Evaluation of Single Vehicle Noise Emission in Different Speed Conditions

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Abstract. Because of the increase of vehicles number, the evaluation and monitoring of road traffic noise assume a significant role for decreasing risks for human health and managing environmental pollution in urban areas. Noise measurements cannot be performed everywhere, or even in a large number of sites, because of high costs and time consumption. For this reasons, Road Traffic Noise predictive Models (RTNMs) can be implemented to estimate the noise levels, knowing certain parameters needed as input. This paper describes the comparison of the results, in terms of sound power level emitted by a single vehicle, obtained with the application of some Emission Models (EMs) to different simulations of driving conditions. After a preliminary comparison between the models, the evaluation of two indicators, namely the average and total source power level, will be discussed in relation to different conditions of the vehicle kinematics.

1. Introduction
Environmental noise and, in particular, road traffic noise, affect the health and well-being of people. According to the European Environment Agency [1], indeed, almost 110 million people are exposed to higher noise level than the standard threshold (55 dBA) daily. The Environmental Noise Directive 2002/49/EC [2] enforces EU member States to start a process of management and containment of noise. For these reasons, the environmental noise impact must be evaluated through the analysis of the data deriving from a measurement campaign, with the use of accurate instruments and in compliance with the technical regulations, or the use of a software simulation. In literature several models to predict traffic noise have been developed in order to obtain reliable results [3-11]. However, the Road Traffic Noise predictive Models need a very precise modelling for the sources, the sound propagation law and the receiver assessment. Specifically, the estimation of noise emissions generated by road traffic requires the knowledge of traffic flow, both of light and heavy vehicles, the vehicle kinematics, engines and exhaust systems, the aerodynamic friction and the environmental features [8, 9]. Speed profiles are extremely important, in order to properly assess the noise emitted in different regimes [10-12]. The main goal of this study is to compare results from single vehicle noise Emission Models (EMs), with reference to the source power level. In particular, the analysis of five models on the acoustic emissions estimation of a vehicle is based on simulations of speed profiles related to urban and suburban routes. After a preliminary comparison between the models, the evaluation of two indicators, namely the average and total sound power level, will be discussed in relation to different conditions.
2. Material and methods

2.1. Predictive models for the evaluation of the sound power level

The present study will focus on light vehicles noise emission estimated according to five models, that are Lelong [13] (used in Quartieri et al. [14]), SonRoad [15], NMPB Routes [16], ASJ-RTN (both for steady and non-steady conditions) [17] and Chossos [18]. In order to compare the above mentioned models, Figure 1 shows the trend of the sound power level of a single vehicle as a function of speed (given in km/h). Such a comparison has been carried out in an ideal scenario, represented by a straight road, no changes in altitude (hence with zero gradient), with common asphalt (neglecting then the corrections due to the road surface) and without considering the possible interactions with other vehicles. Almost all the models have a similar logarithmic trend, especially at medium-high speed, when the noise generated by tire-asphalt contact and rolling is predominant. At low speeds, instead, when the propulsion noise prevails, the differences between the models are more evident.

![Figure 1. Comparison of models: A-weighted sound power level for a single vehicle.](image)

2.2. Definition of indicators for models comparison

Since the aim of this study is the evaluation of sound emissions of a single light vehicle when its dynamic conditions vary, a quantitative comparison between the results deriving from the application of the models can be made. As a consequence, two indicators can be defined in relation to the average and the total sound power levels in a certain time of observation:

\[
L_{w,m} = 10 \log \left[ \frac{1}{T} \sum_{i} 10^{L_{w,i}} \Delta t \right],
\]

\[
L_{w,tot} = 10 \log \left[ \sum_{i} 10^{L_{w,i}} \right]
\]

where \( \Delta t \) is the time interval used for measurement or estimation of sound power level and \( T \) is the total time of observation of the phenomenon.

3. Results and discussion

The models have been applied to three simulations for a single light vehicle, considering the kinematics variables and neglecting the correction terms. The simulations are based on a time interval of 60 seconds and differ in speed profiles. Specifically, the three speed profiles have the aim to simulate a free flow traffic condition (simulation 1) on a high-speed road (e.g. highway) and two different driving conditions on a urban road: a stop&go condition, for instance in proximity of an intersection with traffic light (simulation 2), and a random acceleration condition, for instance in a congested road (simulation 3). The free flow condition aims at simulating the entering a highway from the acceleration lane. The speed
profile is shown in Figure 2(a). The corresponding sound power level curves for the various models are presented in Figure 2(b), in which all the models have similar trends, except for NMPB and ASJ-RTN non-steady, which have lower values. The latter, indeed, is valid up to a speed of 80 km/h on highways, that is reached in about 8 seconds; after this value the steady model should be considered.

![Figure 2](image)

**Figure 2.** Simulation 1: (a) Speed profile, (b) $L_{w,A}$. 

The speed profile of simulation 2, as shown in Figure 3(a), is characterized of both linear and constant trends. The stop at the traffic light occurs at the second 22 and lasts 10 seconds. Then, the vehicle restarts with the same initial acceleration. With regards to the sound power levels (Fig. 4(b)), it is possible to focus on idling stop vehicle at traffic light. For SonRoad and ASJ models, the power level turns out to be zero, because they consider only the sound emissions as a function of speeds different from zero. NMPB model, instead, considers an extremely low power level (approximately 28 dBA) that is almost unrealistic if considering that the emission is approximately 91 dBA at 10 km/h. In the other ranges of time, almost all models are congruent with each other. The only exception is the NMPB that presents a sudden decrease in the levels every time that the vehicle change from a uniform to an accelerated motion. This peculiarity is justified by the abrupt transition from steady to non-steady motion.

![Figure 3](image)

**Figure 3.** Simulation 2: (a) Speed profile, (b) $L_{w,A}$. 

The last simulation is related to a highly variable motion, characterized by a random acceleration instant by instant. Generally, it varies in magnitude and in positive/negative direction, with the exception of the first 10 seconds, where the direction is only positive. Figure 4(a) shows the speed profile in function of
time. This simulation describes real situations of busy roads (with consequent motion disturbance of vehicles) or driver’s aggressive driving style. This is the only simulation that presents a jerk (i.e. the acceleration derivative) different from zero. In Figure 4(b), it is possible to note that almost all the models, after the first phase of acceleration, converge to similar values and slopes. Only NMPB model has a fluctuation of values. Moreover, it is possible to observe the similarity between ASJ non-steady and Cnossos, even though they are based on quite different principles.

A quantitative comparison between the three simulations can be realized with the calculation of the two indicators $L_{w,m}$ and $L_{w,tot}$. The results are presented in Table 1. As expected from the definition of the two indicators, the total sound power levels assume a higher value than the average ones, which are averaged over the total time. Moreover, the speed profile of simulation 1 produces greater power levels, both medium and total. Finally, analysing the individual simulations with reference to the various models, they show similar results, since the differences are generally contained within a ± 3 dBA range, with the exception of the NMPB model, that exhibits values usually lower than the others.

![Figure 4. Simulation 3: (a) Speed profile, (b) $L_{w,A}$.](image)

| Models          | Simulation 1  | Simulation 2  | Simulation 3  |
|-----------------|---------------|---------------|---------------|
|                 | $L_{w,m}$ [dBA] | $L_{w,tot}$ [dBA] | $L_{w,m}$ [dBA] | $L_{w,tot}$ [dBA] | $L_{w,m}$ [dBA] | $L_{w,tot}$ [dBA] |
| Lelong          | 108.1         | 125.9         | 97.2          | 115.0          | 96.5           | 114.2           |
| SonRoad         | 108.5         | 126.3         | 95.6          | 113.3          | 94.6           | 112.4           |
| NMPB            | 102.1         | 119.8         | 93.3          | 111.1          | 94.7           | 112.4           |
| ASJ non-steady  | 102.3         | 120.1         | 97.3          | 115.1          | 97.8           | 115.6           |
| ASJ steady      | 107.4         | 125.2         | 95.4          | 113.2          | 94.4           | 112.1           |
| CNOSSOS         | 107.1         | 124.8         | 95.1          | 112.9          | 94.4           | 112.2           |
| **Average**     | **105.9**     | **123.7**     | **95.7**      | **113.4**      | **95.4**       | **113.2**       |

4. Conclusions

In this paper, different sound power emission models have been analysed by comparing the predictive power levels of a single light vehicle in different conditions. The analysis has enabled the evaluation of the trend of the models considering three simulations of speed and acceleration values, respectively in highway and urban routes. The results revealed several trends for the models, as might be expected
given the different mathematical structures. In particular, the NMPB model presents higher variability and lower values than the others, while Cnossos seems to be more stable in the various applications. Comparing the noise emissions estimated by the selected models, with the evaluation of two indicators, namely the average and the total levels, it is possible to observe a general flattening of the differences between the various calculation techniques. For further developments, the two defined indicators could also be evaluated in real study cases with real measured kinematics data for different routes with the same origin and destination points. The two indicators could address people choices for different routes according to their sensibility to the impact of sound emission.

References
[1] European Environment Agency 2020 Environmental noise in Europe — 2020 Report No 22/2019, (online), https://www.eea.europa.eu/publications/environmental-noise-in-europe
[2] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise Official Journal of the European Communities (OJEC) L189/12-25, 18 July 2002.
[3] Guarnaccia C, Lenza TLL, Mastorakis NE and Quartieri J 2011 A comparison between traffic noise experimental data and predictive models results Int J of Mech 5(4), pp. 379-386
[4] Guarnaccia C, Bandeira J, Coelho MC, Fernandes P, Tcixeira J, Ioannidis G and Quartieri J 2018 Statistical and semi-dynamical road traffic noise models comparison with field measurements AIP Conf. Proc. 1982 pp1-6
[5] Guarnaccia C 2013 Advanced tools for traffic noise modelling and prediction WSEAS Trans. Syst. 12, 121-130
[6] Guarnaccia C, Quartieri J, Mastorakis NE and Tepedino C 2014 Development and application of a time series predictive model to Acoustical noise levels WSEAS Trans. Syst. 13, 745-756
[7] Guarnaccia C, Quartieri J, Rodrigues ER and Tepedino C 2014 Acoustical noise analysis and prediction by means of multiple seasonality time series model, Int. J. Math. Mod. Meth. Appl. Sci. 8, 384-393
[8] Steele C 2001 A critical review of some traffic noise prediction models Appl. Acoust. 62 pp 271
[9] Cirianni F and Leonardi G 2012 Environmental modeling for traffic noise in urban area American Journal of Environmental Science 8 pp 345-51
[10] Can A and Aumond P 2018 Estimation of road traffic noise emissions: The influence of speed and acceleration Transportation Res. 58 pp 155-71
[11] Guarnaccia C 2020 EAgLE: Equivalent acoustic level estimator proposal Sensors 20 (3), 701
[12] Iannone G, Guarnaccia G and Quartieri J 2011 Noise fundamental diagram deduced by traffic dynamics. Proc. of the 4th WSEAS Int. Conf. EMSESEG’11, pp 501-07
[13] Lelong J 1999 Vehicle noise emission: evaluation of tyre/road and motor-noise contributions Proc. of Internoise 1999 pp. 203-08
[14] Quartieri J, Iannone G, Guarnaccia C 2010 On the Improvement of Statistical Traffic Noise Prediction Tools Proc. of the 11th WSEAS Int. Conf. AMTA ’10 pp. 201-07
[15] Heutschi K 2004 SonRoad: new swiss road traffic noise model. Acta Acust. United Acust. 90
[16] Besnard F, Hamet JF, Lelong J, Le Duc E, Guizard V, Fürst N, Doisy S, Dutilleux G 2009 Road noise prediction. 1 — Calculating sound emissions from road traffic Methodol. Guide Ed Sétra.
[17] Yamamoto K 2010 Road traffic noise prediction model ‘ASJ RTN-Model 2008’: report of the research committee on road traffic noise Acoust. Sci. Technol. 31 pp 1–55.
[18] CNOSSOS-EU (2012) Common Noise Assessment Methods in Europe, (online), https://ec.europa.eu/jrc/en/publication/reference-reports/common-noise-assessment-methods-europecnoossos-eu.

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