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Who is The Bigger Culprit? Studying Impacts of Traffic and Land Use on Noise Levels in CBD Area of Karachi, Pakistan

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Abstract

The trend of urbanization has attracted increased attention towards urban areas around the world. Central Business Districts (CBDs) serve as the core of commercial activities of urban areas and are often associated with high density population. Noise pollution in urban areas, especially CBDs, is considered as an important issue for planners and policy makers especially with regards to human health. Noise prediction models for CBD area of Karachi, Pakistan have been developed in this study using land-use and traffic parameters. These models show that traffic and build-up space (especially residential land-use) contribute positively and vacant space contributes negatively to the noise levels. However, it was found that traffic volume has higher impact, than land-use, on noise levels in CBD area. These models can be used for planning of urban CBD areas in other cities where noise levels are well above international health standards. These models were also found useful for calculating rate of traffic volume generated due to residential land-use.

Keywords: Noise prediction; Land-use; Traffic; CBD area; Karachi

1. Introduction

People have traditionally perceived surrounding environments largely through their visual receptors, which has been presented by the term of landscape. In recent years, the aural aspect of the environments has been illuminated in association with soundscape affected by a variety of sources (Wrightson 2000; Raimbault and Dubois 2005; Genuit and Fiebig 2006). Soundscape assesses how people perceive sounds and what impacts the sounds make on them (Wrightson 2000; Schulte-Forkamp and Fiebig 2006).

Some sounds would be able to make people feel relaxed when they are interpreted to be positive. Meanwhile, others could arouse bothered or uncomfortable feelings which are negative. In this sense, noise is designated to be collective sounds that are by-products of human activities and has negative effects on people (Lipscomb and Roettger 1976). It can be either occupational or environmental noise, taking into account its sources. The environmental noise is also referred to be community noise, and it is emitted from transportation such as roads, railways and airports and even neighbourhoods. Transportation is considered to be the major source of environmental noise in many nations, including developed as well as developing countries (Bergluend et al. 1999; Gorai et al. 2007; Moudon 2009; Mehdi et al. 2011; Ko et al. 2011). On the other hand, land-use also has a significant effect on the environment and ecosystem which include producing occupational noise in the area (Hassen and Nazem 2015).

Noise level in a surrounding is affected by two types of processes, namely; processes which may be distant but involve high noise levels and processes which have lower noise levels and are discernible only because of their proximity to the measuring station. Noise levels, in any surrounding, are observed to be different in different times of a day, and different days of a week (Garcia and Faus 1991). These variations could be affected by the characteristics of traffic infrastructure such as vehicular mix, speed, amount and type of intersections, etc. (Guarnaccia 2013).

The global trend of urbanization has resulted in rapid physical expansion of urban areas (Hassan & Nazem 2015; Leeuwen et al. 2015). Karachi is the biggest metropolitan city of Pakistan, with high population density as well as environmental concerns largely attributed to the trend of urbanization. The spatio-temporal variations of traffic noise in the City of Karachi, Pakistan, can be characterized with several unique characteristics. They include old vehicles in use, overloading of passenger or freight vehicles causing excessive engine vibration and noise, driver's behaviour including excessive blowing of horns and playing loud music, weak law enforcement and traffic management that produce congested flow with jam in peak hours (Webster 1995; Barletta et el. 2002; Mehdi et al. 2011; Matin et al. 2012).

This research aims at developing a noise-level prediction model which can be applied to central business district (CBD) areas of an urban region. The prediction model is expected to be an important tool for urban land use planning which would be beneficial in creating sustainable and pleasantly liveable urban locales. The relationships between noise levels and factors affecting were also explored, from literature as well as with local data. This is the first time such models have been developed for CBDs in Pakistan. Moreover, the integration of traffic and land-use variables in noise prediction models will also be a contribution to the present noise prediction modelling literature.

2. Literature Review

Most issues are known to be associated with the zonal patterns of land use that determine the trip generation, i.e., traffic attraction of a given zone. The land use patterns would take a gravitational pull-and-push impact on transportation trips, particularly related to road traffic noise. It could be supported by the traffic regulations where trip permissions are given to some types of vehicle engines in a particular transportation zone (Waddell 2002). In addition, the width of a road segment would determine traffic volume that contributes the degree of transportation flows.

Traffic is a major problem in developing countries such as Pakistan where motorization has become an uncontrolled escalating phenomenon (Kazmi and Zubair 2014). This trend emanates congestion and it is common observation that vehicle horns are used more frequently in congested conditions. Another aspect is the ill-maintenance of roads which accelerates vehicle wear and tear resulting in higher noise levels of engine (Sindhu 2008).

The level of traffic noise has been predicted in previous literature where some analytical models were utilized in terms of noise propagation (Burgess 1977; Garcia and Faus 1991; Guarnaccia 2013; Prascevic et al. 2013). Meanwhile, regression and logarithmic models have also been adopted in forecasting transportation noise level mainly using traffic-associated parameters (Bugess 1977; Garcia and Fauss 1991; Guarnaccia 2013). However, non-traffic parameters such as land use type and pattern as well as physical distance from a given source, were suggested to play an important role in assessing noise level (Bayo et al. 1995; Bolund and Hunhammar 1999; Gidlof-Gunnarson and Ohrstrom 2007; Islam et al. 2012). The spatial pattern of land use is also known to impact on the demand of transportation trips (Institute of Transport Engineers 2008; Al-Zahrani and Hasan 2008; Dean et al. 2010). Aguilera et al. (2015) developed land use regression models for noise predictions for European cities. However, these models were univariate and based on the mean noise levels, instead of considering the temporal variations of noise.

3. Materials and Methods

3.1 Study Area

This study was conducted in Karachi, which is a metropolitan city of Pakistan situated at the gulf of Arabian Sea as shown in Figure 1. Mehdi *et al*. (2011) prepared spatio-temporal traffic-induced noise patterns for Karachi (see Figure 3). These patterns provided the rational to the study to use CBD area, where noise levels remain consistently higher.

Figure 3 (a): Recurring noise levels on weekend mornings; (b) Recurring noise levels on weekend afternoons; (c) Recurring noise levels on weekend evenings

Source: Modified after Mehdi et al. (2011)

The study area is the old core area, including downtown of the city, that is characterized by high density of population and commercial space. Most CBD areas are mixed with residential and commercial land use, which results in heavy traffic around the areas. Therefore, the land use pattern of the city could create negative environmental issues, including noise pollution. In particular, the Karachi CBD would have unique aspect compared with other megacities in Asian countries because many distinct land use activities are practiced from floor to floor even in a given building. Karachi lies in an arid part of the world where natural vegetation in urban area has been highly scarce. In study area vegetated landscape is almost not present except some isolated trees which might reduce the traffic noise as barrier.

Figure 1: Karachi city (https://maps.google.com)

3.2 Data Collection

It has been reported that traffic noise levels had temporal variations, hourly and daily, in association with traffic volume (Kim et al. 2012). We selected 90 locations from the old city area for collecting data related to noise, traffic and land uses. The monitoring location sare shown as black dots in Fig. 2. . In order to maximize the comparison between different time scales as recommended by Prascevic et al. (2013), we developed temporal intervals such as morning (06:30– 10:30), afternoon (12:00–15:00) and evening (16:30–24:00) for two weeks. Noise levels were monitored at 10 minute interval for each sampling period. The survey was conducted in normal days avoiding holiday periods in Pakistan such as Ramadan, Eid, Aashura, and Christmas etc.

Noise meter used for measuring noise data was Micro-14 with windscreen in dry weather, procured from Quest Technologies USA. Road edge (shoulder) was considered as the prime source of noise that varies according to the number of vehicle, time of the day and other traffic conditions. Therefore, noise meters were placed at 5 feet from the edge of the road as safe distance to the source. However, to include the noise from the surrounding land uses we assumed 165 feet radius that may be contributing to the recorded noise data. So the traffic and land use data was measured for buildings/developments within this diameter from the noise meter. Measurements for distribution of floor area were carried out and site-specific maps were drawn for each location using ArcGIS.

Figure 2: Traffic noise and land use data collection locations for the study area

The land use data was classified into several functional categories for statistical modelling as suggested by Carter et al. (2002). The land use types of the study area were reclassified to be residential, commercial, special purpose, transportation right of way, vacant and built-up. Any occupied land use unit for non-residential and commercial uses was classified into the type of special purpose. Transportation right of way was associated with land use area literally for vehicle and pedestrian trips, and vacant space was related to a unit where no land use activity occurs. Vacant land use represents the plots which are not under any use and they were observed to be without any substantial vegetation in the study area. Built-up area was the aggregate of all given land use types except the vacant and transportation right of way. In addition to the land use, the roadway width was also measured and included in the modelling process. Details of individual land use type are presented in Table 1 whereas Table 2 summarizes land use, noise level and traffic volumes of the selected monitoring stations.

Table 1. Subcategories of each land use type adopted in the study.

Table 2. Summary of relevant data sets acquired in sample points.

3.3 Predictive Models

A multivariate regression was used to develop noise prediction models for the study area, equation (1) shows the basis form of such model (Fomby et al. 1984; McCuen 1985; Rogerson 2001). F-statistics were referenced to decide less significant variables in the model, which eliminated prediction variables with statistically insignificant effect on the model (Theil 1978; Gujarati 1995).

$$Y = b_0 + b_1x_1 + b_2x_2 + \ldots\ldots + b_px_p \ldots\ldots\ldots\ldots (1)$$

The coefficient of multiple determinations, i.e., R^2, is the proportion of variation in the dependent variable explained by the regression model (Ali 2000). The sample R^2 tends to optimistically estimate how well the models fit the population (Christ 1966). The value of R^2 is considered to be acceptable for engineering data if it is greater than 0.5 (McCuen 1985; Aguilera et al. 2015). If the probability of the F-statistic is smaller than 0.05, the independent variables of the model would well explain the variation of the dependent variable (Fomby et al. 1984). All of these criteria were found to be satisfied in all the developed models in this research. It was observed that employment of non-linear models resulted in an improvement of less than 0.1 in R^2. Hence, it was decided that linear regression models are more convenient to use with sufficient accuracy. It is also noticed that roadway traffic noise levels are highly variable. Besides physical characteristics of location and traffic on road, behavioural characteristics of driver also plays significant role such as unnecessary honking which is very common in this part of the world. To minimize the impacts of behavioural impacts, mode (most occurring value) of monitored noise was used to create models. In addition to the aforementioned temporal periods, a model for predicting weekly average noise level was also developed. To test the accuracy of the models, approximately 1/3 of the data, chosen randomly, was kept aside. We used Statistical Package for the Social Sciences (SPSS) to estimate regression models (McCuen, 1985; Gujarati, 1995; Ali, 2000).

4. Results

We applied linear and non-linear regression models in predicting traffic noise levels for the study area. Non-linear models have quadratic or bi-linear ($x_1 \times x_2$) relationships; hence, they can be more complex to apply.

It was observed that all linear models have R^2 value of equal or greater than 0.66 for the test dataset. This level of correlation between the predicted and observed values were claimed to be sufficient for the use of regression models for noise predictions by Aguilera et al. (2015). Figure 4 illustrates the graphical comparison between model predictions and actual values of noise levels. It can also be observed from figure 4 that predicted values are overestimated than the actual noise level. A possible reason for that could be that the average hourly traffic volumes were used in the model for specific time periods. This bias may be eliminated with more detailed analysis of commuting patterns and commercial zone analyses (Seong et al. 2011). It is planned to enhance this work further with the use of more detailed traffic counts.

Figure 4: Comparison of model predictions with actual observations

This research estimated the parameters of the model based on equation (1). Table 3 summarizes the parameters of each prediction model. Model intercepts were found to be relatively low as compared to the average of observed mode of noise levels in normal traffic conditions in the study area (shown in table 2). The low value of intercept (constant) was statistically desirable because noise would tend to be zero when no traffic trips and land use activities occurred, i.e., $x_1, x_2, \ldots\ldots, x_8$ all tend towards zero (Hameed 1990; Gujarati 1995).

Models show that the size of vacant land area is negatively correlated with noise levels. For example, the greater the vacant space, the lower the intensity of noise in the vicinity would be. In other words, wind nullifies the echo effect (resonance) of traffic noise caused by barriers and dense built environment which has been proven by (Bolund and Hunhammar 1999).

In all models, traffic volume was positively related with noise level, i.e. higher level of traffic noise when traffic volume increase. This observation is consistent with that made by Prascevic et al. (2013) in their study. Moreover, these coefficients are higher in magnitude as compared with the coefficients of other variables indicating a higher impact on noise level by an order of 10. It confirms the fact that transportation noise is the major contributor to the noise levels.

Table 3. The constants and coefficients of the noise prediction model.

Meanwhile, the coefficients of all the prediction models resulted in positive for residential units, which could be explained with the peculiar vertical distribution of population in study area. In fact, most CBD areas of Karachi are occupied by multi-family flat residential units (or apartments), compared with other residential subcategories. In addition, the higher number of pedestrians on narrow streets played a role of making vehicles moving slower than the regulated speed limit of the city. On the contrary, such vehicle trip environment resulted in the frequent use of brake pedals and horn blowing by drivers, which in turn made noise pollution worse. It was found that the performance of the noise prediction models was improved by adding built-up land use as a single variable. This variable was found to be positively affecting the noise levels in all models.

5. Discussion

In terms of temporal resolution, the variable of either traffic volume or road width were found to be significantly affecting noise levels. Both variables, simultaneously, have not been found to affect any model which indicates the fact they are correlated with each other. Traffic volume has positive impact on the noise level which is obvious as more vehicles will generate more noise. The negative coefficients of road width variable indicate the inverse relationship between noise pollution level and road width. It happens to be a rational aspect as wider road width will result in more available space for dissipation of sound (Bolund and Hunhammar 1999).

The specially-purposed land use was found to increase transportation-related trips, so vehicle-pedestrian conflicts frequently occurred with many pedestrians and vehicles. The drivers' behaviour in the land use also contributed to make the noise pollution worsen in the city of Karachi. The positive coefficients of special purpose area would be produced essentially due to the inherent trip-generating characteristic of this land use category.

The coefficient of traffic count was approximately ten times higher than the coefficient of vacant space with opposite sign. So an increase of one vehicle in traffic nullifies the effect of approximately 10 sq. ft. of vacant space. Study area lies in highly populated mixed-land use part of Karachi city (Mehdi et al., 2011), where hourly average traffic remains more than 2000 vehicles/hour even in normal weekend mornings on many narrow road segments. Therefore, predicted intercepts are more than 70 dBA, reflecting higher prevailing roadway noise.

5.1 Comparison of Impacts

A prime objective of this research is to quantitatively compare the effects of land use and traffic on noise levels. Figure 5 represents a comparison of effects of traffic volume and land-use. The former being taken as the built-up space which indicates the total of all land-uses in the vicinity of the noise meter. It can be observed from this figure that the impact of traffic noise is higher on noise level as compared to land-use in all cases. It should be noted at this point that traffic volume was not found to be statistically significant in the model for Working Days Evening. The coefficients for traffic volume have a higher value on weekend noise levels as compared to weekdays which means that traffic has more impact on weekend noise levels as compared to weekdays.

Figure 5: Comparison of model coefficients for traffic volume and land-use

5.2 Estimating Traffic Volume per Unit Residential Space

It has been established in this study that traffic volume is the major contributor to the noise levels in the area. However, this parameter is dependent upon land-use and density of the area (Institute of Transport Engineers, 2008). Hence, it can be useful to calculate the amount of vehicles added to the traffic volume with a unit increase in the land-use. This is expected to be another useful contribution of this study. Traffic volume and residential land-use are significantly affecting noise levels in almost all the regression models in this study.

Therefore, coefficients of these variables were used to calculate the amount of traffic volume generated per sq. ft. of residential space. This ratio was calculated using equation (2) and the results are shown in table 4.

Vehicles/(residential sq. ft.) = (Coefficient of residential sq. ft.)/(coefficient of traffic volume) ……..(2)

Table 4. Traffic volumes per unit residential land-use

Table 4 shows that the highest volume generated by the residential land-use is during working days afternoon while the lowest is during weekend evening. The former may be explained by the fact that travellers tend to go from office to home during lunch hours. Furthermore, the traffic going to home from educational institutes (schools and universities) is also generated in those hours. These observations are consistent with those made by Venkatram et al. (2016) in their study. People tend to remain in their homes on weekend evenings so that they can wake up early for the next working day which explains the low traffic rate on weekend evenings. The validity of these observations for other areas, although seem true, but must be checked. The model for Working Days Evening did not contain traffic volume coefficient hence its rate cannot be calculated for this case. Secondly, commercial land-use was not found to be significantly affecting the noise level 4 hence traffic volume per unit commercial land-use could not be calculated.

5.3 Application of Prediction Models

The noise propagation models in existing literature (Abou-El-Seoud 1994; Mikkonen and Tuominen 1998) dealt with the phenomenon of noise propagation models (e.g. Hatano et al. 1989; Zannetti 1990; USEPA 1995; Folgert 1997; Hodgin et al. 1997; Comrie et al. 1997; Cartwright et al. 1997; Coe et al. 1998; Dent et al. 1998). The noise prediction model developed in this research is anticipated to be beneficial in providing existing noise propagation models for different temporal (diurnal, weekly) phases in CBD area of a metropolitan city (Karachi). These models have practical applications in urban and transportation planning, land use control, traffic and environmental engineering. For example, they can be used for calculating impacts on noise pollution of desired development projects.

5.4 Limitations of Prediction Models

The land use patterns in the study area exempted an important class of ‘Industrial’ which could be considered a limitation of these models. Therefore, these models have to be validated before use in other cities for such indigenous factors. The traffic mix used in the development of these models may be changed by future changes in transit services of Karachi such as Karachi Mass Transit Program (KMTP) or Bus Rapid Transit

(BRT). Such changes in vehicular mix of traffic can alter the predictability of the derived models. Therefore, the predictive modelling exercise should be validated periodically and modified in order to maintain models' accuracies.

Only simple linear regression models were used in this study to quantify and compare the effects of different parameters on noise levels. This has resulted in higher differences in modelled and observed values as compared to those in previous studies. Hence, these models are more useful for macro-level land use planning in which higher error tolerances are acceptable. These models can further be improved by incorporating 3D geometries of physical structures for meso and micro scale planning.

6. Conclusions and Recommendations

This research quantifies the effect of traffic and land-use on noise levels in an integrated manner through the use of regression models for CBD area of Karachi, Pakistan. The resulting models show positive effects of traffic and built-up space, especially for residential land use. It was also found that traffic volume has more impact on noise levels as compared to combined effect of land-use. The models reinforce the fact that traffic is a major noise generator in urban areas. It has more impact on noise levels on weekends as compared to weekdays. Moreover, vacant space has a negative effect on the noise level. Therefore, use of vacant space as a buffer between the road and population should be considered by urban planners in order to make CBD areas more liveable for residents.

It was inferred from the coefficients of the variables for traffic count and vacant space that every unit increase in traffic count (number of vehicles) has equivalent impact as that of approximately 10 units (sq. ft.) of vacant space. Interestingly, it also points out that residential land use with high density also contributes significantly to the noise level. In this context, it was further observed that residential land-use produce the highest traffic volume on weekday afternoons.

The models developed in this study are intended for noise prediction in CBD areas. Therefore, they can be used for development and planning of core urban areas for quantifying the impact of land use and traffic generation on noise levels. However, their utilization in the peripheral areas should be checked. Further research could be extended by incorporating more variables related to traffic (such as peak flow rate, proportion of different types of vehicles, speed, density and so forth) into these models.

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Table 1. Subcategories of each land use type adopted in the study.

Land use type	Subcategories
Residential	Single family, multi family, flats, hotels
Commercial	Bazaar, petrol pumps, retail stores, shopping areas, warehouses, cottage industries, restaurants, governmental and private offices, banks
Special purpose	Religious, educational, social and cultural institutions, medical facilities, parks, cinemas, playgrounds, zoo, picnic resorts
Transportation right of way	Roads, sidewalks, all sort of parking space, median

Table 2. Summary of relevant data sets acquired in sample points.

Item	Unit	Mean	Variance	Max	Min
Peak hourly traffic count	Vehicles per Hour	5905.76	3374.05	17274.00	1244.00
Roadway width	Feet	58.49	19.64	108.40	26.60
Commercial Space	Sq. Feet	120912.84	61762.29	273631.82	34260.69
Residential Space	Sq. Feet	43860.17	45893.74	191092.00	0.00
Special Purpose Space	Sq. Feet	14755.02	31260.08	220223.00	0.00
Vacant space	Sq. Feet	7942.35	19916.50	111836.00	0.00
Transportation Right of Way	Sq. Feet	46722.37	26264.76	208977.67	4914.00
Built-up Space	Sq. Feet	179528.03	90255.31	435479.82	34316.89
Noise levels	dBA	78.06	45.56	97.00	52.00

*Averages of monitored mode noise values at different time periods.

Table 3. The constants and coefficients of the noise prediction model.

Model Purpose	Parameter Estimates								Model Statistics		
	Constant	**Traffic Count**	**Road Width**	**Residential**	**Special Purpose**	**Transportation**	**Vacant**	**Built-up**	**R^2**	**F**	**Sig. Level**
Working Days Morning[1]	81.079	3.81E-04		3.17E-05	1.49E-05		-2.06E-05	1.63E-05	0.88	1.84	0.001
Working Days Afternoon	74.669	2.70E-04		3.77E-05	1.72E-05	2.77E-05		1.63E-05	0.83	1.52	0.019
Working Days Evening	83.526		-1.95E-02	3.06E-05		3.55E-05	-1.97E-05	1.17E-05	0.66	1.19	0.003
Weekend Morning[2]	76.382	5.43E-04		3.63E-05	2.62E-05		-1.87E-05	2.27E-05	0.80	1.47	0.000
Weekend Afternoon	70.603	5.65E-04		4.00E-05	3.73E-05		-2.73E-05	3.64E-05	0.66	1.19	0.032
Weekend Evening	77.224	5.12E-04		3.23E-05	2.58E-05		-1.58E-05	2.00E-05	0.73	1.32	0.003
Weekly Average	77.419	4.03E-04		3.59E-05	2.34E-05		-1.80E-05	2.12E-05	0.70	1.27	0.028

[1] Monday, Tuesday, Wednesday and Thursday, Mode values of ten minutes at 5 feet from the source about 4 feet above the surface.

[2] Friday, Saturday and Sunday, Mode values of ten minutes at 5 feet from the source about 4 feet above the surface.

Table 4. Traffic volumes per unit residential land-use

Temporal Model	Traffic coefficient	Residential space coefficient	Vehicles/(residential sq. ft.)
Working Days Morning	3.81E-04	3.17E-05	8.32E-02
Working Days Afternoon	2.70E-04	3.77E-05	1.40E-01
Weekend Morning	5.43E-04	3.63E-05	6.69E-02
Weekend Afternoon	5.65E-04	4.00E-05	7.08E-02
Weekend Evening	5.12E-04	3.23E-05	6.31E-02
Weekly Average	4.03E-04	3.59E-05	8.91E-02