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**Article**

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## Traffic noise and energy

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### Abstract

Urban noise depends on several factors from which Traffic Noise is the most important. City centers and main access roads are usually over exposed that is, average day–evening–night noise level [ $L_{DEN}$ ] and/or rest expose level [ $L_{NIGHT}$ ] surpasses a threshold of healthy exposure. About 35M Europeans are over exposed. This is a problem of human health not a comfort one.

In another way, energy consumption associated to Urban Traffic is in the center of human concerns. Average vehicles spend more than 3.5MJ/km. That means that one Barrel of Oil Equivalent (BOE) is spent by Urban Traffic for each 1.700km. This is a problem of human sustainability.

Based on this problematic a model was developed to correlate traffic noise reduction and energy savings in order to produce guidelines for Urban Noise Management. Model is supported on experimental data and bibliographic review, under the “CNOSSOS model for road noise”. It is then possible to produce guidelines regarding noise reduction and its influence on energy savings. Relationships between “velocity reduction”, “traffic volume” and “noise and energy” are now possible.

Results are available in “noise maps” and “energy saving maps” easily understandable by urban traffic managers. A case study is presented.

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*Keywords:* Traffic noise; Traffic energy; CNOSSOS-EU; Sustainability

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### 1. Introduction

In general noise and energy have no research links, except than noise traffic could be related with energy consumption. Noise traffic is proportional to velocity, type of vehicles, flow rate, pavement characteristics (smoothness and slope). The higher is the velocity or the flow rate the noisier is the environment. Smoothness of the pavement is correlated with low noise and vehicle type differs a lot regarding noise production (a truck produces much more noise than a car and the respective energy consumption has a similar correlation) [1]. However energy savings are not proportional to velocity (slow velocity because of low flow rate needs more energy than continuous flow rate at a higher velocity) [2]. Pavement smoothness does not interfere with energy savings at low flow rate. [1], and positive slope proportionally increases energy consumption as negative slope decreases it.

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The above mentioned problematic conducts to the following research question:

**Is it possible to develop a model that correlates traffic noise and energy consumption in order to produce guidelines to urban traffic management?**

In this work is developed and validated a model regarding linear flow traffic in plan slope. Acoustic measurements under pass-by-test [ISO 362-1:2015] were made in order to validate linear flow and noise.

From Mostofa & Kalam work [2] work velocity/gear relation with energy consumption was obtained and both data were correlated according with a polynomial interception.

The obtained methodology was used in an urban area case study showing that velocity reduction, whether it decreases noise does not directly reduce energy consumption. By the contrary reducing urban areas velocity from 50 km/h to 30 km/h (as is widely proposed for safety reasons) increases oil consumption in 50 BOE/ha. That means that in EU-28 with 19.5 million of ha in central urban areas [data from GEOSTAT], 975 millions of BOE will be extra spent. That means 12 days of world oil production [3].

## 2. Traffic noise model

Based on Campbell Steell [4], since 1952 several models were developed to simulate and preview traffic noise:

- 1952 Handbook of Noise Control model was based only on traffic volume and distance from lane;
- 1965 Nickson and Lamure introduced models depending on individual noise levels;
- 1968 Jonhson introduced vehicle speed;
- 1969 Galloway proposed a variable related with the percentage of heavy trucks.

Ten years after U.S. Department of Transportation — Federal Highway Administration approved a model known as FHWA Traffic Noise Model that besides known methodologies considers reference energy emission for different vehicles, ground effects, shielding and barriers, field insertion loss linear flow and stop-and-go flow. Was widely used all over the world.

Since then till the end of the last century at least seven independent models appear:

- FHWA STAMINA (USA) no building effect, energy source
- FHWA TNM (USA) replaces STAMINE no building effect, energy source
- 01 dB MITHRA (FRANCE) no building, ray tracing
- CoRTN (UK) building effect
- RLS 90 (GERMANY) building effect
- STL-86 (SWIZERLAND)
- ASJ-1993 (JAPAN)

In parallel with this methods huge amount of research was delivered concerning these models; innovations on mapping, algorithms, propagation on the air, parking noise, were the main improvements that allow validation generally for high way traffic.

In Europe, after Environmental Noise Directive (2002/49/EC) several programs tried to consider all scientific developments on this matter:

- Harmonoise, 1999–2004
- Imagine, 2004–2007
- CNOSSOS-EU 2008–2014 established as a simpler method, nowadays used as reference for noise maps in EU

### 2.1. CNOSSOS-EU model

The simulation work was based on CNOSSOS-EU model for road traffic noise [1]. In short, this model is based on source-line sound radiation which power is considered for different (m) categories of vehicles as the sum of rolling power noise and propulsion noise. Eq. (1) is the rolling equation for identifying sound power per meter.

$$L_{W',eq,line,i,m} = L_{W,i,m} + 10 \times \lg \left( \frac{Q_m}{1000 \times v_m} \right) \quad (1)$$

where:

$L_{W',eq,line,i,m}$  = directional sound power per meter per octave frequency band (i) from 125 Hz to 4 kHz) of the source line

$L_{W,i,m}$  = instantaneous directional sound power in ‘semi free-field’ of a single vehicle in dB(re. 10–12 W/m).

$Q_m$  = traffic flow of vehicles of category m per hour — yearly averaged

$v_m$  = average speed in km/h

Eq. (2) details instantaneous sound power as de logarithmic sum of rolling and propulsion power identified in Eqs. (3) and (4)

$$L_{W,i,m}(v_m) = 10 \times \lg \left( 10^{L_{WR,i,m}(v_m)/10} + 10^{L_{WP,i,m}(v_m)/10} \right) \quad (2)$$

where:

$L_{W,i,m}$  = instantaneous directional sound power in ‘semi free-field’ of a single vehicle in dB (re. 10–12 W/m).

$v_m$  = average speed in km/h

$L_{WR,i,m}$  = sound power level for rolling noise

$L_{WP,i,m}$  = sound power level for propulsion noise

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} \times \lg \left( \frac{v_m}{v_{ref}} \right) + \Delta L_{WR,i,m}(v_m) \quad (3)$$

where:

$L_{WR,i,m}$  = sound power level for rolling noise

$v_m$  = average speed in km/h

$A_{R,i,m}$  = coefficient related to sound power specific vehicle

$B_{R,i,m}$  = coefficient related to sound power specific vehicle

$v_{ref} = 70$  km/h

$\Delta L_{WR,i,m}$  = sum of the correction coefficients to be applied to rolling noise emission for specific road or vehicle conditions deviating from the reference conditions, road surface, studded tires, traffic lights, temperature

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m} \times \left( \frac{v_m - v_{ref}}{v_{ref}} \right) + \Delta L_{WP,i,m}(v_m) \quad (4)$$

where:

$L_{WP,i,m}$  = sound power level for propulsion noise

$v_m$  = average speed in km/h

$A_{P,i,m}$  = coefficient related to sound power specific vehicle

$B_{P,i,m}$  = coefficient related to sound power specific vehicle

$v_{ref} = 70$  km/h

$\Delta L_{WP,i,m}$  = sum of the correction coefficients to be applied to propulsion noise emission for specific driving conditions deviating from the reference conditions, road porous surface.

## 2.2. Site measurements from pass-by-test

The objective of this site work was to evaluate CNOSSOS-EU method accuracy for the specific objective of this research that is to compare noise reduction to energy savings. An abstraction was made considering a plan surface, average vehicle, plan roads and fluid traffic.

The pass-by-test was made under these standard conditions being ruled by standard ISO 362-1:2015. Equipment used was a sound level meter SOLO dB01 with a type I microphone and site display was arranged as presented in Fig. 1.

The strategic for the site measurements was to collect data from an average vehicle passing at different speeds and compare them with those produced by CNOSSOS-EU method. Table 1 synthetizes data obtained, from where it is possible to conclude that deviation from CNOSSOS-EU is generally comprehended in the standard deviation gap. Based on this data is assumed that the model used is a good tool for urban noise simulation in order to correlate with energy savings.

Data obtained from site measurements were also used for develop a simpler model that allows us to be able to correlate noise and energy. It is a fact that even if it was proved that CNOSSOS-EU is a good simulation for noise variation with speed, connection with fuel consumption is too much complex to establish because of the great

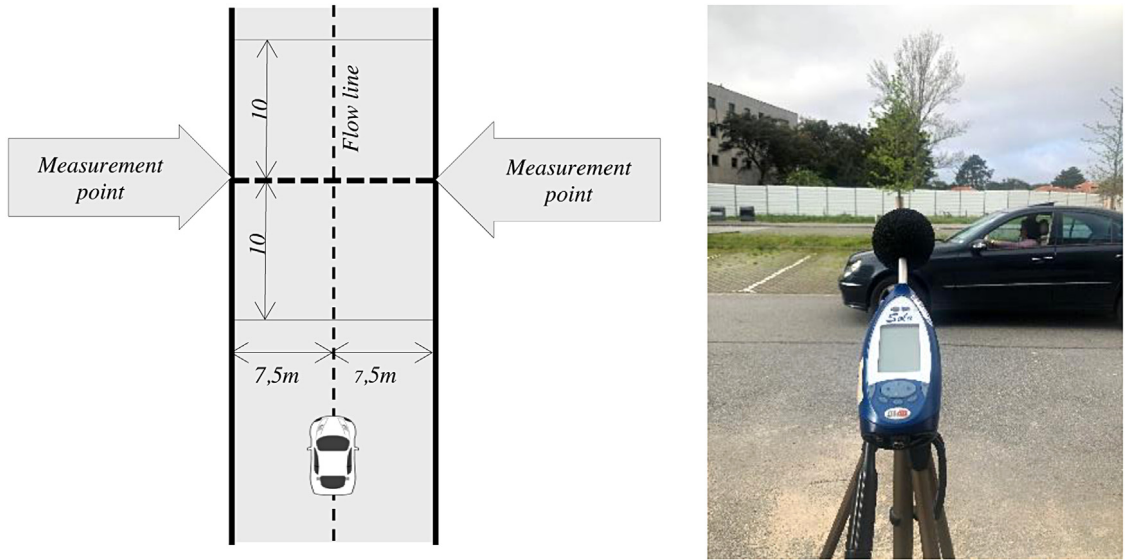


Fig. 1. Site arrangement and photo for measurements.

Table 1. Comparison between measured and modeled data.

Speed [km/h]	Lp [dB(A)]	$\sigma$	CNOSSOS-EU [dB(A)] <sup>a</sup>	$\Delta$ (test – CNOSSOS-EU)
30	54,8	1,9	53,6	1,2
50	50,2	1,8	51,0	-0,8
70	60,2	1,8	61,2	-1,0
90	70,0	1,6	72,0	-2,0
100	70,6	0,9	72,1	-1,5
120	65,4	1,7	67,0	-1,6

<sup>a</sup>Data obtained from B&K Predictor V8.1.

amount of variables referred in 2.1. A polynomial approach based on acquired data was produced. Fig. 2 shows the obtained graph for relationship between speed and 7,5 m distance noise, related to a medium vehicle in a plan road and fluid traffic.

$$L_{A,p(7,5\text{ m},m)} = -5 \cdot 10^{-6} (v_m)^4 + 13 \cdot 10^{-4} (v_m)^3 + 0,114 (v_m)^2 + 4,27 (v_m)^1 - 2,89 \quad (5)$$

where:

$L_{A,p(7,5\text{ m},m)}$  = sound pressure level in dB(A) at 7,5 m for (m) vehicle  
 $v_m$  = average speed in km/h

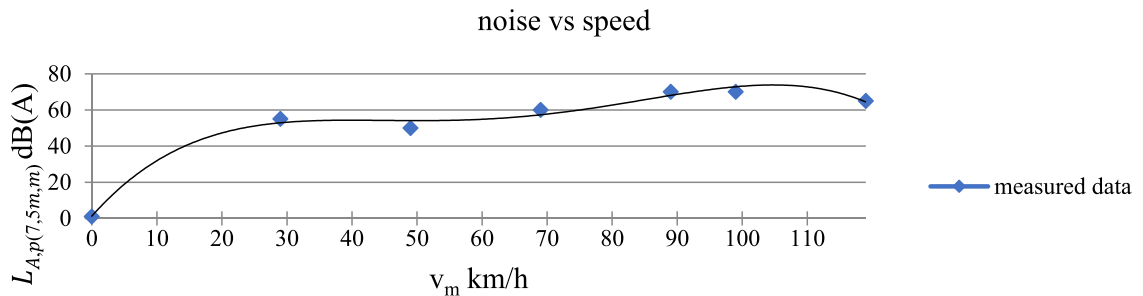


Fig. 2. Polynomial model correlating noise vs. speed.

### 3. Traffic energy model

Relationship between velocity and fuel consumption is quite challenging because several parameters influence it. One of the most important parameters is the engaged gear and the respective speed (see Fig. 3), but the aerodynamic characteristics, engine optimization, propulsion system and skill of the driver should not be forgotten.

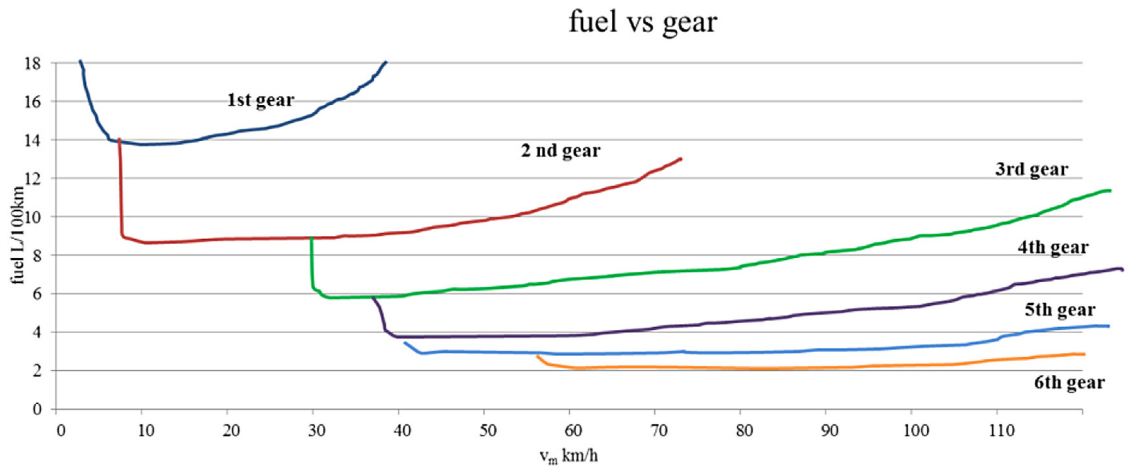


Fig. 3. Relationship between velocity gear and fuel consumption. Source: Adapted from [4].

Nevertheless, averaging all of this, Mostofa & Kalam [2] proposed an important global relationship considering speed and fuel consumption for average vehicles (see Fig. 4).

Data obtained from Fig. 4 allow de interpolation of a polynomial expressed by Eq. (6):

$$FC_{(L/100\text{ km})} = 5 \cdot 10^{-3} (v_m)^2 - 3 \cdot 10^{-1} (v_m)^1 + 13,21 \tag{6}$$

where:

$FC_{(L/100\text{ km})}$  = fuel consumption in liters per 100 km

$v_m$  = average speed in km/h

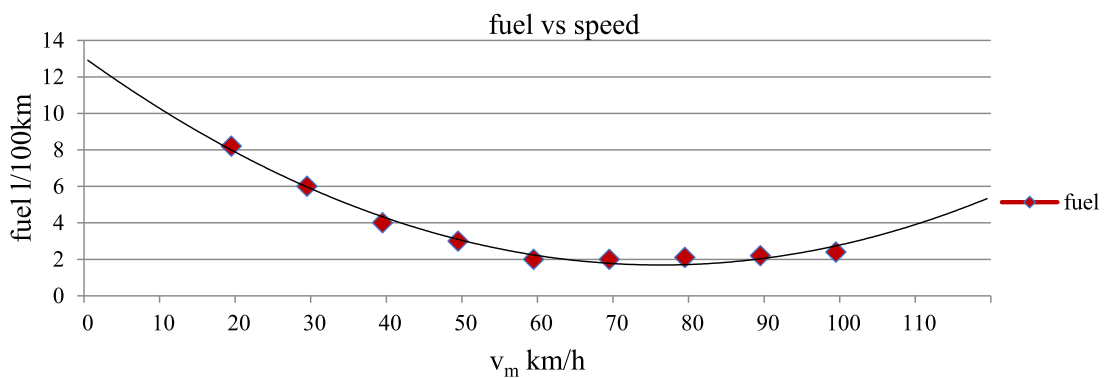


Fig. 4. Relationship between velocity and fuel consumption. Source: Adapted from [2].

### 4. Proposed model

Based on the previous expressions mainly formula (5) and (6) it is possible to obtain a relationship between noise and fuel consumption. A mathematical expression is not the best way to express this relation because different

intervals of vehicle velocity variation have opposite behavior both regarding to fuel consumption  $FC_{(L/100 \text{ km})}$  or noise level  $L_{A,p(7.5 \text{ m,m})}$ . Solution was based on a nomogram that allows a graphic approach as stated in Fig. 5. The example in Fig. 5 shows fuel consumption and noise level at 70 km/h average speed.

$$v_m = 70 \text{ km/h} \Rightarrow \left\{ \begin{array}{l} FC_{(L/100 \text{ km})} = 2,011 \text{ l} \\ L_{A,p(7.5 \text{ m,m})} = 61,6 \text{ dB(A)} \end{array} \right\}$$

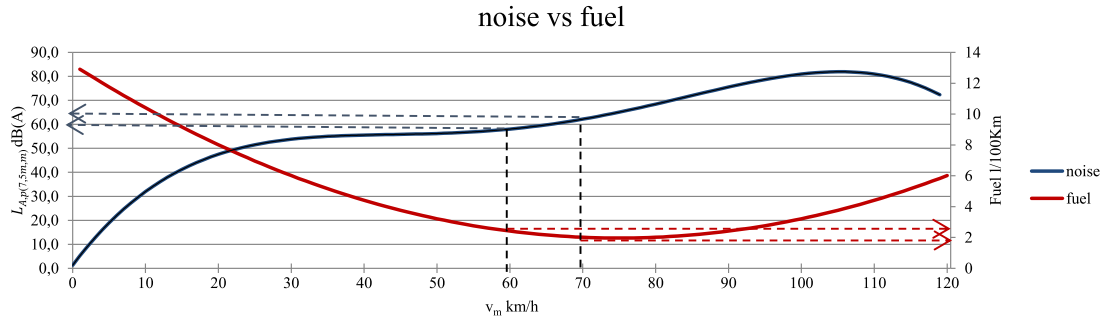


Fig. 5. Nomogram to identify fuel consumption versus noise at given speed.

From the nomogram in Fig. 5 it is possible to evaluate fuel consumption and noise variation on account of a velocity reduction.

$$v_m = 60 \text{ km/h} \Rightarrow \left\{ \begin{array}{l} FC_{(L/100 \text{ km})} = 2,411 \text{ l} \\ L_{A,p(7.5 \text{ m,m})} = 57,8 \text{ dB(A)} \end{array} \right\}$$

And so:

$$\Delta v_m = 70 \rightarrow 60 \text{ km/h} \Rightarrow \left\{ \begin{array}{l} \Delta FC_{(L/100 \text{ km})} = +0,4 \text{ l} \\ \Delta L_{A,p(7.5 \text{ m,m})} = -3,8 \text{ dB(A)} \end{array} \right\}$$

Reduction of velocity has in this case an increase in fuel consumption. If an analysis is made for all possible speed reduction rates a conclusion is acceded that:

$$\Delta v_m = [120: 107] \text{ km/h} \Rightarrow \left\{ \begin{array}{l} \Delta FC_{(L/100 \text{ km})} = \textit{reduction} \\ \Delta L_{A,p(7.5 \text{ m,m})} = \textit{increase} \end{array} \right\} \text{ not interesting noise is over referential limits}$$

$$\Delta v_m = [106: 076] \text{ km/h} \Rightarrow \left\{ \begin{array}{l} \Delta FC_{(L/100 \text{ km})} = \textit{reduction} \\ \Delta L_{A,p(7.5 \text{ m,m})} = \textit{reduction} \end{array} \right\} \text{ most interesting situation}$$

$$\begin{aligned} \Delta v_m &= [75: 001] \text{ km/h} \\ &\Rightarrow \left\{ \begin{array}{l} \Delta FC_{(L/100 \text{ km})} = \textit{increase} \\ \Delta L_{A,p(7.5 \text{ m,m})} = \textit{reduction} \end{array} \right\} \text{ less interesting if speed reduction is below 40 km/h} \end{aligned}$$

## 5. Case study

### 5.1. Area understudy

A 500 m x 500 m urban area was used as case study. The problem concerns to an over exposed noise situation regarding  $[L_{DEN}]$ . A limit of 65 dB(A) is stated and buildings are exposed to over than 75 dB(A).

### 5.2. Results

The speed reduction from 90 km/h to 80 km/h means saving 0.4 l/100 km (green map) means 0.14 M BOE per year (0,4% of oil production) and 7.2 dB(A) reduction.



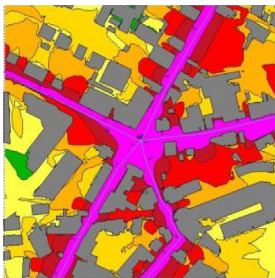
Reduction from 90km/h to 80km/h



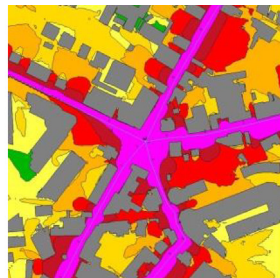
Energy saving class ⇒



The speed reduction from 50 km/h to 30 km/h means increasing 2.8 l/100 km (red map) means 1 M BOE per year (3% of oil production) and 2.7 dB(A) reduction.



Reduction from 50km/h to 30km/h



Energy saving class ⇒



## 6. Conclusions

Urban speed reduction imposing lower limits do not always reduce noise and more important, usually increases energy consumption. So for urban traffic management the possible guide lines based on linear flow are:

- Reduction speed limit from above 107 km/h to this limit is not environmentally interesting;
- Reduction from 107 km/h to 76 km/h is the most environmentally interesting;
- Reduction to below 76 km/h (especially below 40 km/h) is not interesting.

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