Analysis of Road Traffic Noise Propagation

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***Abstract*—**Road vehicular traffic is one of the most important acoustical noise source in the urban environment. The annoyance produced by noise, in fact, can heavily influence the quality of human life. Thus, a proper modeling of the source and of the propagation can give important assistance to the noise prediction and thus to the urban planning and development design. In this paper, the authors approach these issues by means of field measurements analysis, defining and evaluating a "degree of linearity" coefficient, related to the power law of the source-receiver distance in the logarithmic propagation formula. This value is expected to be 10 in the linear scheme, i.e. the approach of several literature studies and regulation models, or 20 in the point scheme. Plotting the results for this parameter in the two available sets of experimental data, the authors will corroborate the linear hypothesis. Even if in this study reflections, absorbing surfaces, atmospheric factors, etc., have not been considered in the theoretical model, but, of course, they are included in the measurement results, the results are in agreement with literature.

In addition, by analyzing the data with respect to traffic flow, i.e. number of running vehicle per hour, "degree of linearity" coefficient results are close to the expected value, i.e. 10, especially in the medium range of traffic flow.

***Keywords*—** Noise Control, Road Traffic Noise, Propagation Model, Source Modeling.

I. Introduction

THE annoyance produced by exposure to road traffic noise has been always recognized as one of the most important problem in urban areas (see for instance [1] and [2]). The effect on human life, in fact, is founded to be relevant, especially when noise occurs during night time and affects sleeping (residential areas), or in area in which careful activities have to be performed (hospitals, libraries, etc.). In general, regulation requires local government to define acoustical zones according to the purpose of buildings therein, and suggests different limits for the noise that can be accepted in each area.

The need for a suitable mathematical prediction of noise emitted by vehicles, led to the development of many predictive models, so called Traffic Noise predictive Models (TNMs). In [3] the authors gave a detailed review of the most used TNMs. Subsequently, in [4], some of these models have been tested on experimental data in two different sites, showing a quite strong dependence of the statistical approach on experimental data used for parameters evaluation.

In general, noise emitted by road traffic is very difficult to be modelled and predicted, because of its intrinsic random nature (see for instance [5] and [6]).

The task to find out the best dependence of the equivalent noise level from the vehicular flow and from other parameters has been pursued in many papers ([7-12] and references therein). In this paper, the authors consider two experimental sets of data taken contemporary in three different points, at four different distances from the road. Since the source during each measurement can be assumed to be the same for all the receivers, an interesting comparison between measured levels can be performed. The distances difference can be used to test the dependence of the level from the source-receiver distance, the so called "geometrical divergence". This dependence is a power law and, in analogy with the electrostatic field, it is $1/r$, for linear sources, and $1/r^2$ for pointlike ones.

The choice of source typology is very important in the modelling of the problem and, in this paper, it is investigated by means of experimental data analysis. Even if engineering models usually model road as a linear source (see for instance [13, 14]), it could be reasonable, especially in low traffic flow conditions, to consider, for instance, a single vehicle as a pointlike source, when observed from a suitable distance. The analysis of a single transit emission is postponed to a further study, while the cumulative effect of many transits, that is enclosed in the equivalent level, i.e. the parameter that the authors consider in the analysis of this study, will be considered.

In section 2 the description of the propagation law for pointlike and linear sources is briefly sketched, while in section 3 the experimental session design and the measured data sets are reported. Thus, in section 4, the analysis results are presented and discussed.

II. Pointlike and Linear Source Propagation

In this section, the theory of propagation for pointlike and linear source is summarized. We will neglect all the correction terms due to reflections, screening, atmospheric absorption, etc., considering only the geometrical divergence, i.e. the attenuation due to the source-receiver distance. Ground is considered completely absorbing.

The acoustical intensity produced by a pointlike source can be written as follows:

$$I = \frac{W}{4\pi r^2} \qquad (1)$$

where W is the power of the source and r is the distance between source and receiver. Let us underline that the denominator is the spherical surface centered in the source, with radius r.

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Dividing by the reference values and going to the intensity level, we obtain:

$$L_{I,point} = 10\log\frac{I}{I_0} = 10\log\frac{\frac{W}{W_0}}{4\pi\left(\frac{r}{r_0}\right)^2} =$$

$$= 10\log\frac{W}{W_0} - 10\log 4\pi\left(\frac{r}{r_0}\right)^2 =$$

$$= L_W - 20\log\frac{r}{r_0} - 11 \qquad (2)$$

The latter expression, (2), is the well-known formula of the propagation of noise intensity level produced by a pointlike source (spherical propagation).

If one considers a linear source, with density of power W', the equation modifies as follow:

$$I = \frac{W\prime}{2\pi r} \qquad (3)$$

that, in case of uniform density of power, can be written as:

$$I = \frac{W}{2\pi r L}$$

where L is the length of the source. Thus, according to (3), the level is:

$$L_{I,line} = 10\log\frac{I}{I_0} = 10\log\frac{\frac{W'}{W_0{}'}}{2\pi\frac{r}{r_0}} =$$

$$= 10\log\frac{W'}{W_0{}'} - 10\log 2\pi\frac{r}{r_0} =$$

$$= L_{W\prime} - 10\log\frac{r}{r_0} - 8 \qquad (4)$$

A sketch of the slope of the two different fields is given in Fig. 1.

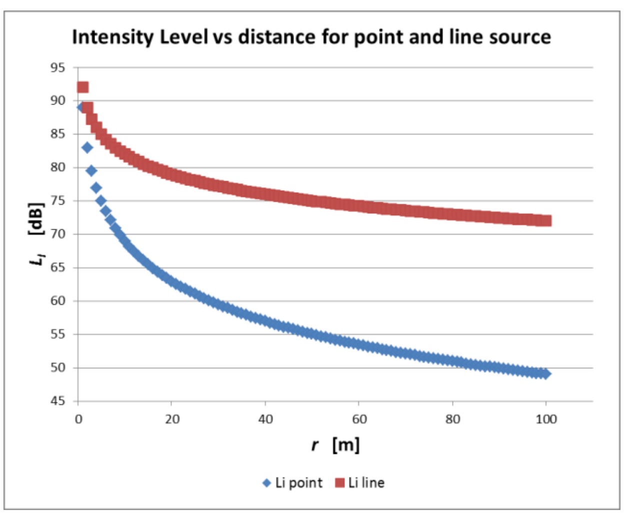

Fig. 1: Intensity level slope versus distance for a pointlike source (L_w = 100 dB, blue diamonds) and for a linear source ($L_{w'}$ = 100 dB, red squares).

The spherical symmetry is obtained in the pointlike source case, while the linear source gives a cylindrical symmetry in the field pattern (see Fig. 2).

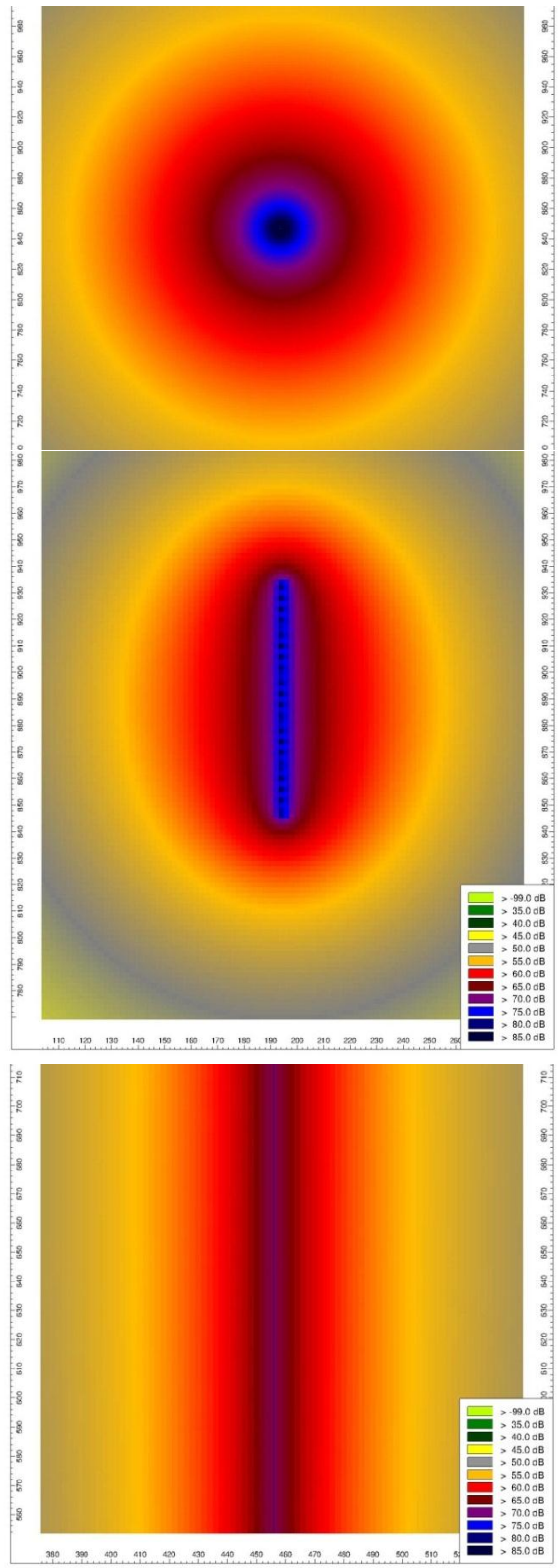

Fig. 2: Single point source (up), multiple point sources (middle) and line source (bottom) noise map simulated in CadnaA © commercial software framework.

In literature, road traffic noise is generally considered an incoherent line source [13]. In terms of computational issues, there are some differences that we will not discuss here, since the aim of the paper is to give indication of source behaviour directly from the experimental data. For a detailed analysis of these effects related to the source scheme choice, the reader may refer to [14], where Salomons et al. presented a proposal to solve some computational problems.

Thus, let us consider the generic formula of propagation for intensity level:

$$L_I = L_W - \eta \,\mathrm{Log}\frac{r}{r_0} - \beta \tag{5}$$

Values for parameters η and β are summarized in Tab. 1.

Tab. 1: η and β values for common source models.

Source model	η [dB]	β [dB]
Point	20	11
Line	10	8

At this point, for instance, if there are two receivers, one can write the intensity level produced by the road, at the distance r_i between the source and the i-esim receiver:

$$L_{I,1} = L_W - \eta_1 \,\mathrm{Log}\frac{r_1}{r_0} - \beta_1 \tag{6}$$

$$L_{I,2} = L_W - \eta_2 \,\mathrm{Log}\frac{r_2}{r_0} - \beta_2 \tag{7}$$

In principle, the two parameters η and β are not uniform (i.e. they depend on the distance), while the power of the source is independent by the distance, since it depends only on the source itself. If one evaluates the difference between these levels, the following parametric formula is obtained:

$$\Delta L = L_{I,1} - L_{I,2} = \mathrm{Log}\frac{r_2^{\eta_2}}{r_1^{\eta_1}} + (\beta_2 - \beta_1) \Rightarrow$$

$$\Rightarrow \Delta L = \mathrm{Log}\frac{r_2^{\eta_2}}{r_1^{\eta_1}} + \Delta\beta \tag{8}$$

At this point, two scenarios can be sketched: a dependence of the source typology from the distance or the uniformity of the source layout assumption. This means that, for instance, one can model the road as a linear source close to the lane and as a pointlike one far from that (the η and β parameters are not uniform); on the opposite one can consider the road as a linear or pointlike (or any other model) source at any distance (the η and β parameters are uniform).

Since this study is performed at a maximum of 35 m, it is reasonable to assume that there is not a drastic change in the source modeling, so one can consider the road as a linear or pointlike source at any distance (included in the range of the measurement site).

In this case, we have that η and β are uniform, i.e. $\eta_1 = \eta_2$ and $\beta_1 = \beta_2$, thus:

$$\Delta\beta = 0$$

and formula (8) can be written as follows:

$$\Delta L = \eta \,\mathrm{Log}\frac{r_2}{r_1} \tag{9}$$

This is the parametric formula that we will use in the analysis section, to estimate the η coefficient, i.e. the "linearity degree" of the source.

III. Experimental session description

The experimental session has been designed and performed using several long term measurements, defined as "spatial monitoring measurements" (MS), and some short term measurements, defined as "punctual monitoring measurements" (MP).

The measurement time of MS was 70 minutes each, while the MP lasted 10 minutes each. In the analysis we will consider the measurements taken contemporarily in three different points (MP moved from position 1 to position 2 and vice versa) and rescaled on one hour range, even if the measurement time was lower, in the case of MP, or higher, in the case of MS. This is allowed because the traffic flow didn't have steep changes during the considered intervals.

Noise levels have been detected with first class devices, 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).

In particular, the MS measurements have been taken with a multichannel Harmonie apparatus (two channels), while the MP measurements have been taken with a SOLO sound level meter.

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 FAST time constant has been used in the data taking and the sampling time is 1 second.

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 measurement site is in Spinetoli, Ascoli Piceno (Italy), and it's placed on a provincial road, with a medium average hourly flow.

The MS and MP measurement points have been highlighted in Fig. 3 with the respective distances.

Fig. 3: Spinetoli site of measurements (Google ©). The area under investigation is highlighted in the bottom figure and the 4 measurement points are indicated with their distances from the road.

IV. Analysis and Results

The results of the experimental session have been processed off line and the two sets of data that are considered in this analysis are presented in Tab. 2 and Tab. 3.

Tab. 2: Equivalent levels and vehicles flows in MS1, MS2 and MP1, first set of measurements.

Measurement number	Measurement points			Hourly Vehicles Flow
	MS1	MS2	MP1	
	Leq [dBA]			
1	56,5	60,3	70,8	876
4	55,7	60,4	70	978
6	59,7	60	70,2	708
7	58,7	59,8	69,9	828
9	56,5	60,4	70,5	912
12	55	60,2	71,2	1050
14	55,8	58	68,9	354
15	52,7	55,7	66,4	270

Tab. 3: Equivalent levels and vehicles flows in MS1, MS2 and MP2, second set of measurements.

Measurement number	Measurement points			Hourly Vehicles Flow
	MS1	MS2	MP2	
	Leq [dBA]			
2	57,2	61,4	68,3	936
3	56,1	61,6	68,2	1206
5	59,8	61,1	66,7	846
8	58,3	59,8	66,4	642
10	56,7	60,7	65,6	1008
11	58,5	62,5	66,3	1068
13	57,4	58	63,3	402
16	52	56,4	60,1	318

Let us first plot the equivalent levels in the two different set of measurements Fig. 4 (let us remind that x axis is not on time scale). It is easy to notice that MS2 and MP1, in the first case, and MS2 and MP2, in the second case, are strongly correlated, showing the same slope but with an almost constant difference. This difference between measurements is due to the different positions of the receivers with respect to the source. This is not evident for MS1, where a quite strong and constant background noise (due to anthropic activities) and the other effects neglected in the model set up (see section 2) are present.

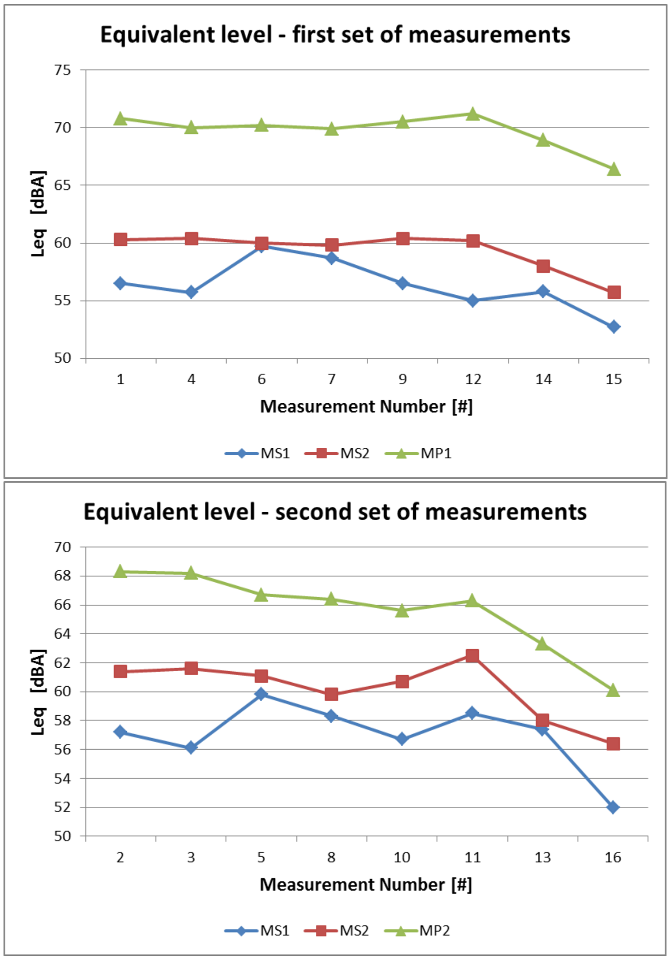

Fig. 4: Equivalent level in the two sets of measurements considered. *x* axis is not on time scale.

Thus, one can estimate the η coefficient, that we define as the degree of "linearity" of the source, starting from formula (9):

$$\Delta L = \eta \, \mathrm{Log}\frac{r_2}{r_1} \Rightarrow \eta = \frac{\Delta L}{\mathrm{Log}\frac{r_2}{r_1}} \qquad (10)$$

and plotting the results for each couple of correlated measurements, that are:

- MP1-MS2
- MP1-MS1
- MP2-MS2
- MP2-MS1

Results are shown in Fig. 5.

Fig. 5 shows that in MP1-MS2 pair, i.e. the couple of measurements where the difference is almost constant and the neglected effects are less relevant, the coefficient is very stable, and close to 10. This means that this propagation can be considered of a cylindrical shape, corresponding to a linear source.

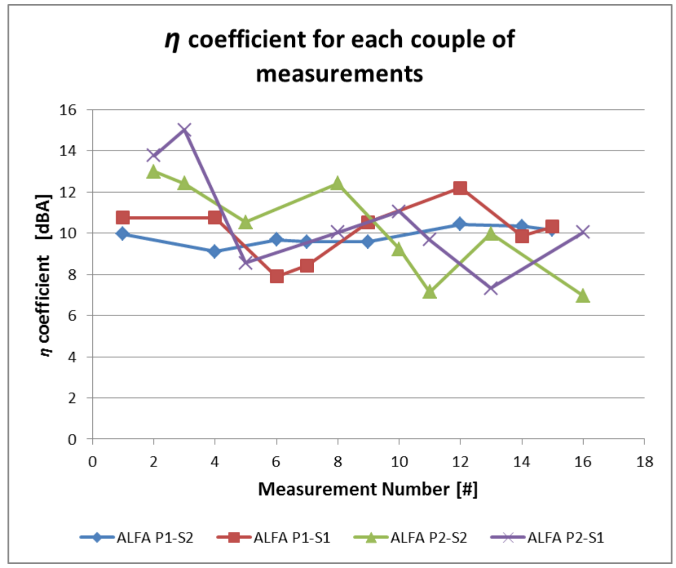

Fig. 5: η coefficient plot for each couple of measurements versus the measurement number.

Despite of the some quite strong variations in the η coefficient, the average is close to 10 for all the measurements couples, as reported in Tab 4. This gives more robustness to the linear source assumption.

Tab. 4: η coefficient average values for each couple of measurements, evaluated on experimental data, in dBA.

P1-S2	P1-S1	P2-S2	P2-S1
9,85	10,09	10,21	10,68

The next analysis performed by the authors is on the flow dependence. Let us plot the equivalent levels, measured in the different points, versus the traffic flow, i.e. the number of vehicles. Results are plotted in Fig. 6.

The logarithmic fit has been reported for each curve, since the slope of equivalent level versus hourly traffic flow is generally assumed to be log based, both on theoretical base or emphirical approach [3], [4], [9].

Fig. 6 shows that MS1 has a different slope. In particular, since MS1 was further than MS2, with respect to the source (road), the fact that in some cases it gives values very similar to the other point shows that the measurements were disturbed, probably by antrhopic activities. This is highlighted also by the coefficient of determination R^2, that is really far from 1.

In Table 5 the fit equations are summarized, together with the coefficients of determination R^2, per each set of data. In Fig. 7, the plot of the six fit equations is presented. Again, the slope of MS1 curves, in both cases, shows a different behavior, especially in the medium range of traffic flow.

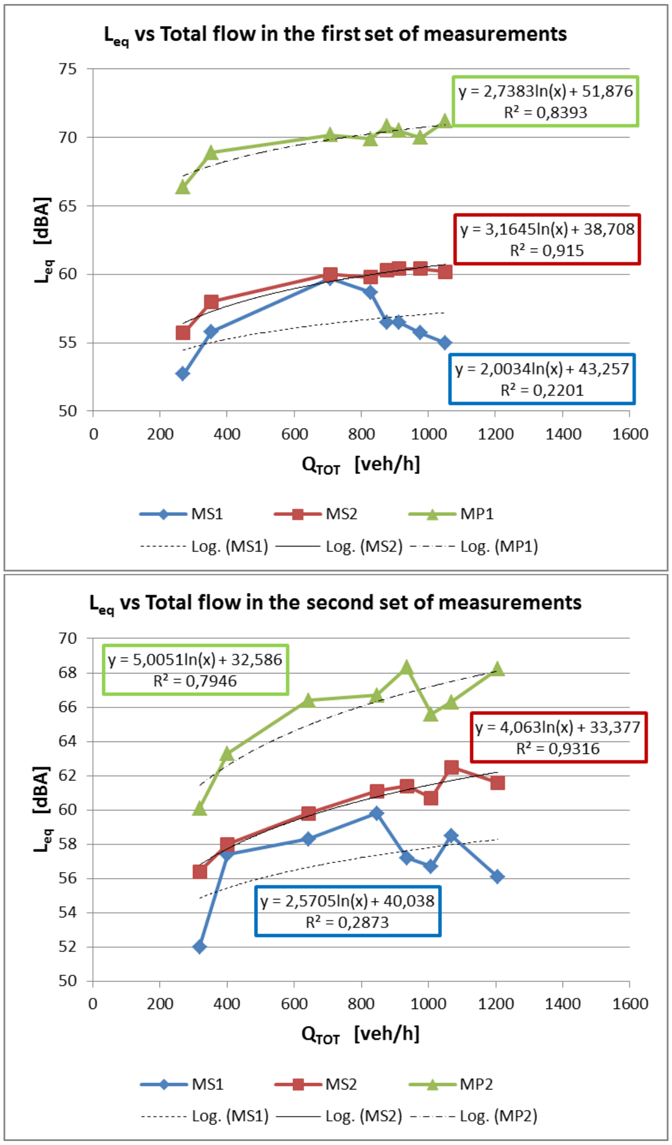

Fig. 6: Measured Equivalent Level plotted versus hourly traffic flow in both set of measurements. The logarithmic fit has been added per each curve and the equations, together with the coefficients of determination R^2, are reported in the graph.

Tab. 5: Fit equations.

	First set of measurements	
	Fit equation	**R^2**
MS1	y = 2,5705ln(x) + 40,038	0,2873
MP2	y = 5,0051ln(x) + 32,586	0,7946
MS2	y = 4,063ln(x) + 33,377	0,9316
	Second set of measurements	
	Fit equation	**R^2**
MP1	y = 2,7383ln(x) + 51,876	0,8393
MS2	y = 3,1645ln(x) + 38,708	0,915
MS1	y = 2,0034ln(x) + 43,257	0,2201

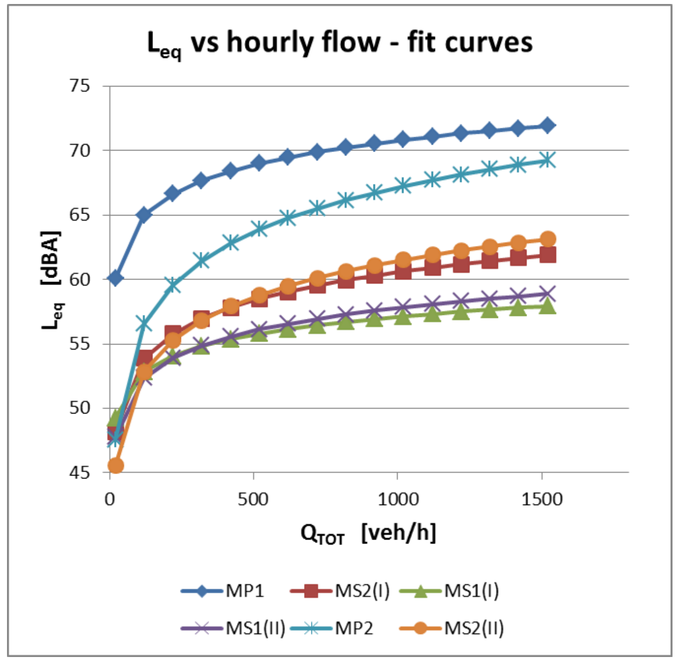

Fig. 7: Simulated Equivalent Level plotted versus hourly traffic flow, obtained with the equations of Table 5.

The fitting formula is:

$$L_{eq} = A \,\mathrm{Ln}\, Q' + B \tag{11}$$

where Q' is the hourly traffic flow, having properly weighted the heavy vehicles with respect to the light ones (see for instance [9]). A and B are the parameters of the fit. Comparing eqq (5) and (11), one can assume that the source power level is related to the traffic flow, while the dependence from the distance is included in the constant term B:

$$B = -\alpha \,\mathrm{Log}\frac{r}{r_0} - \beta \tag{12}$$

Thus, considering again the four pairs:

- MP1-MS2
- MP1-MS1
- MP2-MS2
- MP2-MS1

one can evaluate the ΔL (eq. 9) for each couple of models and obtain the linearity degree coefficient η (eq. 10) plotted versus traffic flow.

Results, reported in Fig. 8, show that the curves are very close to 10 dBA in the medium range of traffic flow, while both low and high values of traffic flow induce a significant deviation from the expected value. In particular, the MP2-MS1 pair shows a very strange slope approaching zero values of flow. This is probably related to the bad log fit obtained by the data, as evidenced by the low determination coefficient, due to the measurements data corruption in the medium range of traffic flow.

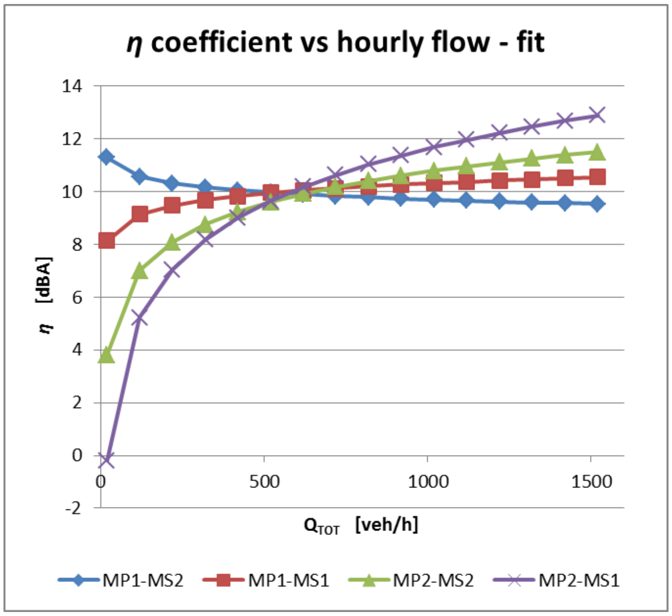

Fig. 8: Linearity degree (η) coefficient versus hourly traffic flow, evaluated on the four possible pairs of theoretical equations in Table 5.

V. Conclusions

In this paper, the authors dealt with the problem of propagation modelling of the road traffic noise.

Starting from an experimental campaign, two sets of data have been analysed in order to understand how the different distances of measurement points affect the propagation. MS2 and MP1 gave a quite identical slope of the equivalent level curve when plotted versus the number of measurements (Fig. 4) or versus the traffic flow (Fig. 6), suggesting that the difference in the level can be related to the difference in the distance. Evaluating the η linearity degree coefficient, that is related to the degree of power of the distance in the logarithmic propagation formula, i.e. the discrimination between a pointlike and a linear source model, the results furnished values very close to 10. This means that, in these measurement conditions (distances, flow volumes, etc.), the road can be considered a linear source. Let us remind that in this study reflections, absorbing surfaces, atmospheric factors, etc., have not been considered in the theoretical model, but, of course, they are included in the measurement results.

In the other measurements analysis processes, MP1-MS1, MP2-MS2, MP2-MS1, even if the η coefficient average value was still very close to 10, the strong oscillations around the mean value showed that this “ideal” procedure must be improved with the adding of corrective terms.

The traffic flow analysis showed that the measurements are distributed according to a logarithmic function, as reported in literature. After the fit of the data, the authors presented six models of Equivalent Levels versus traffic flow. By combining these models, the evaluation of the η coefficient gave results close to the expected value, i.e. 10 dBA, in the medium range of traffic flow, showing almost significant deviations in the low and high ranges.

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