Traffic Noise Predictive Models Comparison with Experimental Data

Claudio Guarnaccia*, Tony LL Lenza°, Nikos E. Mastorakis+ and Joseph Quartieri*

* Department of Physics "E.R. Caianiello", Faculty of Engineering
° Department of Industrial Engineering, Faculty of Engineering
University of Salerno
Via Ponte don Melillo, I-84084 Fisciano (SA) – ITALY
guarnaccia@sa.infn.it , lenza@unisa.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: - The road traffic noise control is often performed by means of Traffic Noise predictive Models (TNMs). The most used and studied models are based on a statistical approach, in the sense that a functional relation is postulated, generally a logarithmic function, between equivalent level and some parameters (mainly vehicle flows, heavy vehicle percentage, distance source-receiver, etc.) and a fit on experimental data is performed, in order to tune the model on the data collected in the area under investigation. This procedure produce a kind of "site bias" in the prediction, that does not make the model suitable in any conditions and in any region.

In this paper, after having summarized some of the most known models, a comparison between simulated and experimental data is performed, in order to highlight the behaviour of models in two different sites.

The strong dependence on the site, and consequently on the vehicle flow volume and typology, will be sketched, together with the influence of climatic parameters.

Key-Words: - Noise Control, Road Traffic Noise, Traffic Noise Models, Experimental data.

1 Introduction

Road traffic noise pollution in urban environments is a quite relevant problem in the framework of human health care. The impact of long term noise exposure, in fact, has been deeply investigated in literature (for instance see [1-4]). On the other hand, road infrastructures and vehicles number have undergone a period of improvement and development, especially in recent advancing countries, where transport facilities are improving in order to support the economical and industrial growth.

In this framework, the development and the utilization of a suitable mathematical predictive model, i.e. a Traffic Noise Model (TNM), is quite relevant in order to perform an estimation of noise immitted in the environment, even without the aid of experimental measurements.

This issue can be of fundamental importance when a new infrastructure has to be settled down, that is in a preliminary planning program, or when a road is already "in operam", in order to monitor the noise impact on the surrounding environment just by knowledge of few traffic and road parameters.

In [5] the authors performed a detailed description and analysis of some of the most used TNMs, first presenting the historical development of the earliest models and then focusing on some countries adopted models. One of the conclusions of that study was that models are strongly influenced by data on which regression formula are applied, since they are all statistical models. The Federal Highway Administration (FHWA Phase 1 report [6]), for instance, at the end of the first evaluation phase of its TNM, concludes that there may be a kind of "site biases". This discrepancy can be due to many environmental factors, such as pavement type, driving skills, road and vehicles maintenance, speed limits, etc., and, in FHWA case, is used to "calibrate" the model in each site, via experimental measurements.

ISBN: 978-1-61804-020-6

In this paper, the authors ideally continue the work presented in [5], where the models have been quantitatively described and compared in function of the number of vehicles. The comparison is here extended to experimental measurements. The behaviour of the models in different sites and in different hours is sketched.

2 Review of some Traffic Noise Models

In this section, some of the most used TNMs, in particular the ones used in the comparison, are briefly sketched. In all the formulas, L_{eq} is the equivalent noise level, Q is the vehicles flow, P is the percentage of heavy vehicles, d is the distance source-receiver.

2.1. Burgess [7]

$$L_{eq} = 55.5 + 10.2 Log(Q) + 0.3P + 19.3 Log(d) \quad (1)$$

One of the most used is the Burgess Model [9] applied for the first time in Sydney in Australia.

2.2. Griffith and Langdon [8]

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

where the statistical percentile indicator are evaluated with the following formulas:

$$\begin{aligned} L_{10} &= 61 + 8.4 Log(Q) + 0.15P - 11.5 Log(d) \\ L_{50} &= 44.8 + 10.8 Log(Q) + 0.12P - 9.6 Log(d) \\ L_{90} &= 39.1 + 10.5 Log(Q) + 0.06P - 9.3 Log(d) \end{aligned} \quad (3)$$

2.3. CSTB [9]

$$L_{eq} = 0.65 L_{50} + 28.8 \ [dBA] \quad (4)$$

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

$$L_{50} = 11.9 \, LogQ + 31.4 \ [dBA] \quad (5)$$

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

$$L_{50} = 15.5 \, LogQ - 10 \, LogL + 36 \ [dBA] \quad (6)$$

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

2.4. German standard: RLS 90 model [10]

$$L_{m,E}^{(25)} = 37.3 + 10 Log[Q\,(1 + 0.082P)] \quad (7)$$

where $L_{m,E}$ is an average level measurable at a distance of 25 m from the centre of the road lane, for given standard conditions.

To this formula, one can apply additive correction terms. In this study we added only the correction for the "real speed", that is

$$R_{SL} = L_{Pkw} - 37.3 + 10 Log\left(\frac{100 + (10^{0.1D} - 1)P}{100 + 8.23P}\right) \quad (8)$$

with

$$\begin{aligned} L_{Pkw} &= 27.7 + 10 Log\left[1 + (0.02 v_{Pkw})^3\right] \\ L_{Lkw} &= 23.1 + 12.5 Log(v_{Pkw}) \\ D &= L_{Lkw} - L_{Pkw} \end{aligned} \quad (9)$$

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.

2.5. Italian C.N.R. model [11]

$$L_{Aeq} = \alpha + 10 Log(Q_L + \beta Q_P) - 10 Log\left(\frac{d}{d_0}\right) + \Delta L \quad (10)$$

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 m and d the distance between the lane center and observation point on the road's edge. In ΔL all the additive correction terms are included.

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 = 8 are assumed - see for instance [12]).

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

$$L_{eq} = A \cdot LogQ\left[1 + \frac{P}{100}(n-1)\right] + b \cdot Log(d) + C \quad (11)$$

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:

$$Q_{eq} = Q\left[1 + \frac{P}{100}(n-1)\right] \quad (12)$$

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 or by single vehicle emission measurements. Similarly it is possible to define an acoustical equivalent for other categories such as motorcycles, buses, etc..

3 Experimental session description

The experimental campaign has been planned in details, with a preliminary acquisition of all data and documents needed to a better understanding of the areas under investigation. In particular, the local cartography and design have been considered, in order to evaluate the best points of measurement.

Noise levels have been detected with a first class apparatus, according to national and international regulations (DM 16/03/1998, EN 60651/1994, EN 60804/1994, EN61094-1-2-3-4/1994, CEI 29-4).

The apparatus is based on a SOLO sound level meter, with a proper calibration. Before and after each measurement the calibration has been verified with a CAL21 calibrator.

All measurements have been taken with A-weighting and the noise indicator is the hourly equivalent level.

The first site is in Fabriano, Ancona (Italy). The measurement point is placed in an urban area, in Via Dante, with a speed limit of 50 *Km*/*h*. In this site 13 blocks of measurements have been performed during all the day. Each blocks is about 10 minutes long and sampling time is 1 second. The overall observation time is 2 hours and 10 minutes. All the experimental data have been collected in absence of rain, with a wind speed below 5 *m*/*s* and relative humidity below 79% (maximum value).

The second site is in Francavilla a Mare, Chieti (Italy). The measurement point is placed along the national road S.S. 16, in the urban area of the town, with a speed limit of 50 *Km*/*h*. In this site 8 blocks of measurements have been performed during all the day. Each blocks is about 50 minutes long and sampling time is 1 second. The overall observation time is 7 hours and 15 minutes. All the experimental data have been collected in absence of rain, with a wind speed below 5 *m*/*s* and relative humidity below 82% (maximum value).

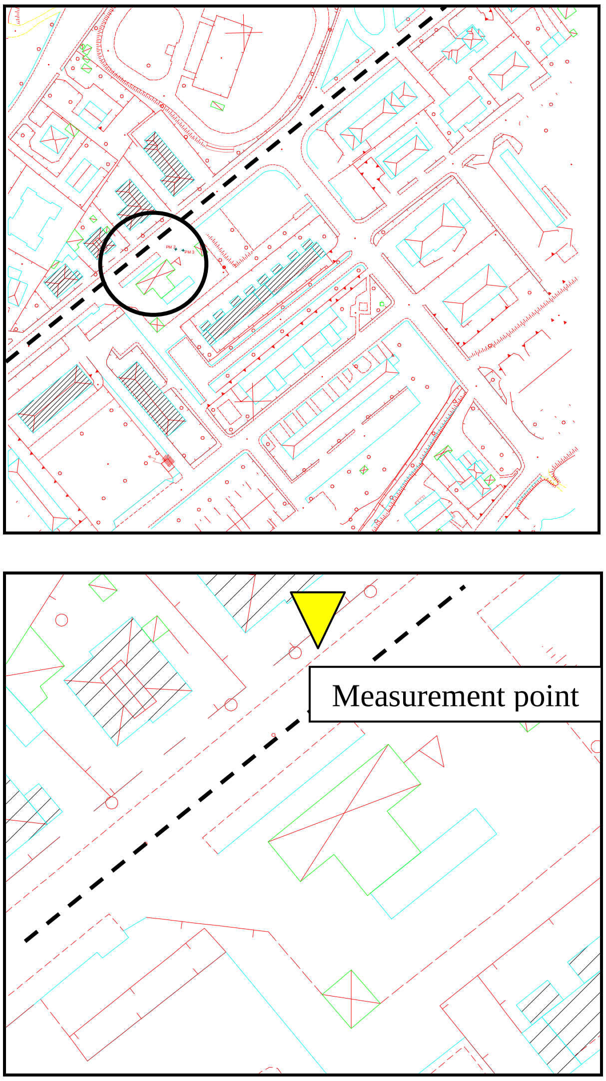

Fig. 1: Fabriano site of measurements. The area under investigation is in the circle, the dashed line represents the road and the triangle points to the sound level meter position.

ISBN: 978-1-61804-020-6

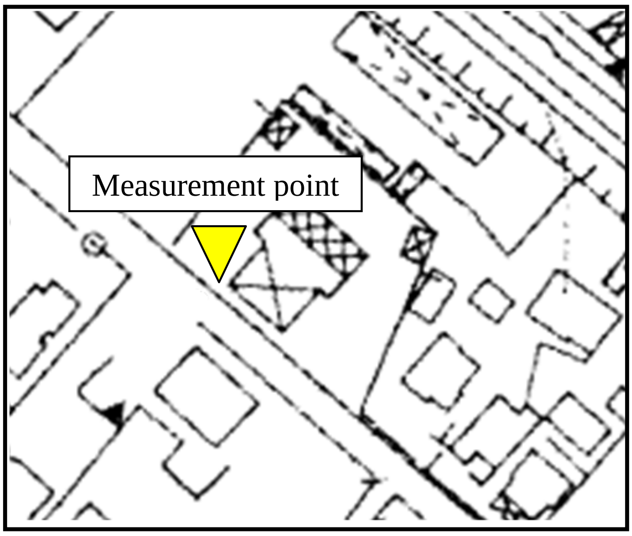

Fig. 2: Francavilla site of measurements. The triangle indicates the sound level meter position.

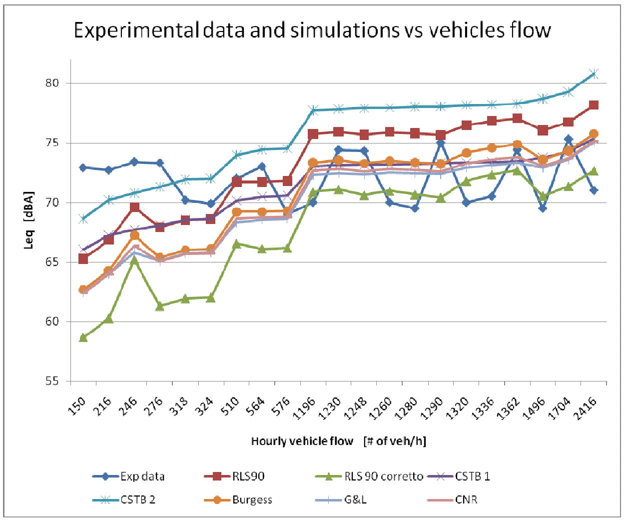

Fig. 3: Measured and simulated L_{eq} plotted versus hourly vehicles flow for various measurements in both sites. *x* axis is not on scale.

4 Analysis and results

In this section, a quantitative comparison between TNMs and experimental data is performed.

Of course, since the experimental setting is the same in both sites, one should expect a similar behaviour of data. This is not always true because the acoustical measurement is in general strongly influenced by propagation effects and environmental influence.

In Fig. 3, in fact, the comparison of measured data and models predictions are plotted versus hourly vehicle flow. Let us underline that the *x* axis is not on scale.

One should expect a logarithmic growth in the experimental data, according to formula (12). Instead, it is clear that when data are taken in different sites, there can be a kind of "*site bias*", due first of all to the different percentage of heavy vehicles, then to other elements, such as for example to pavement type, driving skills, traffic flow conditions, vehicle typologies and maintenance, etc.. This has been studied, for instance in [6], and the discrepancy between measured and predicted results has been used as a "correction factor", in order to adjust levels predicted and perform a sort of "calibration" process to be performed in each site. Even if this process improved the sensibility of the model, in some sites measured and predicted results still differ by each other of 3 to 5 dBA ([13]). Moreover, the calibration needs a measurements campaign, which usually the TNM aims to avoid.

Also the slope of models is not regular due to different percentage of heavy vehicles.

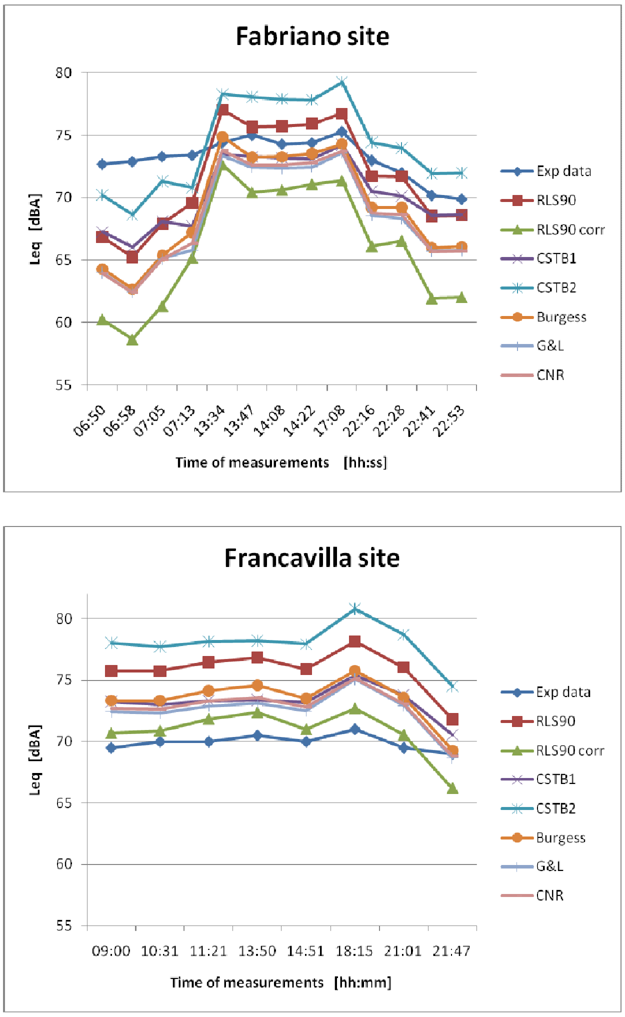

Fig. 4: Measured and simulated L_{eq} plotted versus time of measurements in both sites (up: Fabriano; down: Francavilla). *x* axis is not on scale.

ISBN: 978-1-61804-020-6

In Fig. 4 the comparison in different sites is performed versus time of measurement. Again, the *x* axis is not on scale.

It is evident that in Fabriano site there is a strong underestimation in the early morning. A similar trend can be evidenced in night time. This is partially explained by environmental conditions, in particular temperature and humidity values. In ISO 9613, the attenuation due to temperature and humidity is given and, even if this attenuation is related to long range propagation, one can think that a similar order relation can be adopted in proximity of the source. Thus, in early morning and late evening, when temperature is lower and humidity is higher than during day time, according to ISO 9613 the attenuation is reduced and the equivalent level is higher than the predicted values, in which no climatic factors are included. Let us underline that this is a partial explanation, that needs further investigation since the attenuation is function of the frequency and have to be quantified and integrated with other environmental factors. In Table 1 and Fig. 5, data on temperature and humidity in Fabriano site are resumed for a sample evening-night-early morning period.

In Francavilla site, instead, there is a quite constant overestimation of the models with respect to experimental data. This is mainly related to high traffic volume conditions (always higher than 1000 veh/h, except for last measurement), in a urban environment, with 50 *km/h* as a speed limit. The statistical models, in fact, do not consider the traffic flow conditions and let just the vehicles produce a certain amount of acoustical energy, such as if they are isolated sources. This is not true in the reality, where vehicles interact each other, breaking if traffic is going to be congested and accelerating if it is going to be more fluid. This approximation, together with a general lower speed because of not fluid flow, leads to a quite strong overestimation of the equivalent level predicted by the models.

In the end, it is interesting to plot simulated data versus measured ones, with the measured hourly vehicle flows, in the so-called "bisector plot", shown in Fig. 6. In this plot, of course, the most data are close to the bisector, the best the predictions are. One can notice that data have a quite big spread, that confirms the not perfect suitability of some models in some environments and highlights the existence of the "site bias" that makes impossible a statistical model to be universally adopted without a "tuning" on experimental data.

Tab. 1: Temperature and humidity data in Fabriano

Date	Time	Temperature °C	Humidity %
21/04/2011	19:00:00	19,3	43
21/04/2011	20.00.00	18,4	44
21/04/2011	21.00.00	17,2	43
21/04/2011	22.00.00	15,1	54
21/04/2011	23.00.00	13,9	59
22/04/2011	0.00.00	12,6	63
22/04/2011	1.00.00	11,6	67
22/04/2011	2.00.00	10,8	70
22/04/2011	3.00.00	09,9	73
22/04/2011	4.00.00	09,4	74
22/04/2011	5.00.00	09,3	75
22/04/2011	6.00.00	08,7	76
22/04/2011	7.00.00	08,6	79
22/04/2011	8.00.00	09,7	76
22/04/2011	9.00.00	11,5	68

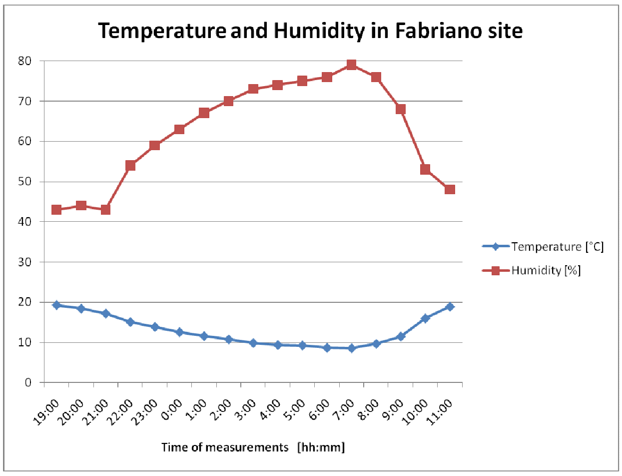

Fig. 5: Temperature (°C) and relative humidity (%) plotted versus time in Fabriano.

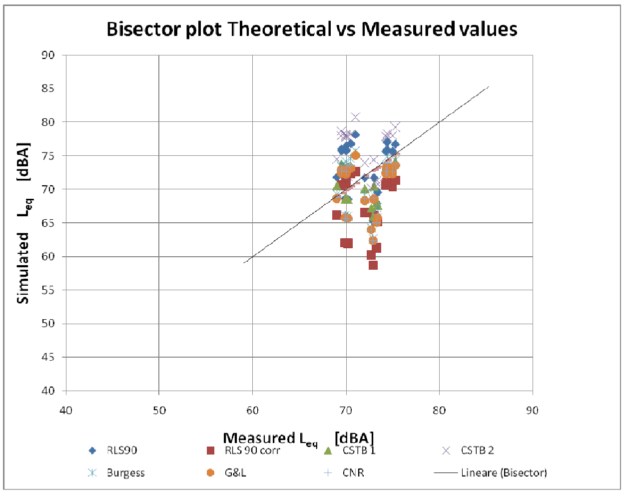

Fig. 6: Simulated versus Measured Leq, for both sites and all the measurements.

5 Conclusions

In this paper the review of models presented by some of the authors in [5] has been extended to experimental measurements comparison.

The "site bias" that is expected to appear when one is dealing with statistical models, is strongly confirmed on both measurement sites, Fabriano and Francavilla. In particular, in Fabriano there is a strong discrepancy between models and experimental data. This discrepancy, that is quite always an underestimation, is mainly due to the influence of environmental conditions, for instance climatic parameters (temperature and humidity), presence of reflecting surfaces, etc.. The other important factor is the low traffic volume, that let the flow be very fluid and the vehicle run at the desired speed. This leads to a higher equivalent level, since the acoustical power level increases with the speed of the vehicle (see for instance [14]-[15]).

In Francavilla, instead, the models predictions resulted to be quite always in an overestimation regime. This behaviour can be explained again with the traffic volume values (always higher than 1000 veh/h, except for last measurement). Since the road is in an urban environment, with 50 km/h as a speed limit, a so high number of vehicles can give a quite strong discrepancy in the prediction. Vehicles, in fact, are forced to reduce their speed because of congestions, traffic jams and safety distance, resulting in a lower than expected equivalent level.

These results confirm the main conclusion of [5]. The main limit of the statistical models is that they don't take into account the intrinsic random nature of traffic flow, in the sense that they don't take care of how vehicles really run, considering only how many they are. This result gives motivation to the development of dynamical TNMs, able to consider vehicle speed distributions, traffic flow conditions, etc.. An example of this attempt is given in [16], where the authors proposed a TNM that integrates in noise predictions, a Cellular Automata model, able to furnish dynamical parameters.

References:

[1] Langdon FJ, Noise nuisance caused by road traffic in residential areas: Part I and II, *Journal of Sound and Vibration*, 47 (2), 1976, pp 243–282.

[2] Kryter KD., Community annoyance from aircraft and ground vehicle noise, *Journal of the Acoustical Society of America*, Vol. 72, Issue 4, 1982, pp. 1222-1242.

[3] Ouis D., Annoyance from road traffic noise: a review, *Journal of Environmental Psychology*, Vol. 21, 2001, pp 101–120, and references therein.

[4] Theo Bodin, Maria Albin, Jonas Ardö, Emilie Stroh, Per-Olof Östergren, Jonas Björk, Road traffic noise and hypertension: results from a cross-sectional public health survey in southern Sweden, *Environmental Health* 2009, 8:38 doi:10.1186/1476-069X-8-38.

[5] Quartieri J., Mastorakis N. E., Iannone G., Guarnaccia C., D'Ambrosio S., Troisi A., Lenza T.L.L, *A Review of Traffic Noise Predictive Models*, Proc. of the 5th WSEAS Int. Conf. on "Applied and Theoretical Mechanics" (MECHANICS'09), Puerto De La Cruz, Canary Islands, Spain, December 14-16, 2009. ISBN: 978-960-474-140-3 / ISSN: 1790-2769, pp. 72-80.

[6] TNM Version 2.5 Addendum to Validation of FHWA's Traffic Noise Model® (TNM): Phase 1. U.S. Department of Transportation, Federal Highway Administration, Final Report, July 2004.

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

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

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

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

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

[12] 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.

[13] Hankard M., Cerjan J., Leasure J., *Evaluation of the FHWA Traffic Noise Model (TNM) for Highway Traffic Noise Prediction in The State of Colorado*, Report No. CDOT-2005-21, Colorado Department Of Transportation Research Branch, November 2006.

[14] Lelong J., Michelet R., Effect of acceleration on vehicle noise emission, in Proceedings of Forum Acustica (Joint ASA/EAA Meteting), Berlin, Germany (1999).

[15] Lelong J., Vehicle noise emission: evaluation of tyre/road and motor noise contributions, Internoise conference, Florida, USA (1999).

[16] Quartieri J., Mastorakis N.E., Guarnaccia C., Iannone G., *Cellular Automata Application to Traffic Noise Control*, Proc. of the 12th Int. Conf. on "Automatic Control, Modelling & Simulation" (ACMOS '10), Catania (Italy), 29-31 May 2010.

[17] Quartieri J., Guida M., Guarnaccia C., D'Ambrosio S., Guadagnuolo D., 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).

[18] 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).

[19] 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).

[20] Guarnaccia C., Analysis of Traffic Noise in a Road Intersection Configuration, *WSEAS Transactions on Systems*, Issue 8, Volume 9, (2010), pp.865-874, ISSN: 1109-2777.

[21] Quartieri J., Mastorakis N. E., Guarnaccia C., Troisi A., D'Ambrosio S., Iannone G., Traffic Noise Impact in Road Intersections, *International Journal of Energy and Environment*, Issue 1, Volume 4 (2010), pp. 1-8, ISSN: 1109-9577

[22] Quartieri J., D'Ambrosio S., Guarnaccia C., Iannone G., 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).

[23] Quartieri J., Sirignano L., Guarnaccia C., 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).

[24] 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.

[25] Quartieri J., Guida M., Guarnaccia C., D'Ambrosio S., Guadagnuolo D., *Complex Network Applications to the Infrastructure Systems: the Italian Airport Network case*, WSEAS Int. Conf. on Urban Planning and Transportation (UPT'07), Heraklion, Crete Island, Greece, July 22-24, 2008.

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

[27] 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*, Proc. of the 10th Int. Conf. on "Acoustics & Music: Theory & Applications" (AMTA '09), Prague (Rep.Ceca), 23-25 March 2009

[28] 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*, Proc. of the 10th Int. Conf. on "Acoustics & Music: Theory & Applications" (AMTA '09), Prague (Rep.Ceca), 23-25 March 2009.

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

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

[31] 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

[32] Guarnaccia C., Mastorakis N. E., Quartieri J., *A Mathematical Approach for Wind Turbine Noise Propagation*, in Applications of Mathematics and Computer Engineering, American Conference of Applied Mathematics (AMERICAN-MATH '11), Puerto Morelos, Mexico, 29-31 January 2011, pp. 187-194. ISBN: 978-960-474-270-7; ISSN (electronic): 1792-7269; ISSN(printed): 1792-7250.