A Review of Traffic Noise Predictive Models

J. Quartieri*, N. E. Mastorakis+, G. Iannone*, C. Guarnaccia*,S. D'Ambrosio°, A. Troisi°, TLL Lenza°

* Department of Physics "E.R. Caianiello", Faculty of Engineering
° Department of Mechanical Engineering, Faculty of Engineering
University of Salerno
Via Ponte don Melillo, I-84084 Fisciano (SA) – ITALY
iannone@sa.infn.it , quartieri@unisa.it

+ Technical University of Sofia,
English Language Faculty of Engineering
Industrial Engineering, Sofia 1000, Sofia
BULGARIA
http://www.wseas.org/mastorakis

Abstract: - In the traffic noise investigation framework, the need for a suitable predictive model is quite important, since it allows to evaluate the environmental impact, in case of existing infrastructures, or to design the road network such that noise is minimized, if the infrastructures are going to be built.

The traffic noise produced by motor vehicles, as main sources in urban areas, is part of general environment problem which inflicts a serious damage to the health of human beings and lowers the labour productivity. In order to control acoustical sound level in urban areas, methods for prediction of the traffic noise are necessary. In the literature many works are devoted to the development of a predictive Traffic Noise Model (TNM). In this paper, we present the TNMs usually employed in Europe, following their historical evolution starting from a general and elementary concept of noise prediction to a more detailed formula which may include many corrective terms.

Key-Words: - Noise Control, Traffic Noise, Vehicles Flow, Predictive Models.

1 Introduction

In the framework of urban settlements, the evaluation of traffic noise impact is very important. The quality of human life, in fact, is heavily influenced by a continuous exposure to acoustical noise exceeding a threshold [1-3], usually defined in the dedicated country regulation or in the International Standards.

Therefore, the evaluation of Environmental Noise Impact due to acoustical noise has to be performed. This can be achieved both by a measurement campaign or by a software simulation. The latter needs a very precise mathematical modelling of the environment, of the sources and of the propagation law of sound.

The development of models to predict traffic noise started more than 50 years ago and, the results have often been very accurate. Usually these kind of models are developed taking into account mainly traffic flow, both of light and heavy vehicles, features of the road surface, distance between carriage and receivers. Moreover, since several models have been developed all around the world, the peculiarities of different countries, in terms of roads, kind of vehicles and weather features have to be taken into account.

The aim of using a Traffic Noise Model (TNM) is twofold: on one side it can be used in the designing of new road infrastructures in order to evaluate the acoustical impact and to avoid post-construction mitigation actions that often present a greater cost; on the other side it can be used on an existing road network, so that the measurement campaign can be minimized and can be used just for the tuning of the model.

Many countries decided to regulate the use of these models, establishing which one can be adopted in a traffic noise simulation.

In this paper we present a quantitative review of the most used models, exploiting the main features and peculiarities of each of them.

2 Review of the most used Traffic Noise Models

2.1 Basic statistical models

First attempts of making a traffic noise prediction can be collocated into 1950/1960 decades; they mainly evaluate the percentile L_{50}, defined as the sound level exceeded by the signal in 50% of the measurement period.

These models refer principally to a fluid continuous flux, considering a common constant velocity with no distinction between vehicle typologies.

One of the first models, developed in 1952, is the one reported in Handbook of Acoustic Noise Control [4]. This model states that the 50 percentile of traffic noise for speed of 35-45 mph (about 55-75 Km/h) and distances greater than 20 feet (about 6 meters) is given by:

$$L_{50} = 68 + 8.5 Log(Q) - 20 Log(d) \tag{1}$$

where Q is traffic volume in vehicles per hour and d is the distance from observation point to center of the traffic lane, in feet; no specification is included about vehicles and roads type.

In the following years, Nickson et al. [5-6] presented a new model in which a new parameter is included to relate the model with the experimental data. They proposed:

$$L_{50} = C + 10 Log\left(\frac{Q}{d}\right) \tag{2}$$

where C is a constant value that can be evaluated making an analysis of experimental data and L_{50} is the sound level in dBA.

Later, Johnson et al. [7] presented a new TNM taking also into account the mean speed of vehicles in mph, v. They proposed for L_{50} the following expression:

$$L_{50} = 3.5 + 10 Log\left(\frac{Q\,v^3}{d}\right) \tag{3}$$

This model presents a good agreement with the experimental data for a percentage of heavy vehicles from 0% to 40%. It also include some corrective factor for ground attenuation and gradient.

Some years later, Galloway et. al [8] improved this model taking into a account the percentage of heavy vehicles P. Their expression for the L_{50} level in dBA was:

$$L_{50} = 20 + 10 Log\left(\frac{Q\,v^2}{d}\right) + 0.4P \tag{4}$$

The models developed in the next years introduced the equivalent level L_{eq} as sound level indicator. One of the most used is the Burgess Model [9] applied for the first time in Sydney in Australia. Using the same notation of the previous expression, the sound level is given by:

$$L_{eq} = 55.5 + 10.2 Log(Q) + 0.3P - 19.3 Log(d) \tag{5}$$

Another most used calculation formula is called “Griffiths and Langdon Method” [10]. In particular they propose the evaluation of equivalent level starting from the percentile level as follow:

$$L_{eq} = L_{50} + 0.018(L_{10} - L_{90})^2 \tag{6}$$

where the statistical percentile indicator have the expression:

$$\begin{aligned} L_{10} &= 61 + 8.4 Log(Q) + 0.15P - 11.5 Log(d) \\ L_{50} &= 44.8 + 10.8 Log(Q) + 0.12P - 9.6 Log(d) \\ L_{90} &= 39.1 + 10.5 Log(Q) + 0.06P - 9.3 Log(d) \end{aligned} \tag{7}$$

where Q, P and d have the same meaning of previous formula.

Several years later Fagotti et al. [11] improved the previous models introducing the motorcycles and buses flux, Q_M and Q_{BUS}. The formula they propose is the following:

$$L_{eq} = 10 Log(Q_L + Q_M + 8Q_P + 88Q_{BUS}) + 33.5 \tag{8}$$

Another model was formulated by the French “Centre Scientifique et Technique du Batiment” (C.S.T.B.) [12], which proposed a predictive formula of equivalent emission level, based on the average acoustic level (L_{50}) with the following expression:

$$L_{eq} = 0.65 L_{50} + 28.8 \ [dBA] \tag{9}$$

The value of L_{50} is calculated taking into account only the equivalent vehicular flows (Q_{eq}), and is given by:

$$L_{50} = 11.9\,LogQ + 31.4 \;\; [dBA] \qquad (10)$$

for urban road and highway with vehicular flows lower than 1000 vehicles/hour;

$$L_{50} = 15.5\,LogQ - 10\,LogL + 36 \;\; [dBA] \qquad (11)$$

for urban road with elevated buildings near the carriageway edge, with *L* the width (in meters) of the road near the measurement point.

It is easy to notice that all the previous models can be deducted by the general expression of the equivalent level calculated according to a statistical traffic noise model is:

$$L_{eq} = A \cdot LogQ\left[1 + \frac{P}{100}(n-1)\right] + b \cdot Log(d) + C \qquad (12)$$

Since a heavy vehicle generates a stronger noise than a light one, a factor *n*, called acoustical equivalent of heavy vehicles, has been considered. Therefore an equivalent traffic flow, Q_{eq}, can be formulated as follows:

$$Q_{eq} = Q\left[1 + \frac{P}{100}(n-1)\right] \qquad (13)$$

The *A*, *b* and C coefficients may be derived, for a fixed investigated area, by linear regression methods on many L_{eq} data taken at different traffic flows (*Q*,*P*) and distances (*d*). The acoustical equivalent, *n*, (defined as the number of light vehicle that generate the same acoustic energy of an heavy one) can be estimated both by regression method both by single vehicle emission measurements. Similarly it is possible to define an acoustical equivalent for other categories such as motorcycles, buses, etc..

2.2 England standard: CoRTN procedure

The CoRTN procedure (Calculation of Road Traffic Noise) has been developed by the Transport and Road Research Laboratory and the Department of Transport of the United Kingdom in the 1975 [13] and has been modified in the 1988 [14]. It estimates the basic noise level L_{10} both on 1h and 18 h reference time. This level is obtained at a reference distance of 10 m from the nearest carriageway edge of an highway.

The parameters involved in this model are: traffic flow and composition, mean speed, gradient of the road and type of road surface. The basic hypothesis of the model are a moderate wind velocity and a dried road surface.

The CoRTN procedure is divided in five steps:

1. Divide the road scheme into one or more segments, such that the variation of noise level within the segment is less than 2 dBA;
2. Calculate the basic noise level 10 meters away from the nearside carriageway edge for each segment. It depends on the velocity, traffic flow and composition. The traffic is considered as a linear source positioned at 0.5 m from the road surface and at 3.5 m from the carriage edge;
3. Evaluate the noise level, for each segment, taking into account the attenuation due to the distance and screening of the source line;
4. Adjust the noise level taking into account:
    a. reflection due to buildings and facades on the other side of the road and reflective screen behind the reflection point.
    b. Size of source segment (view angle);
5. Join the contributions from all segments to give the predicted noise level at the reception point for the whole road scheme.

Operatively the basic hourly noise level is predicted at a distance of 10 meters from the nearest carriageway, according to the following equation:

$$L_{10}(1h) = 42.2 + 10Log(q) \quad (dBA) \qquad (14)$$

and the basic noise level in terms of total 18-hour flow is:

$$L_{10}(18h) = 29.1 + 10Log(q) \quad (dBA) \qquad (15)$$

where *q* and *Q* are the hourly traffic flow (vehicles/hour) and 18-hour flow (vehicles/hour), respectively. Here it is assumed that the basic velocity is *v* = 75 km/h, the percentage of heavy vehicles is *P* = 0 and road’s gradient is *G* = 0%. It is also assumed that the source line is 3.5 m from the edge of the road for carriageways separated by less than 5.0 meters.

Subsequently the level will be correct to take into account mean traffic speed, percentage of heavy vehicles and gradient contribute.

In particular the corrections for heavy vehicles and speed are determined using the following expressions:

$$\Delta_{pV} = 33Log\left(v + 40 + \frac{500}{v}\right) + \\ +10Log\left(1 + \frac{5P}{v}\right) - 68.8 \quad (dBA) \tag{16}$$

where the mean speed *v* depends on road type and is reported in [14] for various roads. The percentage of heavy vehicles is then given by:

$$P = \frac{100f}{q} = \frac{100F}{Q} \tag{17}$$

where *f* and *F* are respectively the hourly and 18-hour flows of heavy vehicles. The value of *v* to be used in equation (16) depends on the road gradient. In particular, for roads with gradient, traffic speed in the previous relation will be reduced by the value ΔV which is predicted from:

$$\Delta V = \left[0.73 + \left(2.3 - \frac{1.15p}{100}\right)\frac{p}{100}\right]G, \quad km/h \tag{18}$$

where *G* is the gradient expressed as a percentage.

Once the traffic speed is known also the sound level is adjust for the extra noise from traffic on a gradients with the correction

$$\Delta_G = 0.3G \quad dBA \tag{19}$$

The noise depends also upon the road surface. In fact for roads which are impervious and where the traffic speed used in expression (16) is *V > 75Km/h* a correction to the basic noise level is applied as:

- $\Delta_{TD} = 10Log(90TD + 30) - 20, \quad dBA$ for concrete surfaces;
- $\Delta_{TD} = 10Log(20TD + 60) - 20, \quad dBA$ for bituminous surface;

where TD is the texture depth.
If instead $v \le 75\, km/h$ the correction are:

- $\Delta_{TD} = -1, \quad dBA$ for impervious bituminous road surfaces;
- $\Delta_{TD} = -3.5, \quad dBA$ for pervious road surfaces.

The model also consider the correction for receiver points located at distances $d \ge 4.0\, m$ from the edge of the nearest carriageway, which is:

$$\Delta_d = -10Log\left(\frac{d'}{13.5}\right), \quad dBA \tag{20}$$

where *d'* is the shortest distance between the effective source and receiver.

The last correction is the one associated with the propagation obstacles, such as the nature of the ground surface between the edge of carriageway and the receiver point (for example grass land, cultivated fields, etc.) or the presence of buildings, walls, barriers, etc..

2.3 German standard: RLS 90 model

In the Guideline for Noise Protection on Streets [15], the RLS90 (Richtlinien für den Lärmschutz an Straben) traffic noise model has been defined as an improvement of oldest standard RLS81 [16]. RLS90 is an effective calculation model, able to determine the noise rating level of road traffic and, at current day, is the most relevant calculation method used in Germany. The model requires an input of data regarding the average hourly traffic flow, separated into motorcycles, heavy and light vehicles, the average speed for each group, the dimension, geometry and type of the road and of any natural and artificial obstacles.

This model takes also into account the main features which influence the propagation of noise, such as obstacles, vegetation, air absorption, reflections and diffraction. In particular it makes possible to verify the noise reduction produced by barriers and takes into account also the reflections produced by the opposite screens. In addiction this is one of the few models present in literature that is able to evaluate the sound emission of a parking lot.

The starting point of the calculation is an average level L_{mE} measurable at a distance of 25 m from the centre of the road lane. This $L_{mE}^{(25)}$ is a function of the amount of vehicles per hour *Q* and of the percentage of heavy trucks *P* (weight > 2.8 tons), under idealized conditions (i.e. a speed of 100 km/h, a road gradient below 5% and a special road surface). Analytically $L_{mE}^{(25)}$ is given by

$$L_{m,E}^{(25)} = 37.3 + 10Log[Q\,(1 + 0.082P)] \tag{21}$$

The next step is to quantify the various deviations from these idealized conditions by means of corrections for the “real speed”, the actual road gradient or the actual surface, etc. In particular these correction depends upon whether day (6:00-22:00 h) or night (22:00-6:00 h) is considered. So for each lane the mean level in dBA L_m is calculated as

$$L_m = L_{m,E}^{(25)} + R_{SL} + R_{RS} + R_{RF} + R_E + R_{DA} + R_{GA} + R_{TB} \quad (22)$$

where

- R_{SL} is a correction for the speed limit;
- R_{RS} is a correction for road surfaces. It's given in a table and depends upon kind of surface and vehicle speed. It ranges from 0 to 6 dB. In particular:

  $$R_{RS} = 0.6|g| - 3 \quad for\ |g| > 5\%$$
  $$R_{RS} = 0 \quad for\ |g| \leq 5\%$$
- R_{RF} is a correction for rises and falls along the streets;
- R_E is a correction for the absorption characteristics of building surfaces;
- R_{DA} is a attenuation's coefficient that takes into account the distance from receiver and the air absorption;
- R_{GA} is a attenuation's coefficient due to ground and atmospheric conditions;
- R_{TB} is a attenuation's coefficient due to topography and buildings dimensions.

In particular the R_{SL} is given by the formula:

$$R_{SL} = L_{Pkw} - 37.3 + 10Log\left(\frac{100 + (10^{0.1D} - 1)P}{100 + 8.23P}\right) \quad (23)$$

with

$$\begin{aligned} L_{Pkw} &= 27.7 + 10Log\left[1 + (0.02v_{Pkw})^3\right] \\ L_{Lkw} &= 23.1 + 12.5Log(v_{Pkw}) \\ D &= L_{Lkw} - L_{Pkw} \end{aligned} \quad (24)$$

where v_{Pkw} is the speed limit in the range of 30 to 130 km/h for light vehicles and v_{Lkw} is the speed limit in the range of 30 to 80 km/h for heavy vehicles.

Evaluating the $L_{m,E}^{(25)}$ for each lane as described, we can obtain:

$$L_m = 10Log\left[10^{0.1L_{m,n}} + 10^{0.1L_{m,f}}\right] \quad (25)$$

where n represent the nearer and f the further lane respectively. Finally the sound pressure level for the street is given by:

$$L_r = L_m + K \quad (26)$$

K is the additional term for the increased effect of traffic light controlled intersections and other intersections.

2.4 Italian C.N.R. model

Nowadays the Italian legislation does not suggest any TNM of reference, but the most used by technician is the one developed by the Italian “Consiglio Nazionale delle Ricerche” (CNR) [17] and than improved by Cocchi et al. [18].

This model represents a modification of the German standard RLS 90, adapted to the Italian framework; a relation between the traffic parameters and the mean sound energy level is supposed and the traffic flow is modeled as a linear source placed in the center of the road. So the equivalent sound level in dBA is given by

$$\begin{aligned} L_{Aeq} = \alpha + 10Log(Q_L + \beta Q_P) - 10Log\left(\frac{d}{d_0}\right) + \\ + \Delta L_V + \Delta L_F + \Delta L_B + \Delta L_S + \Delta L_G + \Delta L_{VB} \end{aligned} \quad (27)$$

where Q_L and Q_P are the traffic flow in one hour, related to light and heavy vehicles respectively, d_0 is a reference distance of 25 meter and d the distance between the lane center and observation point on the road's edge. Then:

- ΔL_V is the correction due to mean flux velocity defined in the following table;

Flux mean speed (Km/h)	ΔL_V (dBA)
30-50	+0
60	+1
70	+2
80	+3
100	+4

- ΔL_F and ΔL_B are the correction for the presence of reflective façade near the observation point (+2.5 dBA) or in opposite direction (+1.5 dBA) respectively;
- ΔL_S is the correction for the road's pavement defined in the following table;

Road's pavement	ΔL_S (dBA)
Smooth Asphalt	-0.5

Rough Asphalt	0
Cement	+1.5
Rough pavement	+4

- ΔL_G is the correction for a road's gradient greater than 5% . The correction value is +0.6 dBA for each % gradient over 5% .
- ΔL_{VB} is a coefficient that takes into account the presence of traffic lights (+1.0 dBA) or slow traffic (-1.5 dBA).

Whilst all the cited parameters have a general validity, independent by countries (because related just to physical or urban parameters), the α e β parameters are influenced by characteristics of countries roads and vehicles. In particular α is related to noise emission from the single vehicles and β is the weighting factor that takes into account the greater emission of heavy vehicles (very frequently for Italian roads α = 35.1 dBA and β = 6 are assumed).

2.5 French model: NMPB – Routes

The European directive 2002/49/CE [19] for what concern the traffic noise prevision model suggest to use the official interim French standard model "Nouvelle Methode de Prevision de Bruit" or simply NMPB-Routes-96 [20].

This method has been developed by different French Institutes of Ministère de l'Equipement (CSTB, SETRA, LCPC, LRPC) and represents an improvement of an oldest one defined in the "Guide de Bruit" of 1980 [21], that takes into account the meteorological conditions and the long distance (d > 250m) prevision, as suggested in the ISO 9613.

Nowadays it represents one of the most used TNM, being also integrated in some commercial software such as CadnaA™ by 01dB.

In the 2000, under request of SETRA, a revision of NMPB-Routes-96 started, bringing to the NMPB-Routes-2008.

The method is based on the concept of propagation path. Several paths between a source and a receiver can exist, depending on topography and obstacles and, at each of them, a long term sound level $L_{Ai,LT}$ may be associated.

Despite of previous models, NMPB takes into account the standard meteorological conditions, as suggested by the ISO 9613, to adjust the prevision on long-period. They are classified in two types: meteorological conditions "favorable to the propagation" (as defined in ISO 9613) and "homogeneous acoustical conditions" (corresponding to the conditions used in the oldest French model).

So, the long-period prediction level for each path $L_{Ai,LT}$ is evaluated adding the terms corresponding to this two conditions:

$$L_{Ai,LT} = 10Log\left(p_i \, 10^{(0.1L_{Ai,F})} + (1-p_i)10^{(0.1L_{Ai,H})}\right) \quad (28)$$

where $L_{Ai,F}$ and $L_{Ai,H}$ are the global levels evaluated respectively for favorable and homogeneous conditions and p_i represent the probability of occurrence of favorable conditions.

These levels are calculated for each octave band and for each path from the source, according to the following formulas:

$$\begin{aligned} L_{Ai,F} &= L_{A,w} - A_{div} - A_{atm} - A_{grd,F} - A_{diff,F} \\ L_{Ai,H} &= L_{A,w} - A_{div} - A_{atm} - A_{grd,H} - A_{diff,H} \end{aligned} \quad (29)$$

For each path the algorithm computes three different attenuations: the geometrical spreading A_{div} and the atmospheric absorption A_{atm}, that are the same in both formulas, and the boundary attenuations A_{bnd}, which depends on the propagation conditions and are determined by ground effect (A_{grd}) and diffraction (A_{diff}).

The sound power level, $L_{A,w}$, is evaluated considering the hourly flux Q, reported in [21], and directly obtaining the equivalent hourly level in dB(A), E, associated to a single light or heavy vehicle. By this procedure the pointlike source acoustical power representing the road is given by:

$$\begin{aligned} L_{Awi} &= \left[(E_L + 10LogQ_L) + (E_P + 10LogQ_P)\right] + \\ &+ 20 + 10Log(I_i) + R(j) \end{aligned} \quad (30)$$

where E_L and E_P are the emission levels obtained from [21] for light and heavy vehicle, I_i the length in meter of considered road and R(j) is the value of normalized noise spectra from CEN 1793-3(1995) that take into account the frequency behavior of propagation.

The predictions of NMPB-Routes-96 have been validated on a great number of experimental campaign with various topography and meteorological conditions, founding a very good agreement with the noise data but generally an overestimate level is found in downward propagation conditions. That's why SETRA required the revision of the model. The NMPB-Routes-2008 presents a better estimation of noise level in downward condition, takes into account reflections on embankments, is able to evaluate the correction due to diffraction by low barriers and has implemented other minor corrections.

3 Comparison between TNMs

In this paragraph a quantitative comparison between different TNMs is presented. The aim of this comparison is an evaluation of the ranges of good functioning of each model. We expect, in fact, that a stable model do not diverge for any value of the traffic flux and that the general slope of the various curves is more or less similar for all the models, once one has neglected the corrective factors which usually strongly influence the behaviour of the prediction in some particular conditions.

Therefore, the adopted procedure is to fix some parameters, such as the percentage of heavy vehicles, the distance from the lane, the average speed and limit, and then to plot each model versus the traffic flux, adopting the “normalized” traffic flux whenever is needed, i.e. CSTB model. The results of these plots are showed in Figure 1.

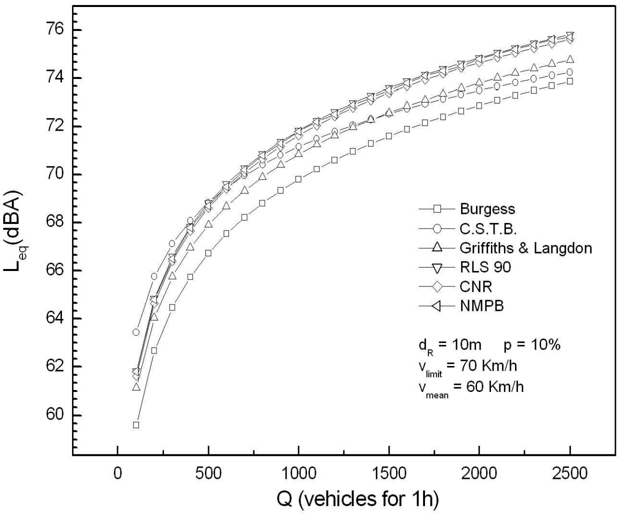

Fig.1: Comparison between different Traffic Noise Models, with fixed parameters (see legenda).

From this graph it is easy to see that quite all the models follow the same slope, with very few intersections. In this scenario, it can be evidenced that CSTB model has a slower growth with respect to the traffic flux. This is probably due to the fact that this model do not consider the difference between heavy and light vehicles, so for high values of *Q*, it underestimates the equivalent level.

It is also interesting to underline that the models developed and/or adopted in three of the biggest countries of Europe, that are RLS90 for Germany, NMPB for France and CNR for Italy, are practically overlapped in almost the entire range traffic fluxes. Moreover these models represent the highest curves, that is probably due to a precautionary estimation of acoustical noise.

4 Conclusions

In this paper a quantitative review of the most used traffic noise models has been presented.

Within their range of validity, the models here reviewed meet the requirements of various countries government regulations. In particular, the NMPB-Routes-96 actually represents the official standard TNM adopted by the European community.

The main features of the models have been presented and their peculiarities have been exploited. Almost all of them distinguish between vehicles type such as light passenger cars, light and heavy trucks, motorcycles, buses, etc; one of these models (RLS90) can simulate also the noise emitted by a parking lot.

All the TNMs here discussed adopt an acoustic energy descriptor, usually, the equivalent sound level L_{eq}; in some cases the percentile levels L_{10} or L_{50} are considered. Afterwards, the calculated sound level is generally corrected by means of various parameters, such as ground absorption, meteorological conditions, road's gradient, mean speed, flow type, etc.

In conclusion, we can affirm that the main limit of the presented models is the statistical basis adopted for the evaluation of the parameters of the model equation. In fact, both the fit of experimental data (e.g. Burges, Griffit-Langon.) and the employment of experimental plots (e.g. NMPB-Routes), don’t take into account the intrinsic random nature of traffic flow.

In our opinion, an ideal model should reproduce the random feature of the traffic type, with a well defined distinction between vehicles (also in the same categories, due both to the vehicles conditions and to conductor attitudes) and without any assumption of collective speed. The development of such a procedure will be object of forthcoming studies.

References:

[1] Ouis D., *Annoyance from road traffic noise: a review*, J. Environ. Psychol. 2001;21:101–20. and references therein.

[2] Kryter KD., *Community annoyance from aircraft and ground vehicle noise*, J. Acoust. Soc. Am. 1982; 72:1253–7.

[3] Langdon FJ, *Noise nuisance caused by road traffic in residential areas: Part I and II*, J. Sound. Vib. 1976;47:243–82.

[4] Anon., *Handbook of acoustic noise control WADC technical report*, 52-204. Wright Air Development Center, 1952.

[5] Nickson AF, *Can community reaction to increased traffic noise be forecast?*, Proc. Fifth International Congress on Acoustics, 1965.

[6] Lamure C., *Niveaux de bruit au voisinage des autoroutes*, Proc. Fifth International Congress on Acoustics, 1965

[7] Johnson DR, Saunders EG, *The evaluation of noise from freely flowing road traffic*, J. Sound. Vib., 1968; 7(2):287-309

[8] Galloway WJ, et al., *Urban highway noise: measurement, simulation and mixed reactions*, NCHRP report, 78, 1969.

[9] Burgess M.A., *Noise prediction for Urban Traffic Conditions. Related to Measurement in Sydney Metropolitan Area*, Applied Acoustics, vol. 10, pp 1-7, 1977.

[10] Griffiths ID, Langdon, FJ (1968), *Subjective Response to road traffic noise*, Journal of Sound and Vibration 8, 16-32.

[11] C. Fagotti and A. Poggi, *Traffic Noise Abatement Strategies. The Analysis of Real Case not Really Effective*, in Proc. of 18th International Congress for Noise Abatement, pp. 223-233, Bologna, Italy, 1995

[12] Centre Scientifique et Technique du Batiment, *Etude théorique et expérimentale de la propagation acoustique*, Revue d'Acoustique n.70, 1991.

[13] Anon, *Calculation of Road Traffic Noise*, London, United Kingdom Department of Environment and welsh Office Joint Publication, HMSO, 1975.

[14] Department of Transport, *Calculation of Road Traffic Noise*, HMSO, UK, 1988

[15] RLS, 1990. *Richtlinien für den Lärmschutz an Strassen*. BM für Verkehr, Bonn, 1990.

[16] Der Bunderminister fur Verkehr - "*Richtlinien fur den Larmschutz an Strassen*" - RLS81 (1981).

[17] Canelli G. B., Gluck K., Santoboni S. A., *A mathematical model for evaluation and prediction of mean energy level of traffic noise in Italian towns*, Acustica, 53, 31, 1983

[18] Cocchi A., Farina A., Lopes G., *Modelli matematici per la previsione del rumore stradale: verifica ed affinazione del modello CNR in base a rilievi sperimentali nella città di Bologna*, Acta of 19° Convegno Nazionale AIA, Naples 10-12 April, 1991.

[19] Directive 2002/49/EC of the European Parliament and of Council of June 25 2002 relating to the assessment and management of environmental noise, Official Journal of the European Communities, L189/12-25,18.7.2002

[20] NMPB-Routes-96 (SETRA-CERTU-LCPC, CSTB), is the French national computation method, referred to in 'Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, Article 6' and in the French standard 'XPS 31-133'. For input data concerning emission, these documents refer to the 'Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR1980.)

[21] *Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores*, CETUR, 1980.

[22] J. Quartieri, M. Guida, C. Guarnaccia, S. D'Ambrosio, D. Guadagnuolo, *Topological Properties of the Italian Airport Network studied via Multiple Addendials and Graph Theory*, International Journal Of Mathematical Models And Methods In Applied Sciences, Issue 2, Vol.2, pp 312-316 (2008), ISSN 1998-0140

[23] Quartieri J., Troisi A., Guarnaccia C., Lenza TLL, D'Agostino P., D'Ambrosio S., Iannone G., *Application of a Predictive Acoustical Software for Modelling Low Speed Train Noise in an Urban Environment*, WSEAS Transactions on Systems, Issue 6, Vol.8, pp. 673-682 (2009), ISSN: 1109-2777

[24] Quartieri J., Troisi A., Guarnaccia C., Lenza TLL, D'Agostino P., D'Ambrosio S., Iannone G., *An Acoustical Study of High Speed Train Transits*, WSEAS Transactions on Systems, Issue 4, Vol.8, pp. 481-490 (2009), ISSN: 1109-2777

[25] J. Quartieri, S. D'Ambrosio, C. Guarnaccia, G. Iannone, *Experiments in Room Acoustics: Modelling of a Church Sound Field and Reverberation Time Measurements*, WSEAS Transactions on Signal Processing, Issue 3, Vol.5, pp. 126-135 (2009), ISSN: 1799-5022

[26] J. Quartieri, L. Sirignano, C. Guarnaccia, *Infinitesimal Equivalence between Linear and Curved Sources in Newtonian Fields: Application to Acoustics*, International Journal of Mechanics, Issue 4, Vol.1, pp. 89-91 (2007), ISSN: 1998-4448

[27] J. Quartieri, L. Sirignano, A. Troisi, C. Guarnaccia, S. D'Ambrosio, *An Operatorial Approach to Sturm-Liouville Theory with Application to the Problem of a Spherical Conductor Embedded in a Uniform Field*,

International Journal Of Mathematical Models And Methods In Applied Sciences, Issue 2, Vol.2, pp 285-293 (2008), ISSN 1998-0140.

[28] J. Quartieri, L. Sirignano, C. Guarnaccia, *Equivalence between Linear and Curved Sources in Newtonian Fields: Acoustics Applications,* WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology (EMESEG '08), Heraklion, Crete Island, Greece, July 22-24, 2008.

[29] D'Ambrosio S., Guarnaccia C., Guida D., Lenza T.L.L., Quartieri J., *System Parameters Identification in a General Class of Non-linear Mechanical Systems,* International Journal of Mechanics, Issue 4, Vol. 1, pp 76-79 (2007), ISSN: 1998-4448

[30] J. Quartieri, M. Guida, C. Guarnaccia, S. D'Ambrosio, D. Guadagnuolo, *Complex Network Applications to the Infrastructure Systems: the Italian Airport Network case*, WSEAS International Conference on Urban Planning and Transportation (UPT'07), Heraklion, Crete Island, Greece, July 22-24, 2008. ISBN: 978-960-6766-87-9 / ISSN 1790-2769, pp 96-100.

[31] J. Quartieri, L. Sirignano, C. Guarnaccia, *Equivalence between Linear and Curved Sources in Newtonian Fields: Acoustics Applications,* WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology (EMESEG '08), Heraklion, Crete Island, Greece, July 22-24, 2008. ISBN: 978-960-6766-88-6 / ISSN 1790-2769, pp 393-395

[32] Quartieri J., Troisi A., Guarnaccia C., Lenza TLL, D'Agostino P., D'Ambrosio S., Iannone G., *An Italian High Speed Train Noise Analysis in an Open Country Environment*, Proceedings of the 10th WSEAS International Conference on "Acoustics & Music: Theory & Applications" (AMTA '09), Prague (Rep.Ceca), 23-25 March 2009. ISBN: 978-960-474-061-1 / ISSN: 1790-5095, pp 92-99.

[33] Quartieri J., Troisi A., Guarnaccia C., Lenza TLL, D'Agostino P., D'Ambrosio S., Iannone G., *Analysis of Noise Emissions by Train in Proximity of a Railway Station*, Proceedings of the 10th WSEAS International Conference on "Acoustics & Music: Theory & Applications" (AMTA '09), Prague (Rep.Ceca), 23-25 March 2009. ISBN: 978-960-474-061-1 / ISSN: 1790-5095, pp 100-107.

[34] Quartieri J., Guarnaccia C., D'Ambrosio S., Iannone G., *Room Acoustics Experimental Study: Characterization of the Sound Quality in a New Built Church*, Proceedings of the 10th WSEAS International Conference on "Acoustics & Music: Theory & Applications" (AMTA '09), Prague (Rep.Ceca), 23-25 March 2009. ISBN: 978-960-474-061-1 / ISSN: 1790-5095, pp 108-115

[35] J. Quartieri, M. Guida, C. Guarnaccia, et al., *Measurement and Analysis of Train Noise Detected on a Building Façade*, Proceedings of the 13th International Conference on "Applied Mechanics and Mechanical Engineering" – AMME13, Il Cairo, Egypt, 27-29 Maggio 2008.

[36] J. Quartieri, C. Guarnaccia, et al., *Measurements of high speed Train Noise Detected at a Relevant Distance and a Simple Numerical Model*, Proceedings of the 13th International Conference on "Applied Mechanics and Mechanical Engineering" – AMME13, Il Cairo, Egypt, 27-29 Maggio 2008

[37] S. D'Ambrosio, C. Guarnaccia, D. Guida, T.L.L. Lenza, J. Quartieri, *Lie Series Application to the Identification of a Multibody Mechanical System*, Proceedings of the 9th WSEAS International Conference on Automation and Information (ICAI '08), Bucharest (Romania), 24-26 June 2008. ISBN: 978-960-6766-77-0 / ISSN: 1790-5117, pp 480-483

[38] J. Quartieri, L. Sirignano, A. Troisi, C. Guarnaccia, S. D'Ambrosio, *Heavyside's Approach to an Elliptical PDE in a Significant Physical Problem*, 5th WSEAS / IASME International Conference on Engineering Education (EE'08), Heraklion, Crete Island, Greece, July 22-24, 2008. ISBN: 978-960-6766-86-2 / ISSN 1790-2769, pp 443-450