Journal of Environmental Management xxx (2016) 1–8

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Vehicular traffic noise prediction using soft computing approach

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ARTICLE INFO

Article history:
Received 3 April 2016
Received in revised form
11 August 2016
Accepted 21 August 2016
Available online xxx

Keywords:
Vehicular traffic noise
Soft computing methods
Modelling

ABSTRACT

A new approach for the development of vehicular traffic noise prediction models is presented. Four different soft computing methods, namely, Generalized Linear Model, Decision Trees, Random Forests and Neural Networks, have been used to develop models to predict the hourly equivalent continuous sound pressure level, L_{eq}, at different locations in the Patiala city in India. The input variables include the traffic volume per hour, percentage of heavy vehicles and average speed of vehicles. The performance of the four models is compared on the basis of performance criteria of coefficient of determination, mean square error and accuracy. 10-fold cross validation is done to check the stability of the Random Forest model, which gave the best results. A *t*-test is performed to check the fit of the model with the field data.

1. Introduction

The world is witnessing an exponential rise in the number of vehicles on the roads, leading to an increase in the traffic noise levels. The high noise levels have been shown to affect the health and well-being of a considerable section of society, especially those living in close proximity of highways and urban roads (Banerjee, 2012). Studies (Ramirez and Dominguez, 2013; Guarnaccia et al., 2014; Ingle et al., 2005) have shown that in many cases the noise levels are higher than the prescribed limits set by the regulating agencies, for a particular region. There have been numerous attempts across the globe, which have tried to find methods to study, predict and mitigate the road traffic noise levels (Kephalopoulos et al., 2014; Garg and Maji, 2014; Chevallier et al., 2009; Singh et al., 2016).

Some of the existing vehicular traffic noise prediction models include Federal Highway Administration (FHWA), Calculation of Road Traffic Noise (CoRTN) and Richtlinien für den Lärmschutz an Straben (RLS-90) (Steele, 2001). A critical review of the different traffic noise prediction models, along with their historical development, has been presented by Steele (2001). These models consider the traffic conditions and database generated in terms of variables like traffic volume, percentage of heavy vehicles (single-unit trucks with 10 wheels and buses), average speed of vehicles and traffic composition for the respective country or region for which they have been developed. The models can predict the noise levels with high accuracy (in general, within ±2 dB(A)) for the particular region, but cannot be used as such, in a region where the road traffic conditions are significantly different. Also, the collection of a huge amount of data for formulating the reference energy mean emission level (REMEL) equations (FHWA, 2016) for different vehicle types remains a big challenge.

Some researchers have also tried using techniques like Artificial Neural Networks (ANNs) (Cammarata et al., 1995; Givargis and Karimi, 2010; Kumar et al., 2014) and Genetic Algorithms (GAs) (Gundogdu et al., 2005; Rahmani et al., 2011) for developing such models, with fairly good results. The use of different soft computing techniques for making a traffic noise prediction model for the Indian road traffic conditions seems to be a promising option, and has been explored in the present work.

The different types of vehicles plying on the Indian roads include two wheelers, three wheelers, cycle rickshaws, animal carts, cars, trucks, buses and agricultural tractor trailers. The presence of all types of vehicles on the roads, topology of the roads and intersections, pavement surfaces, driving habits of people and very large number of vehicles due to the ever increasing population make the traffic conditions and traffic characteristics quite different and peculiar to the Indian sub-continent. The noise pollution standards have been defined by the government of India under 'the noise pollution (regulation and control) rules' (Noise pollution, 2000). This document contains the prescribed noise level limits in different commercial and residential zones during day and night time.

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http://dx.doi.org/10.1016/j.jenvman.2016.08.053
0301-4797/

Please cite this article in press as: Singh, D., et al., Vehicular traffic noise prediction using soft computing approach, Journal of Environmental Management (2016), http://dx.doi.org/10.1016/j.jenvman.2016.08.053

In this work, four different soft computing methods have been used for model development, by considering the variables: traffic volume, percentage of heavy vehicles and average speed of vehicles in Patiala city, taking it as a representative set of the traffic conditions in India. The experimental values of these variables along with the equivalent continuous sound pressure level (L_{eq}) values constitute the data set that has been used to develop the models and to validate them.

The different soft computing methods that have been used, in the present work, include *Generalized Linear Model*, *Decision Trees*, *Neural Networks and Random Forests*. Artificial Neural Networks (ANNs) have been used for vehicular traffic noise modelling by Cammarata et al. (1995), Givargis and Karimi (2010) and Kumar et al. (2014). Genetic Algorithms (GAs) have also been used for traffic noise prediction by Gundogdu et al. (2005) and Rahmani et al. (2011). The different soft computing methods have been extensively applied for protein structure estimation (Rana et al., 2015), traffic light control (Turky et al., 2009), derivation of exposure-response curves for respiratory outcomes (Eliseeva et al., 2013), and in many more applications.

Studies that compare multiple linear regression with ANN (Kumar et al., 2014) and some of the other soft computing methods, which show that these methods outperform linear regression, are available, but a comparison of the different soft computing methods with each other, while developing the traffic noise models, seems to be missing. Also, a study which reports the use of these methods in the development of traffic noise prediction models which have higher accuracy as compared to linear regression, and the potential to consider large number of variables and datasets from different locations, seems to be missing. An attempt has been made in the present work to apply the four different soft computing methods in the development of vehicular traffic noise prediction models in Indian road traffic conditions and compare their performance.

The paper is structured as follows: first, an overview of the considered variables that significantly affect the road traffic noise level, the noise level descriptors, the data sets used and the different soft computing methods, is presented in Section 2; then, the development of the prediction models using these methods for the given variables and data sets is also presented in Section 2; model evaluation, results and discussion are given in Section 3 and finally, the conclusion is presented in Section 4.

2. Materials and methods

2.1. Assessment of traffic noise level

The traffic noise is composed of many individual vehicle noise sources. The individual vehicle noise, at the micro level, can be attributed to its components, which can be classified into: the engine noise, exhaust noise, transmission, tyre road interaction, aerodynamics, body and road rattle. Apart from the individual vehicle noise, the different variables which contribute significantly to the overall level of traffic noise include: traffic volume (number of vehicles on the road per unit time), traffic speed (average speed of vehicles on the considered road section), traffic composition (different types of vehicles present, like cars, buses, trucks, two-wheelers), gradient of road (slope) and pavement surface. There are studies where the effects of vehicle horns (Sharma et al., 2014) and acceleration/deceleration due to interrupted traffic flow conditions (Agarwal et al., 2009) have also been considered.

The traffic noise level at a particular location is assessed by using different descriptors. These descriptors are used to capture the time varying nature of traffic noise, because of short-term and long-term fluctuations in the noise level. L_{eq} and L_{10} are the commonly used descriptors in traffic noise assessment and abatement studies.

L_{10} denotes the noise level exceeded 10 percent of the time during the measurement period, usually the noisiest hour of the day. L_{eq} denotes the constant average sound pressure level that contains the same amount of acoustic energy as the fluctuating levels of noise during the measurement period. L_{eq} has been very frequently used as a standard descriptor to evaluate noise near urban roads, highways, residential and commercial areas.

The equivalent continuous sound pressure level, L_{eq} (Crocker, 2007) is given by

$$L_{eq} = 10\log\left[\frac{p_{rms}^2}{p_{ref}^2}\right] = 10\log\frac{1}{T}\int_0^T 10^{L(t)/10}\mathrm{d}t = 10\log\frac{1}{N}\sum_{i=1}^{N}10^{L_i/10} \quad (1)$$

where

p = A-weighted instantaneous acoustic pressure
p_{ref} = reference acoustic pressure = 20 (μ Pa)

The averaging time T can be one minute, one hour, one day and so on. The sound pressure levels L_i can be aggregated and the overall level obtained for a particular time period using Eq. (1). 'A' weighting filter (Crocker, 2007; Harris, 1997) is generally used to process the sound pressure level. Though L_{10} is easy for people to understand, L_{eq} is considered more useful and relevant, and is internationally accepted for most of the traffic noise analyses. Also, it can be used for summing up noise level of different sources, and then included in the analyses. L_{eq} is generally 3 dB(A) less than L_{10} for same traffic conditions.

Some other noise descriptors include the L_{90} (the background noise level), L_{50} and L_{dn} (day night average sound level).

2.2. Data sets and variables

In the present work, the variables, traffic volume (Q), percentage of heavy vehicles (p) and average speed of vehicles (V) have been considered to develop the traffic noise prediction models, as these variables are known to significantly contribute to the overall traffic noise level, as also confirmed by the variable importance study, described later. 502 experimental data sets of these variables and the equivalent continuous sound pressure level (L_{eq}), have been extracted from the different traffic noise studies on 3 sites, carried out by the authors in and around Patiala city, between year 2009 and 2015. The locations have straight and flat roads, and are at a sufficient distance from any traffic signals, roundabouts and speed breakers, so the acceleration or deceleration effects of vehicles can be safely ignored. The sound pressure level (L_{eq}) has been measured using a class 1 sound level meter and other measurements were done manually. The average speed of the vehicles has been obtained by using videography. A fixed distance (50 m) was marked on the road and the time taken by a vehicle to cover this distance was noted from the video. Thus, the speed was calculated for different vehicles and then the average was taken.

The considered variables, their description and a sample data set of a few values taken randomly are shown in Table 1.

2.3. Approach

The approach used in the development of the traffic noise prediction model is described in Fig. 1. First, suitable locations are selected in the Patiala city, on the basis of significant traffic flow,