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RESEARCH ON THE CORRELATION BETWEEN THE CHARACTERISTICS OF TRAFFIC AT INTERSECTIONS AND THE ROAD NOISE LEVEL

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Abstract: *Correlations between road traffic and noise in the proximity of road intersections remains a topic that is incompletely elucidated, so that research in this regard is of particular interest, as demonstrated in the introductory part of the present paper. The research carried out in the two types of intersections – intersections with traffic lights and roundabout intersections – led to a number of helpful observations, which demonstrate that roundabout intersections are quieter than intersections with traffic lights and the functioning of the engine at moderate speeds ensures a lower level of road noise.*

Keywords: traffic lights intersection, roundabout intersection, noise level, speed, engine speed, gear ratio.

INTRODUCTION

An estimation of road noise in the proximity of urban intersections remains a less discussed matter in specialised literature, the difficulty being represented not only by the description of noise propagation (because, actually, this is a mere process of acoustic energy dissipation on half a sphere), nor by the cumulation of the noise produced by vehicles to result in the noise produced by traffic flows (for which there are calculation models of satisfactory accuracy), but rather by estimating the noise emitted by different motorvehicles.
This difficulty arises from the diversity of the motorvehicles that compose the traffic flows (different classes of vehicles, different models with different engines), as well as from the diversity of the engine operating regimes (stable or transient, at different loads and speeds).
The papers published in the field unanimously consider that the noise emitted in the area of intersections (where the speed does not exceed 30 km/h) is generated almost entirely by the engine, the rolling noise being practically zero - Figure 1.

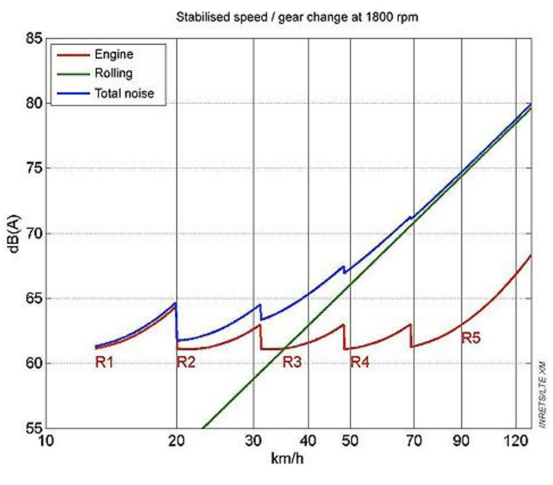

Figure 1. Road n20oise level depending on vehicle speed, at constant speed [15].

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However, little road noise prediction models take the following factor into account, a factor that is decissive for road noise – the vehicle engine (type, capacity and operating conditions thereof).
Thus, since the '70s, there have appeared road noise prediction models that indirectly take this into consideration – through the proportion of heavy vehicles in traffic flow, which results in a coefficient of sound equivalence, but that does not account for various engine operating schemes [Quartieri, 2010; Guarnaccia, 2011]: Galloway, Burgess, Griffiths and Langdon, Fagotti.
The noise level is acknowledged to vary depending on the type of vehicle and the differences according to speed, as shown in Figure 2.

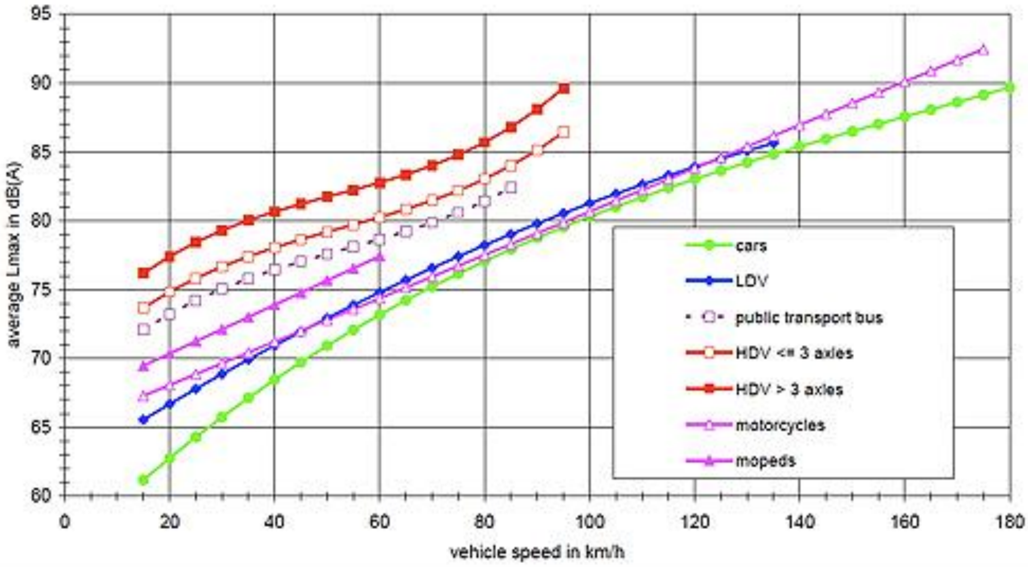

Figure 2. Road noise level depending on the speed and type of vehicle [16].

Trying to aggregate all these models in a general expression, one which should include any of them through customization, the general expression of the equivalent level is reached, calculated according to the statistical model of traffic noise given by the equation [Quartieri, 2010]:

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

where Q is the traffic volume, P is the percentage of heavy vehicles, d is the distance from the traffic flow to the receiver and A, B and C are constants that customize various road noise prediction models.

Regarding the expression contained in the parenthesis on the right, through it the proportion of heavy vehicles P is taken account of, because these vehicles emit a more powerful noise than light vehicles, the ratio of noise due to a heavy vehicle and the one due to a light vehicle is n, called *acoustic equivalent of heavy vehicles*.
As a result, an equivalent traffic flow from the point of view of noise can be defined according to the equation:

$$Q_{eq} = Q\left[1 + \frac{P}{100}(n-1)\right] \quad (2)$$

where Q is the flow of vehicles (total number of vehicles, regardless of their type), P is the proportion of heavy vehicles, and n is the acoustic equivalent of heavy vehicles.
The acoustic equivalent of heavy vehicles (defined as the number of light vehicles that generate acoustic energy equal to that generated by a single heavy vehicle) can be estimated through regression methods, as well as through measurements performed for the sound emission of a single vehicle. The same can be done to estimate the acoustic equivalent of other categories of vehicles as well, such as motorcycles, buses, etc.
Thus, the ***CNR 91*** Italian model developed by the National Research Council (Consiglio Nazionale delle Ricerche – CNR) in Italy in the ’80s and then updated in 1991 takes into account the acoustic equivalent of heavy vehicles value n = 6.
On the other hand, the ***RLS 90*** German model (*Richtlinien für den Straßen Lärmschutz year* -- Guidelines for protection against road noise), developed in 1981 and then updated in 1990, takes into account the proportion of heavy vehicles P with the maximum authorized mass of over 2.8 t, through the expression:

$$Q(1+0{,}082P) \qquad (3)$$

where the acoustic equivalent value for heavy vehicles is found with the value n = 0,082*100+1=9,2.
This model also adds a correction to take account of the possible existence of a nearby intersection with traffic lights (being recognized that this type of intersection contributes to increased noise level), the values of the correction dropping from 4 dBA (for distances under 40 m) to zero (for distances above 100 m).
The American ***FHWA Traffic Noise Level 95***, conducted by the National Administration of USA Highways (Federal Highway Administration - FHWA), proposes a unified-emission bill, which does not depend on speed on various road sections, parameterizable function of the type of the rolling tread, road declivity and traffic conditions (two types of movement are considered: accelerated movement and constant-speed movement).
This mathematical model has the advantage of simplicity, since it uses fewer parameters and a single variable – vehicle speed, but, on the other hand, given these simplifying assumptions, the use of this model to represent the emission of road noise in the case of urban traffic seems less relevant. Thus, a constant noise throughout the basic gear range [http://www.fhwa.dot.gov/environment/noise/measurement], as illustrated by this model (Figure 3) does not correspond to the real noise emitted on urban road networks, even if there is a correction for accelerated movement on a horizontal road.

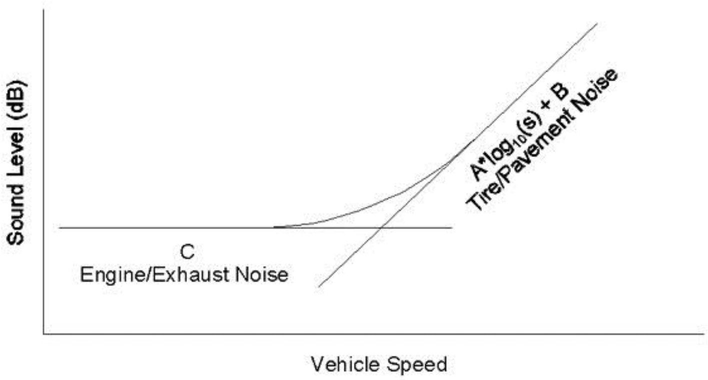

Figure 3. Road traffic noise level in FHWA Trafic Noise Level [17]

Directive 49/2002 of the European Parliament on the assessment and management of environmental noise recommended that the forecasting of road noise be achieved based on the

French model “Nouvelle Methode of Prevision of bruit - Routes '96”, developed in 1980 and updated successively in 1996 and 2008 (new method of forecasting traffic noise), known as ***NMPB Routes – 96***.
As a result, in Romania (as well as in other states of the European Union), this method applies for the preparation of maps with ambient noise caused by road traffic, as mentioned in Government Emergency Ordinance of May 5, 1995 relating to the noise produced by traffic on road infrastructure [Boroiu A-A, 2016].
The E emission level is stated in a nomogram, separately for heavy vehicles and light vehicles, for 4 types of traffic (fluid, pulsatory, accelerated or decelerated) and 3 types of road declivity (horizontal, going up or going down).
To determine the overall noise level, it is sufficient to identify the type of movement and the road declivity for each vehicle category and to sum up the total noise, weighing them according to the traffic flow for each vehicle class.
But a major factor remains the functioning mode of the engine, being acknowledged that at higher revs the noise emitted is much stronger [http://www.silence-ip.org].
Another aspect to be highlighted is that, at the same speed, the manner to increase noise with the engine speed is presented differently in the research literature.
Thus, while in Figure 1 growth is considered accelerated [1], there are works in whose case this growth fades (the rate of noise increase along with engine speed is reduced) - Figure 4 and Figure 5.

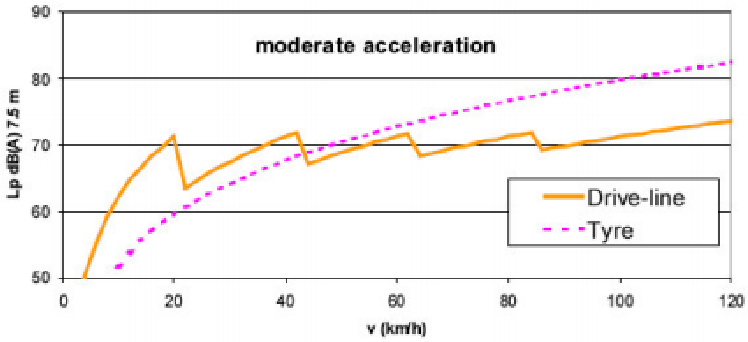

Figure 4. Noise level based on vehicle speed, slight acceleration [18]

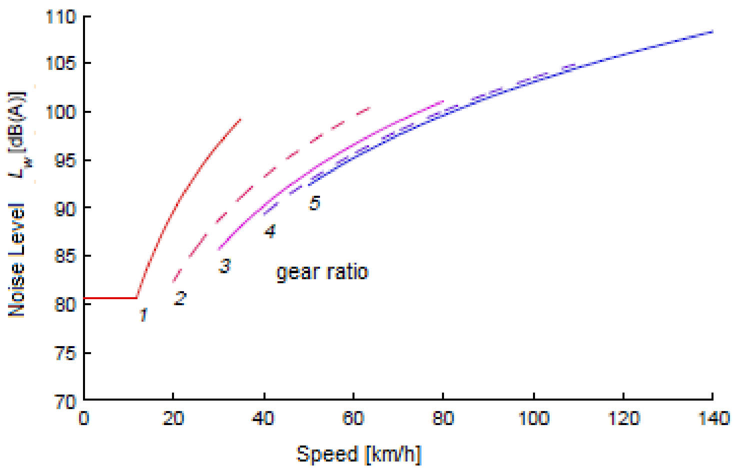

Figure 5. Noise level depending on gear [8]

As a result, it is found that - unlike the noise emitted along the road arteries, for which there are many models, all leading to quite close results - Figure 6, noise prediction near intersections is quite vaguely expressed.

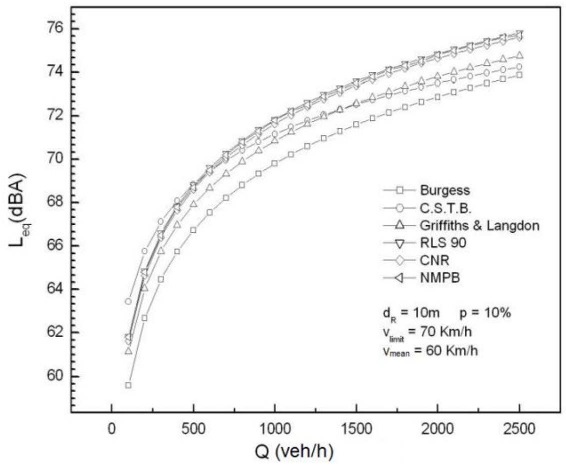

Figure 6. Noise level depending on traffic volume, for various models [11]

Therefore, this paper aims to present research conducted by the authors to identify the correlations between the noise level near intersections and the road traffic characteristics [2].

ASSESSMENT OF ROAD NOISE AT THE MAIN ROAD INTERSECTIONS FROM THE DOWNTOWN AREA OF PITEŞTI

To identify the manner in which road traffic causes noise pollution, it is required that traffic measurements be simultaneous with noise measurements, and that the latter highlight, apart from physical indicators of road noise (which are determined only by the physical characteristics of road noise), a series of psychophysical indices (which characterize the degree to which the human being is affected by noise).

Measurements were performed in 3 of the most important intersections in the center of Pitesti municipality, represented as follows (Figure 7):

- Maior Şonţu traffic lights intersection;
- Podul Viilor and Rectorate roundabout intersections.

Figure 7. The 3 road intersections in the central area [6]

The measurements were performed according to specific regulations on road noise measurements (microphone height of 1.30 m from the roadway and of 1.00 m from the roadside) in the vicinity of the vehicle flow in intersections.

The processing of the results obtained resided in determining the physical indicators and the psycho-physical distribution of values obtained from performing the noise measurements (Fig. 8). For reasons of simplicity, the usual notation L was employed for the noise level.

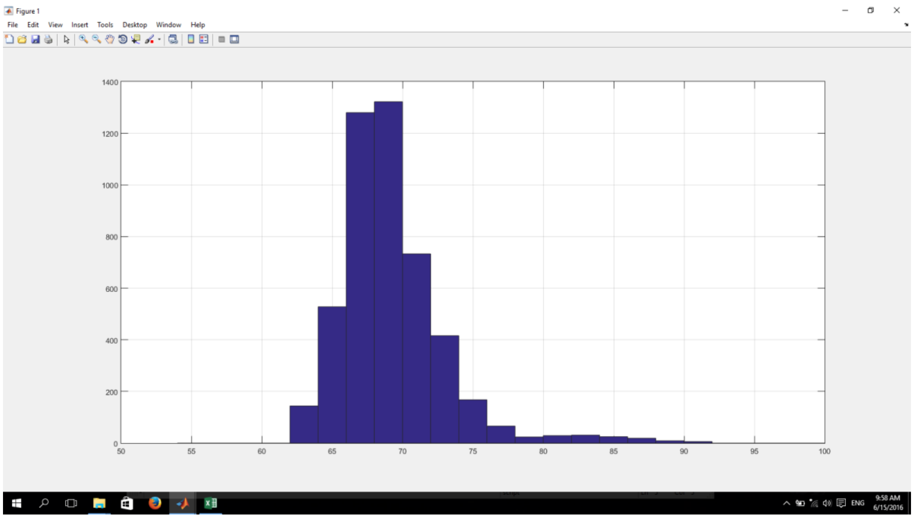

Figure 8. Instantaneous noise histogram of the Maior Șonțu intersection (LAF)

The ***statistical indicators of the noise measured*** were established: L_{10}[dB(A)], L_{50}[dB(A)], L_{90}[dB(A)], representing the noise levels exceeded in 10%, 50% and 90% of the measurement time, these values are, in fact, noise-level quantiles (of 10%, 50% and 90%).
Based on these quintiles, the more complex statistical indicators were also determined, including the psycho-acoustics ones, as shown below [10].
The noise climate c that characterizes the noise level variation and is defined as the difference between the 10% and 90% quintiles of noise level:

$$c = \mathrm{L}_{10} - \mathrm{L}_{90} \qquad (4)$$

Based on the 3 quintiles of noise level (L_{10}, L_{50}, L_{90}) or based on the quintile of 50% of the noise level (median of noise level), L_{50}, and on the noise climate already calculated**, *the psychophysical index level of acoustic pollution LNP*** is determined, which expresses the degree of discomfort about the human being's subjective response to noise in a given period:

$$L_{NP} = \mathrm{L}_{50} + c + \frac{c^2}{60} \qquad (5)$$

The psychophysical index of traffic noise TNI [dB(A)] expresses the degree of discomfort caused by a random noise and is determined based on the statistical distribution of the measured noise level with a certain sampling frequency, in a certain period of time, with the following calculation formula:

$$TNI = 4 \cdot (\mathrm{L}_{10} - \mathrm{L}_{90}) + \mathrm{L}_{90} - 30 = 4 \cdot c + \mathrm{L}_{90} - 30 \qquad (6)$$

It is noted that in the calculation formula a significant weight is distributed to noise climate, which characterizes the variability of noise levels (given that a significant noise level variation is more disturbing than a quasi-constant noise).
The ***average noise level L_m*** is the arithmetic average of noise level; it can be estimated by means of the statistical relationship shown in [Boroiu A-A, Paper 3, 2016] or can be calculated directly with the known relation for the arithmetic average based on the histogram of noise frequency values (Fig. 1), this being a more accurate estimation:

$$L_m = \frac{\sum_{i=1}^{15} f_i \cdot L_i}{\sum_{i=1}^{15} f_i} \quad (7)$$

Similarly, ***the standard deviation of noise level*** $\boldsymbol{\sigma}$ can be calculated based on:

$$\sigma^2 = \frac{\sum_{i=1}^{15} f_i \cdot (L_i - L_m)^2}{\sum_{i=1}^{15} f_i} \quad (8)$$

from which:

$$\sigma = \sqrt{\sigma^2} \quad (9)$$

The psychophysical index $\boldsymbol{L_{ech}}$ [dB(A)], which represents the average energy measured (weight A) of a noise level during a certain period of time, is automatically calculated by the software dedicated to noise analysis, with the relation:

$$L_{ech} = 10 \cdot \frac{q}{3} \cdot \left| \log \frac{1}{T} \sum_{i=1}^{n} 10^{0,3 L_i \frac{t_i}{T}} \right| \quad (10)$$

where:

- $T = \sum_{i=1}^{n} t_i$, complete recording length (10 minutes or 600 seconds);
- t_i, L_i (i = 1,2...n), are the time intervals (the length of time for L_i noise level, which (statistically) means, in fact, the frequency of this level;
- n, the number of intervals used to produce histograms;
- q , weighting constant, q = 4 for traffic noise (A weighting).

SYNTHESIS AND ANALYSIS OF RESULTS OBTAINED

Based on the values measured for a period of 10 minutes (600 seconds) with a sampling frequency of 8 measurements/second (every 0.125 seconds), the graphs of LAF noise level can be drawn in Microsoft Excel, as shown below.

In case of the Maior Şonţu intersection, one can notice a certain cyclicity (Figure 9) which corresponds to the intermittent movement that occurs on each group of lanes, the intersection being a traffic lights intersection.

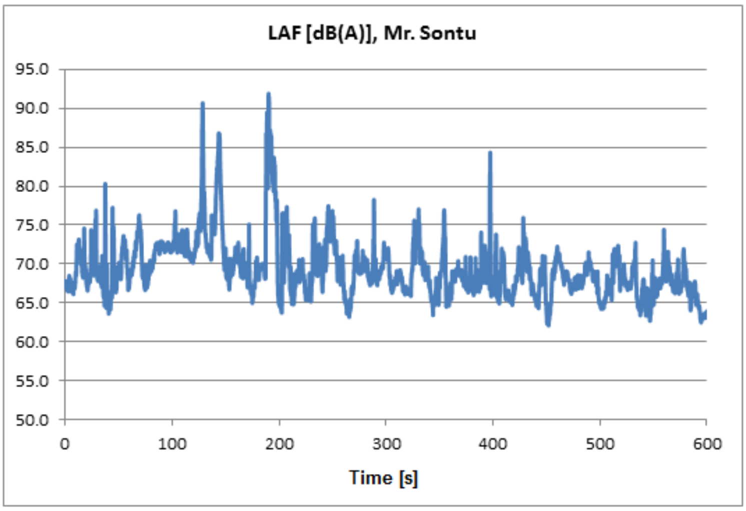

Figure 9. LAF noise level measured at the Maior Şonţu intersection

Noise peaks can be explained through the presence of large vehicles (garbage trucks, concrete mixers, buses) that have a major contribution to road noise, very much when starting off, but even while waiting for the green traffic light signal.
In the case of the Podul Viilor roundabout intersection (Fig. 10), where the measured noise is produced by the entry stream (vehicles that circulate fluently, with average acceleration) and by the conflict stream (vehicles moving at a constant speed), one can notice the overlapping of two distributions of noise values: a distribution with average values of 70-75 dB (A) and with noise peaks of around 80 dB (A), and, respectively, a less extensive distribution with average values of 65-70 dB (A).

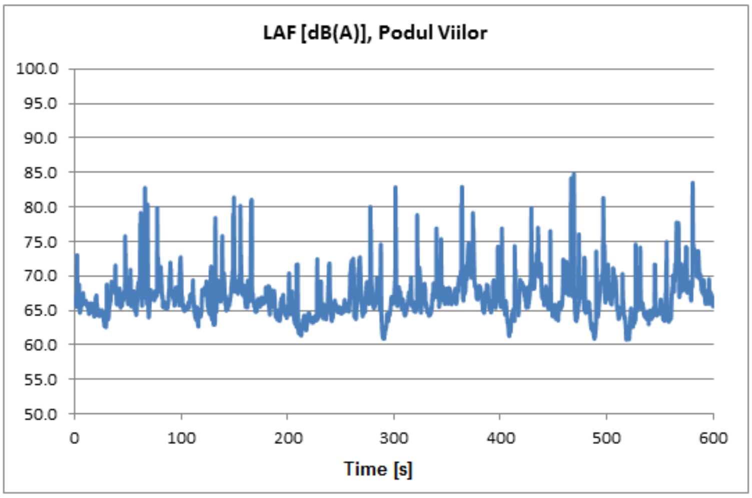

Figure 10. LAF noise level measured at the Podul Viilor intersection

In the case of the Târgul din Vale roundabout intersection (Fig. 11), where vehicles circulated under the "stop and go" regime, with small accelerations, and where traffic composition included in a small proportion heavy vehicles as well, the noise measured presents average values in the range 65-70 dB (A), but towards the end of the measuring interval these values even lowered to the range of 60-65 dB (A), which can be explained through the fact that, from that moment on, traffic congestion began to decrease (the peak hours were on the verge of finishing).

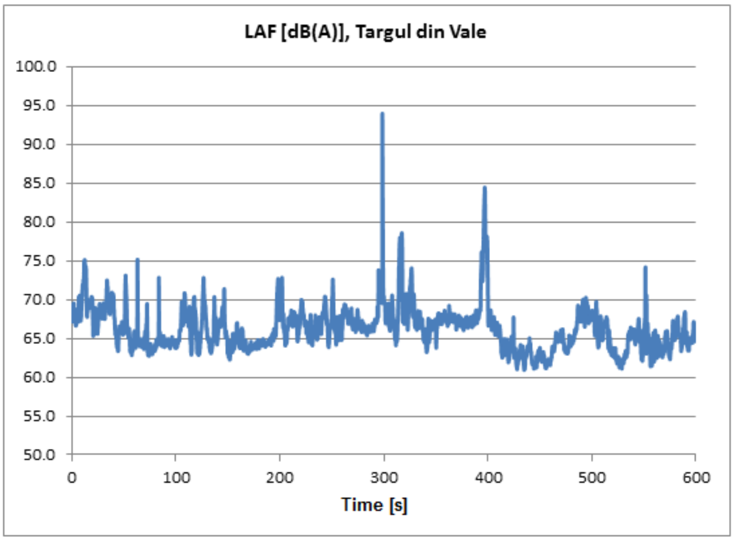

Figure 11. LAF noise level measured at the Targul din Vale intersection

A few noise peaks can also be observed, of which at least two represent outliers actually, because they correspond to “greetings” expressed by sounding the horn to the team that was performing noise measurements (normally not happening, so they should be excluded from the calculation).
For a comparative analysis of the results obtained through noise measurements performed at the three intersections, these results are presented in the following synopsis.

Table 1. The values of noise indices for the 3 road intersections

Nr. crt.	*Noise index*	*Maior Şonţu*	*Podul Viilor*	*Rectorate*
1	$\mathbf{L_{min}}$ [dB(A)]	62,1	60,8	60,9
2	$\mathbf{L_{90}}$ [dB(A)]	65,5	64,0	63,1
3	$\mathbf{L_{50}}$ [dB(A)]	68,6	66,4	66,0
4	$\mathbf{L_{90}}$ [dB(A)]	73,1	70,4	69,3
5	$\mathbf{L_{max}}$ [dB(A)]	**91,9**	**84,8**	**78,6** (after eliminating the 2 sound outliers)
6	*Noise climate, **c*** [dB(A)]	**7,6**	**6,4**	**6,2**
7	*Psychophysical index of acoustic pollution level **LNP*** [dB(A)]	**77,2**	**73,5**	**72,8**
8	*Psychophysical index of traffic noise **TNI*** [dB(A)]	**65,9**	**59,6**	**57,9**
9	*Average noise level* L_m [dB(A)]	69,3	66,9	66,2
10	*Std. dev. of the noise level* σ [dB(A)]	3,8	2,9	2,8
11	*Psychophysical index* L_{ech} [dB(A)]	**72,7**	**68,4**	**68,1**

CONCLUSIONS

In light of the considerations on road traffic at the three intersections during the periods of noise measurement, based on the results presented in the synoptic table above, the following observations and conclusions can be drawn:

• *All noise indices (physical or psychophysical) have higher values at the Maior Șonțu traffic lights intersection than at the two roundabout intersections*, Podul Viilor şi Rectorat. This remark is in full compliance with what, in fact, specialised literature records, the explanation being that, in traffic lights intersections, the traffic is intermittent, with stong accelerations in the first gear (specific to the starting off regime), unlike roundabout intersections, where traffic is fluent (without stopping, with average accelerations in the first gear) or is of the “stop and go” type (with light braking and mild acceleration in the first gear).

• *The differences (to the detriment of the intersection with traffic lights) are higher in the case of psychophysical indices* (the psychophysical index of acoustic pollution level LNP, the psychophysical index of traffic noise TNI, the psychophysical index L_{ech}), which confirms that they are analytically defined so as to highlight more strongly the differences in phonic pollution felt by the human body in the various situations.

• *The noise produced by sounding the motor vehicles’ horn reaches very high values* - values that exceed an instantaneous noise level LAF of 90 dB (A) and which were excluded from data processing as they were considered outliers - which justifies the prohibition againt sounding the horn on the territory of localities, except for in cases of necessity.

• Unlike the case of roundabout intersections, *in the case of the intersection with traffic lights the average noise level is much higher and the dispersion of the noise is much* *wider* (which entails a higher noise climate), which shows that, from this point of view as well, roundabout intersections are superior to those with traffic lights in relation to noise pollution caused by traffic.

• In the case of the two roundabout intersections – Podul Viilor, respectively the Rectorate – it is to be noticed that the values of noise indices are very close, but for all indices higher values were reached in the Podul Viilor intersection, which is explained through the difference between the rolling regime of vehicles in the two intersections: *fluent traffic at low speeds (without stopping, with average acceleration in the first gear*) at the Podul Viilor intersection, respectively *"stop and go" traffic* (*with light braking and mild acceleration in the first gear*) at the Rectorate intersection.

The general conclusion that can be deduced from the research presented is that roundabout intersections are quieter than traffic lights intersections and that the functioning of the engine at moderate speeds ensures a lower road noise level.

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