology has been presented in this study. A layer based approach with common co-ordinate system was added to
all the required thematic layers of the as built spaces. The use of a mapping grade GPS used to stake a set of predetermined points facilitates the decision maker to ensure executed survey reflects the effect of temporal changes in the noise climate. Through this study it was found that the maximum noise levels in the campus during office hours ranges between 69.4 – 86.5 dB in the low frequency (63 Hz) range, 54.8 – 66.6 dB in the mid frequency (1 KHz) range and 40.5 – 63.7 in the high frequency range (8 KHz). A –weighted sound pressure levels vary from 50 dB(A) to 75 dB(A) during office and 50 dB(A) to 60 dB(A) during non-office hours. It is found that GIS forms a useful tool for evaluation of noise climate in this kind of campus environment. The GIS based noise maps provide spatial presentation of acoustic situation which can be used as a good visualization tool for evaluation of noise propagation, calculation of areas affected by noise and to assist in development of noise mitigation measures. GIS based noise survey mapping could be used to decide the orientation of the newly constructed building envelope and location of mechanical equipment in less noise sensitive area.

A detailed study on the impact of the traffic noise on two office buildings located in close vicinity to the traffic corridor is carried out. Indoor evaluation of noise levels in these buildings showed that the NC levels in the open-plan office areas were NC 38 and 53 during non-office and office hours respectively. Similarly, the NC levels in private office areas (located predominantly in the peripheral areas and experience the impact of outdoor traffic noise) were NC 40 and 45 during non-office and office hours respectively. The study shows that the office spaces are dominated by internal noise sources as compared to outdoor noise ingress (Table 1). It was found that though the open office spaces experienced fairly high background noise levels, associated discomfort is registered only above 57.5 dB(A). A linear relationship thus established (r²=0.61) shows that the subjective perception of acoustical discomfort exhibits an unit increase for every 5 dB(A) increase in the background noise levels.

ACKNOWLEDGEMENTS

We wish to thankfully acknowledge Prof. A. Ramachandraiah from IIT Madras for extending support with some of the instruments used in this study.

REFERENCES