Assessment of the CNOSSOS-EU model for road traffic noise prediction

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ABSTRACT:

The prediction of noise through theoretical and computational models has gained in the last years an increasingly significant role in the planning and management of it. With this increase in relevance, it became crucial that these models produce very similar results, if not identical, to real situations. The existence of various models for the various sources of noise, each with its features, led to a problem, namely the comparison of the predicted results from the different models. It is this problem that CNOSSOS-EU addresses significantly, since a common method is set for each noise source.

This dissertation aims to assess to what extent the CNOSSOS-EU model differs from the existing, commonly used, models and if the predicted noise levels are closer to reality, or if the main attribute is to establish itself as a common evaluation method legally defined by the European Commission to be used by all EU Member States. This assessment is based on a theoretical comparison of models and their outcomes, together with a comparison of several simulations and with real acoustic measurements undertaken in urban scenarios. A complete programming in MATLAB of the NMPB-1996, NMPB-2008 and CNOSSOS-EU models was therefore developed and implemented by the author.

The outcome of the several comparisons done allow concluding that the CNOSSOS-EU model does not present a considerable improvement relative to the other existing models considered, despite the results obtained may be more accurate compared to reality, which is, however, yet unclear because the comparison between CNOSSOS-EU model predicted noise levels and the measured noise levels is not conclusive. CNOSSOS-EU implementation is still essential and it is justified in order for all EU member states to be provided with an official common model thus allowing the creation of a comparable database and the development of a more structured and consistent European noise policy.

KEY WORDS: CNOSSOS-EU; Noise prediction; Road traffic noise; Models; Assessment

1. INTRODUCTION

Recent studies from the World Health Organisation (WHO) [Berglund, Lindvall, & Schwela, 1999; WHO Europe, 2009, 2011] proved a direct relationship between noise and health risks. The *Noise in Europe 2014* [EEA, 2014], the first noise assessment report from the European Environment Agency (EEA) reinforces the conclusion, that noise pollution is a major environmental health problem, stating that "road traffic is the most dominant source of environmental noise with an estimated 125 million people affected by noise levels greater than 55 decibels (dB) - L_{den}" and that "environmental noise causes at least 10 000 cases of premature death in Europe each year".

To face the noise pollution problematic, strategies to manage and reduce noise exposure have been developed and prediction of noise has gained special importance in this field. There exist currently many noise prediction models for the different types of noise sources: road, railway, aircraft and industrial. Each model has their own specifications regarding data quality and validity of application and this fact can be an issue when one tries to compare results obtained by each of them. In addition, differences in the used methodological approaches made it difficult (if not impossible) to obtain consistent and comparable figures on the number of people being exposed to noise levels within and across European Union (EU) member states (MS). [EEA, 2014; European Commission, 2011; Kephalopoulos et al., 2014; Licitra & Ascari, 2014]

In response to this problem, the European Commission undertook the development of Common Noise Assessment methods (CNOSSOS-EU) that represent a harmonised and coherent approach to assess noise levels from the main noise sources (road, rail and aircraft traffic, and industrial noise) [Kephalopoulos et al., 2012]. The full implementation of CNOSSOS-EU will be achieved when the process of associated software implementation finishes, which is expected to be on time for the 2017 mapping round [Licitra & Ascari, 2014].

1.1. DESCRIPTION OF THE WORK DONE

This work can be resumed in three parts. The first part, more theoretical, is a comparative analysis between CNOSSOS-EU model and NMPB-1996 model, which describes the main conceptual differences between the models and intends to realize if the existent differences are in the key elements of the models and how significant are these differences are. The second part, which constitutes a significant work of this dissertation, is a comparison of results between different models for various case studies. To do this comparison it was necessary to fully develop a computer program that implemented the CNOSSOS-EU model for road noise, once when this dissertation began to be written, there was not any software available, or if there was, it was not public, that allowed to do simulations with the newly developed CNOSSOS-EU model. In addition, it was also necessary to implement NMPB-1996 and NMPB-2008 models in a similar computer program in order to obtain comparable results for the different scenarios studied. This task was additionally complemented with simulations obtained with the CADNA A software for the purpose of reassurance[1]. Finally in the third part of the work, acoustic measurements were done with a sound level meter in three different places, representative of typical urban environments. The scenarios where the real measurements were made were than replicated in MATLAB simulations with the purpose of testing the developed models and reach some conclusions about the validity and applicability of them.

2. FRAMEWORK

2.1. NOISE POLICIES

Noise policies, or their predecessors, date back to the 6th century BCE but it was only in the 1970's that the relevant ones started to appear and to be rightly implemented. In the mid-1990s, it became clear that noise policies should not only be directed towards the sound source, but also towards the reception side.

Portugal established in 1987 for the first time at the national level the so-called "Regulamento Geral do Ruído", a legal structure to handle noise production and mitigation. In 2000 this document was revised and the current legislation on noise is encompassed in the 2007 "Regulamento Geral do Ruído", which results from the need to harmonize the Portuguese legislation with the new EU environmental noise indicators and to amend certain aspects, in order to facilitate the reading of the law. [Perez, Leite, Guedes, & Bernardo, 2007]

2.2. MODELS FOR ROAD NOISE PREDICTION

The first models mainly evaluated the percentile L_{50}, defined as the sound level exceeded by the signal in 50% of the measurement period, and they referred principally to a fluid continuous flux of

[1] A beta version of the CADNA A program, which has integrated a version of the CNOSSOS-EU model, became available at an advanced stage of this dissertation.

vehicles, considering a common constant velocity with no distinction between vehicle typologies. Along the years some new parameters were added in order to improve the existing models. Parameters like corrective factors for the ground attenuation and for terrain gradients, together with heavy vehicles percentages, are some examples. Later, the equivalent sound pressure level L_{eq}, was introduced as noise indicator, and more types of vehicles started to be considered. [J. Quartieri et al, 2009].

Examples of noise prediction models existent: RLS 90 / VBUS (Germany) [J. Quartieri et al, 2009], CNR (Italy) [J. Quartieri et al, 2009], CoRTN (UK) [Department of Transport and the Welsh Office, 1988], NORD 2000 (Scandinavia) [DELTA et al, 2002], NMPB-1996 and NMPB-2008 (France) [CERTU et al, 1980, 1997] [Sétra, 2009, 2011].

3. CNOSSOS-EU

The CNOSSOS-EU model is the European Union's set of noise prediction models which will be applied for strategic noise mapping in Europe. It is expected that CNOSSOS-EU is implemented and operational in EU MS in 2017, in other words, in time for the third round of strategic noise mapping.

The calculations are made in octave bands, from 125 Hz to 4 kHz. The emission model has five categories of vehicles and is based also on breaking down representative source lines into point sources. The sound propagation model is based on the NMPB-Roads-2008.

3.1. METEOROLOGICAL CONDITIONS

The CNOSSOS-EU model takes into account two meteorological conditions: Homogeneous conditions, in which sound rays are straight segments and Favourable conditions that considers sound rays curved towards the ground due to downward atmospheric conditions.

3.2. ROAD TRAFFIC NOISE SOURCE EMISSION

Vehicles were grouped in five categories: Light motor vehicles (m=1), Medium heavy vehicles (m=2), Heavy vehicles (m=3), Mopeds and motorcycles (m=4) and an Open category.

For categories m=1, 2 and 3, the sound power corresponds to the energetic summation of the rolling noise ($L_{WR,i,m}$)(tyre/road interaction) and the propulsion noise ($L_{WP,i,m}$) (engine, exhaust, etc.) for a average speed (v_m) and frequency band *i*. Thus, the sound power level of the source lines is defined by:

$$L_{W,i,m}\,(v_m) = 10 \times \log\left(10^{\frac{L_{WR,i,m}(v_m)}{10}} + 10^{\frac{L_{WP,i,m}(v_m)}{10}}\right)$$

For category m=4, only propulsion noise is considered for the source line.

The directional sound power per metre, per frequency band *i*, of the source line, expressed in dB, is defined by:

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

$\boldsymbol{Q_m}$ - Traffic Flow (vehicles of category m per hour); $\boldsymbol{v_m}$ - average speed (km/h); $\boldsymbol{L_{W,i,m}}$ - instantaneous directional sound power in 'semi free-field' of a single vehicle (omni-directional sources) for frequency band i.

3.3. SOUND PROPAGATION

The model provides results per octave bands, from 63 Hz to 4000 Hz, although the frequency range used together with the emission data is only from 125 Hz to 4000 Hz. The calculations are made for each of the centre frequencies. The limit of validity of the calculations in terms of distance is 800 m, for a normal distance to the road, and it is recommended that the receiver points should be located at least 2 m high in relation to the ground.

3.3.1. Long-term sound level at reception point R in decibels A dB(A)

The total sound level in dB(A) is obtained by summing levels in each frequency band:

$$L_{Aeq,LT} = 10 \times \log\left(\sum_{i} 10^{\frac{L_{tot,LT,i+AWC_i}}{10}}\right)$$

i - index of the frequency band; ***AWC*** - A-weighting correction; $L_{tot,LT}$ **-** Long-term sound level at point R for all paths.

This level $L_{Aeq,LT}$ constitutes the final result, i.e. the long-term A-weighted sound pressure level at the receiver point on a specific reference time interval.

3.3.2. Propagation analysis

Only 'Direct' paths from the source to the receiver, which are straight paths in plane view and which may nevertheless include diffractions on the horizontal edges of obstacles have been considered.

- **Ground effect**

The attenuation due to the ground effect is mainly the result of the interference between the reflected sound and the sound that is propagated directly from the source to the receiver. For operational calculation requirements, the acoustic absorption of a ground is represented by a dimensionless coefficient *G*, between 0 and 1. *G* is independent of the frequency. G_{path} is defined as the fraction of absorbent ground present over the entire path covered.

- **Diffraction**

As a general rule, the diffraction should be studied at the top of each obstacle located on the propagation path. If the path passes 'high enough' over the diffraction edge, A_{dif}=0 can be set and a direct view calculated, in particular by evaluating A_{ground}. Ray bending is taken into account in the calculation of the path difference and to calculate the ground effects before and after diffraction.

4. ASSESSMENT OF THE CNOSSOS-EU MODEL

4.1. COMPARATIVE ANALYSIS OF CNOSSOS-EU WITH NMPB-1996+GDB80

4.1.1. Emission model

Some differences between GdB 1980 and CNOSSOS-EU exist, starting with the characterization of the traffic composition, for which CNOSSOS-EU requires a more detailed information, by having more vehicles categories. Contrary to CNOSSOS-EU, GdB 1980 does not take into account the road surface effect.

In CNOSSOS-EU sound power level calculation takes into account the two main components of traffic noise, rolling and propulsion noise, which did not happen with the power level values found in GdB 1980 abaques [CERTU (Abaques), 1980]. More precisely, this separation was not made explicitly, because the total noise was already considered instead of being separated to these two components. Table 1 shows some emission values differences between both models for light vehicles (LV) and heavy vehicles (HGV) - m=3 category.

Table 1 - Emission values difference between GdB 1980 and CNOSSOS-EU

	LV		HGV		
Speed	**Horizontal / Downwards**	**Upwards**	**Horizontal**	**Downwards**	**Upwards**
20	2.6	9.7	5.7	5.3	5.2
50	0.7	3.6	2.7	1.4	0.5
80	1.3	0.8	2.6	0.8	-1.7
100	1.2	0.7	3.4	1.3	-1.7

GdB 1980 presents values significantly higher for low speeds, as seen in Figure 1 and verified in Table 1. The only situation where CNOSSOS-EU presents values higher than GdB 1980, is in the HGV/Upwards case, for speeds beyond 50 km/h.

Observing the LV/Upwards case, the two models show a very different behaviour. The CNOSSOS-EU model presents a growing regular behaviour, such as the horizontal/downwards case, the values being 0.5 dB higher. The GdB 1980 shows a decreasing behaviour from 20 to 45 km/h, from there presents a growth, being slight till 80 km/h. Beyond 80 km/h up, the two models evolve equally. (difference between them is constant)

Observing the HGV/Horizontal case, GdB 1980 and CNOSSOS-EU show a similar behaviour, GdB 1980 varying more, however; both start with a downward trend, up to 50 km/h followed by constant power emission up to 70 km/h, passing then to an increasing noise power emission behaviour. The only difference to the downwards case, is that CNOSSOS-EU shows a faster growth than in the horizontal case, as verified by the values in the Table 1.

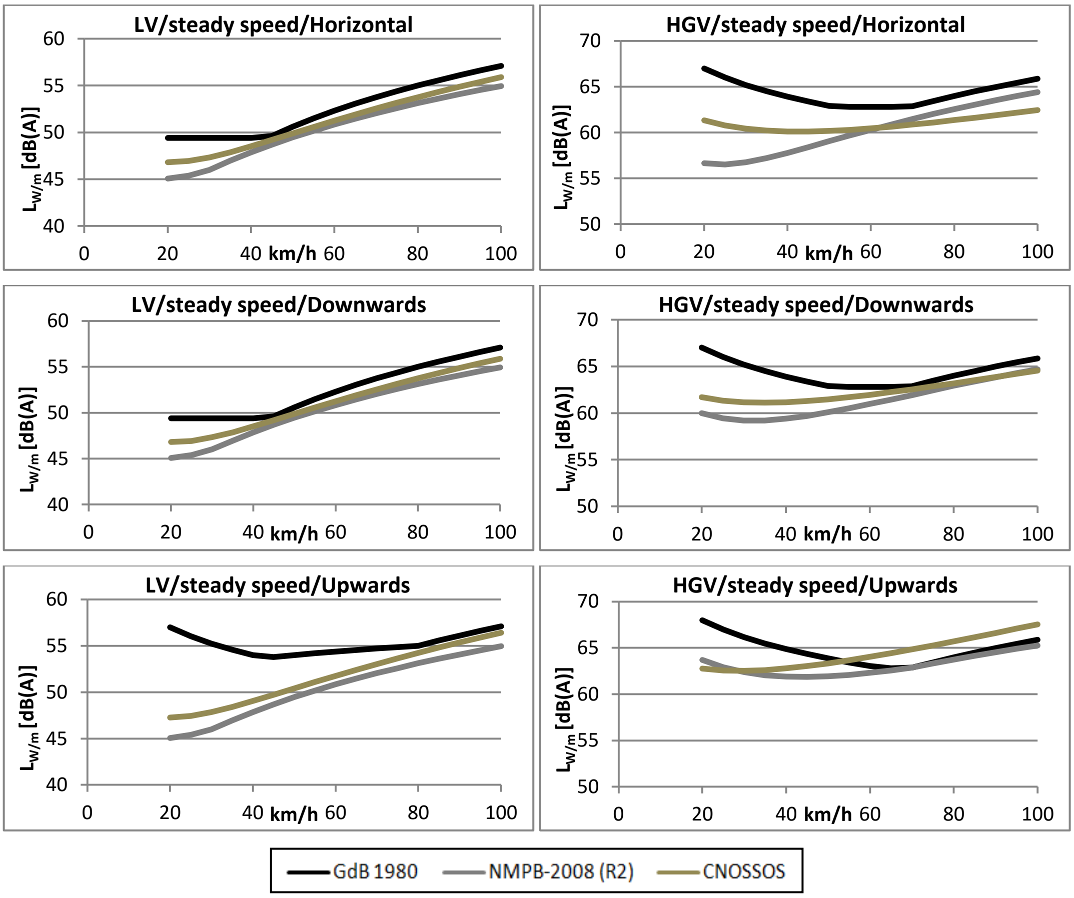

Figure 1 - Emission values for one vehicle. Upwards (6%), Horizontal (0%), Downwards (-6%)

When comparing LV with HGV emission values, it is easy to see that the relations with speed are substantially different and that the HGV emission values are much higher, as would be expected.

Table 2 shows the differences between the HGV emission values and the LV emission values, for each model. In the GdB 1980, the differences for horizontal/downwards gradient vs upwards gradient exist only for low speeds and it is seen that for the horizontal and downwards gradient the differences are way larger. In the CNOSSOS-EU, the differences between the gradients are getting larger as higher is the speed, showing that as long as the speeds increase the differences between HGV and LV are getting smaller for each of the gradients, and it is possible to see that for the horizontal gradient this reduction is a lot faster. Comparing the two models, we see that the general behaviour is shared.

Table 2 - Emission values difference between HGV and LV

	GdB 1980		CNOSSOS-EU		
Speed	**Horizontal / Downwards**	**Upwards**	**Horizontal**	**Downwards**	**Upwards**
20	17.6	11.0	14.5	14.9	15.5
50	12.3	9.9	10.3	11.6	12.9
80	9.0		7.6	9.4	11.4
100	8.8		6.6	8.7	11.1

4.1.2. Propagation model

The only differences between the models, besides the frequency range and resolution, are related with the calculations of the ground effect and diffraction path difference under favourable conditions. For the other situations both propagation models are equivalent.

Ground effect

In the NMPB-1996 model, the $A_{ground,F}$ formulation is derived from the ISO 9613-2 norm, which was developed for industrial sources, for calculating the ground effect it is necessary to divide the path in three areas: source, middle and receiver areas. However, for CNOSSOS-EU only two areas are considered: source and receiver and to calculate the ground effect for favourable conditions (downward) it is only necessary to adapt the formulae given for the homogeneous conditions. The result is a more coherent formulation regarding the ground effect, with the same formula valid for both atmospheric conditions. This did not occur for NMPB-1996.

Diffraction path difference calculation

A simple calculation for a scenario where the source and receiver are both at 10m from the obstacle (height - 4m), and both are at same height (2m), showed that NMPB-1996 returns higher values for path difference, however this difference is in the order of hundredths. The same is verified for a case where the source and receiver are placed higher than the obstacle. Thus, in practice both models return approximately the same value for the paths difference.

Diffraction attenuation

CNOSSOS-EU, introduces the term C_h, whose value can be maximum equal to 1. This term allows to reduce the diffraction attenuation if $\frac{f_m h_0}{250}$ is smaller than one. This occurs when $f_m h_0 < 250$, where f_m is the nominal centre frequency of a frequency band (125, 250, 500, 1000, 2000, 4000) and h_0 is the greatest of two heights of the diffraction edge in relation to each of the two mean ground planes source side and receiver side.

Taking into account the above centre frequencies, C_h can only be less than 1 if h_0 is lower than the following values for each frequency: 2, 1, 0.5, 0.25, 0.125, 0.0625 m. For the normally found diffraction cases one can see that the value will be always one because h_0 is usually always higher than 2m.

4.2. SIMULATED SCENARIOS

In order to assess the CNOSSOS-EU model in practice, and in order to compare it with the NMPB-1996 - GdB1980 model, four scenarios were defined and simulated with the developed and implemented MATLAB code. The main differences between these four scenarios derive from considering an absorbent (G=1) or reflective ground (G=0) and from including or not the effect of sound diffraction by a barrier.

Each simulated scenario considered a set of base parameters, given in the Tables 3 and 4, for defining both the geometric arrangement and the road traffic. For each of the simulated scenarios some parameters values were then varied over some defined interval in order to see the implications that these variations have in the results obtained by the CNOSSOS-EU model and by the NMPB-1996 - GdB 1980 model (and also by the NMPB-2008 model, for comparing purposes). When analysing the results from the MATLAB simulations, it is useful to compare them to the results obtained by CADNA A software, specially for the NMPB-1996 model, which is fully implemented in CADNA A software for several years. The four scenarios and the set of base parameters values were chosen so that they can represent real situations found in practice.

Table 3- Simulated scenarios

Scenario parameters	
	[m]
h_R	2
d_1	3
d_2	97
$h_{barrier}$	3 or 4

Table 4 - Base parameters values

Base parameters values		
Traffic flow	10000	veh/h
% Heavy vehicles	10	%
Velocity	80	km/h
Temperature	20	ºC
Slope	0	%
Receiver height	2	m
Barrier height	0 3 4	m
Distance SR	100	m
Prob. Favourable	0,5	%/100
Age Surface	4	years
	No Porous	
Road length	500	m
Segment length	10	m
Lane width	3	m

Traffic flow base values used for both models simulations were defined as given in the Tables 5 and 6.

Table 5 - Traffic composition - CNOSSOS-EU

Base Values - CNOSSOS-EU					
	Traffic 1	Traffic 2	Traffic 3	Traffic 4	
Traffic flow	10000				veh/h
% Heavy	10		30		%
m=1	8100	6300	7000		veh/h
m=2	750		3000	0	veh/h
m=3	250		0	3000	veh/h
m=4a	0				veh/h
m=4b	900	2700	0		veh/h

Table 6 - Traffic composition - NMPB

Base Values - NMPB			
	Traffic A	Traffic B	
Traffic flow	10000		veh/h
% Heavy	10	30	%
m=1	9000	7000	veh
m=2	1000	3000	veh

4.2.1. Scenario results obtained with base parameters values

The results obtained from first simulations with Traffic 1 and 2 showed that the changes in the sound levels are not significant when there is an increase of the motorcycles weight of 20% in the light vehicles share. Taking this observation into account, it was opted to consider only Traffic 1 in the subsequent simulations using the CNOSSOS-EU model.

The differences in the results obtained whether using Traffic 3 or 4 show, as would be expected, that it is in fact relevant if the heavy vehicles are ascribed to the medium or heavy tonnage categories of CNOSSOS-EU model. When defined as category m=3, corresponding to heavy tonnage (Traffic 4), the obtained sound levels are approximately 2 dB higher than when defined as category m=2, corresponding to medium tonnage (Traffic 3).

Due to this finding, and having in mind the best comparison of the CNOSSOS-EU model with the NMPB-1996 model, Traffic 4 was chosen for the subsequent analysis of parameters variation because the sound levels obtained using this traffic composition were closer to the ones obtained with NMPB-1996. This fact allows also one to conclude that the heavy tonnage vehicles category (m=3) of CNOSSOS-EU corresponds to the heavy vehicles category (m=2) of the NMPB-1996 model.

The resulting sound levels given in the Tables 7 and 8, for G=0 and G=1, show that CNOSSOS-EU predicts always lower values than NMPB-1996, and also than NMPB-2008, for all the simulated scenarios. It is also possible to see that the insertion loss caused by the barrier presence is higher for CNOSSOS-EU.

Table 7 - Differences - Base Values - G=0

Sound Pressure Level - dB(A)						
	Traffic 1			Traffic 4		
	Ho=0	Ho=3	Ho=4	Ho=0	Ho=3	Ho=4
CNOSSOS-EU	68.6	50.9	48.8	67.9	50.9	48.8
CADNA A	71.4	50.4	48.7	63.0	49.4	48.0
	Traffic 1 - Traffic A			Traffic 4 - Traffic B		
NMPB-1996	-4.4	-6.5	-6.3	-4.8	-6.2	-5.9
CADNA A	-1.6	-7.3	-6.7	-2.0	-7.1	-6.6
NMPB-2008	-2.1	-3.3	-3.3	-2.7	-3.1	-3.1
CADNA A	-2.4	-5.2	-4.7	-2.7	-5.1	-4.7

Table 8 - Differences - Base Values - G=1

Sound Pressure Level - dB(A)						
	Traffic 1			Traffic 4		
	Ho=0	Ho=3	Ho=4	Ho=0	Ho=3	Ho=4
CNOSSOS-EU	65.7	48.0	46.0	67.9	50.9	48.8
CADNA A	61.2	46.9	45.5	63.0	49.4	48.0
	Traffic 1 - Traffic A			Traffic 4 - Traffic B		
NMPB-1996	-4.0	-5.3	-5.1	-4.4	-5.0	-4.9
CADNA A	-6.8	-6.0	-5.4	-7.5	-6.1	-5.5
NMPB-2008	-2.1	-3.3	-3.2	-2.7	-3.1	-3.1
CADNA A	-1.4	-4.4	-4.3	-2.2	-4.5	-4.4

The levels for G=1 are lower than G=0, as expected, once the ground absorption is higher. The variations for G=1 are smaller than the ones verified for G=0, besides that the behaviours are equal.

4.2.2. Parameters Variation

Starting from the base parameters defined before, one parameter at a time was selected, from

Table 9, to replace the base values. With this proceeding one can assess the influence of the particular parameters' variation in the predicted sound levels.

Table 9 - Parameters values

Parameters values	
Speed (km/h)	20, 30, 40, 50, 60, 70, 80, 90, 100
Barrier height (m)	0,0.5,1, 2, 2.6, 3, 3.6, 4, 4.6, 5
Heavy vehicles (%)	0, 2.5, 5, 10, 20, 30, 40, 50
Distance SR (m)	10, 50, 100, 200, 500, 800
Slope (%)	-6, -4, -2, 0, 2, 4, 6
Prob. Favourable (%)	0, 25, 50, 75, 100
G	0, 1

4.2.3. Summary of the simulated scenarios results

The behaviours of the NMPB-1996 model and CNOSSOS-EU model, for each parameter, are always similar, except for the speed variation, specially for low speeds.

Changing the ground absorption factor and/or considering the presence or absence of a noise barrier, only influences the final noise levels, not affecting the overall trends.

Table 10 resumes the average differences in the levels calculated with both models between the considered scenarios.

Table 10 - Average levels difference

		TC1			TC2			TC1-TC2		
		No Barrier	**Barrier**	**Δ**	**No Barrier**	**Barrier**	**Δ**	**No Barrier**	**Barrier**	**Δ**
NMPB-1996	**G=0**	72.5	57.0	**15.5**	74.7	59.2	**15.5**	-2,2	-2,2	**0,0**
	G=1	69.1	52.9	**16.2**	71.3	55.1	**16.2**	-2,2	-2,2	**0,0**
	Δ	**3.4**	**4.1**	**-**	**3.4**	**4.1**	**-**	**0,0**	**0,0**	
CNOSSOS-EU	**G=0**	67.6	50.2	**17.4**	69.9	53.0	**16.9**	-2,3	-2,8	**0,5**
	G=1	64.5	47.3	**17.2**	66.8	50.1	**16.7**	-2,3	-2,8	**0,5**
	Δ	**3.1**	**2.9**	**-**	**3.1**	**2.9**	**-**	**0,0**	**0,0**	
NMPB-1996 - CNOSSOS-EU	**G=0**	4,9	6,8	**-1,9**	4,9	6,2	**-1,4**			
	G=1	4,6	5,6	**-1,0**	4,5	5,0	**-0,5**			
	Δ	**0,3**	**1,2**		**0,4**	**1,3**				

From this table it is possible to verify that traffic composition is not a factor when calculating the noise levels difference between a no barrier scenario and a barrier scenario for NMPB-1996. And that even for the CNOSSOS-EU model it is not that relevant because the difference is only 0.5 dB. One can also verify that TC2 average levels are always 2.2 dB higher than for TC1 for NMPB-1996. This difference is almost the same for CNOSSOS-EU, however for the barrier scenario this model predicts levels in the TC2 case that are a little bit higher, reaching a difference of 2.8 dB.

When comparing the NMPB-1996 and CNOSSOS-EU average levels, one can see that NMPB-1996 levels are a lot higher than CNOSSOS-EU ones. The differences vary from 4.5 to 4.9 dB and from 5.0 to 6.8 dB, for the no barrier scenario and the barrier scenario, respectively. In addition the CNOSSOS-EU variations are larger than the NMPB-1996 ones.

When comparing the various scenarios, it is possible to conclude that without barrier the levels are always higher, as expected, being the difference larger for CNOSSOS-EU than for NMPB-1996. (G=0: 15.5 dB; G=1: 16.2 dB) vs (G=0: 17.4/16.9 dB; G=1: 17.2/16.7 dB).

Also the difference between predicted noise levels for scenarios with and without barrier are slightly higher in CNOSSOS-EU, therefore meaning that the insertion loss of barriers calculated with CNOSSOS-EU model is somewhat higher than with NMPB-1996.

The difference between G=0 and G=1 predicted noise values are lower in CNOSSOS-EU model, meaning that for this model the ground effect attenuation has apparently less importance when compared with NMPB-1996. And this difference is enhanced for the barrier scenarios.

Finally for the CNOSSOS-EU model the biggest difference between G=0 and G=1 predicted noise values occur for a no barrier scenario, while for the NMPB-1996 model the opposite is verified. So the variation of the ground effect in the presence of a barrier is not as important with CNOSSOS-EU as with NMPB-1996 model.

4.3. EXPERIMENTAL EVALUATION

4.3.1. Acoustic measurements

For the assessment of validity and accuracy of the models developed, some acoustic measurements were made, with approximately 10 minutes duration each.

Three different locations were chosen on the basis of some characteristics that were defined as important to do a good experimental assessment. These characteristics consisted in a regular traffic flow, presence or absence of a noise barrier at least at one location and the possibility to do acoustic measurements and counting cars at the same time. The main characteristics of the chosen locations are portrayed in table 11.

Table 11 - Locations' geometrical dimensions

Location	1	2	3
h_R	1.5	1.5	1.5
$h_{barrier}$	3.6	0.0	3.6
d_1	15.8	13.5	14.2
d_2	18.6	19.0	8.5

Table 12 - Measurements

Location	1	2		3	
L_{Aeq} (dB)	58,6	57,4	57,9	66,4	66,5

Table 12 resumes the L_{Aeq} sound levels obtained.

4.3.1.1. Location 1 - Eixo Norte-Sul

This measurement site is located in a parking lot of an adjacent residential area to Eixo Norte-Sul, an interurban road, with a high traffic flow (~8% of heavy vehicles and ~2% of motorcycles) and high speeds (~ 80km/h or more). The segment studied has six lanes, three in each direction, and a slope of approximately 4%. The entire segment is provided with a sound barrier of 3.6 m height. The road is at a greater height with respect to the receiver.

Figure 2 - Photos of the measurement site 1 - Eixo Norte-Sul

4.3.1.2. Location 2 - LISPOLIS

The second measurement site is located on a lawn next to an urban road which, has a regular traffic flow (~3% of heavy vehicles and 0% of motorcycles - first measurement and ~6% of heavy vehicles and 2% of motorcycles - second measurement) and medium speeds (~50 km/h). The segment studied is flat and has 6 driving lanes, three in each direction.

Figure 3 - Photos of the measurement site 2 - LISPOLIS

4.3.1.3. Location 3 - 2ª Circular

The third measurement site is located on a parallel road to the 2ª Circular, a interurban road with a high traffic flow and high speeds (80 or more). The studied segment is flat and has seven lanes, three in one direction and four in another. A sound barrier 3.6 m high, parallel to the entire segment, exists at this site. Location 3 is similar to location 1 but with half of the heavy vehicles percentage.

Figure 4 - Photos of the measurement site 3 - 2ª Circular

4.3.2. Comparison of the experimental measures with simulation

Table 13 - Results comparison[2]

Location	1	2		3	
Measure	1	3	4	5	6
Sound Pressure Level - dB(A)					
Real	58.6	57.4	57.9	66.4	66.5
NMPB-1996					
MATLAB	59.5	63.2	64.9	66.2	66.1
Δ	+0.9	+5.8	+7.0	-0.2	-0.4
% error	1.5	10.1	12.1	0.3	0.6
CNOSSOS-EU					
MATLAB	53.9	58.9	59.7	60.9	60.7
Δ	-4.7	+1.5	+1.8	-5.5	-5.8
% error	7.9	2.6	3.1	8.3	8.7
NMPB-2008					
MATLAB	56.8	59.9	60.9	63.4	63.3
Δ	-1.8	+2.5	+3.0	-3.0	-3.2
% error	3.1	4.4	5.2	4.5	4.8

When comparing the results from the MATLAB simulations, with the acoustic measurements, as shown in table 13 is possible to verify that there are some significant deviations.

Recalling the locations characteristics one can divide them into two groups, without and with diffraction cases, and within the diffraction cases one can still separate in slope and no slope condition.

Looking at the non diffraction cases (measurements 3 and 4) one sees that the CNOSSOS-EU is the model that records a minor error in relation to the measured sound levels, once it presents a 1.5 dB and 1.8 dB higher sound level than the measured level, while the NMPB-1996 model is the one with the worst predictions for this case, providing higher levels between 5.8 dB and 7.0 dB. The NMPB-2008 presents intermediate values.

As for the diffraction cases one sees that the NMPB-1996 presents a smaller error when compared with the other models, around 0.5% in the no slope case. For these diffraction cases the CNOSSOS-EU model presents a considerable error, predicting lower levels between 4.7 dB and 5.8 dB, thus it is the model that fits less for these cases. The NMPB-2008 again shows intermediate values.

So for measurements 3, 4, 5 and 6 one can safely say which model best fits the measured situations, as the measurement 1, where the picture is more complex, given the existence of slope and the gap between road and the measurement location such clarification is not as direct.

The differences with acoustic measurements in scenarios with diffraction, are very significant in CNOSSOS-EU compared to the NMPB-1996 which may indicate a limitation in CNOSSOS-EU in such scenarios. Looking to the difference between the MATLAB results for NMPB-1996 and CNOSSOS-EU, one sees that on average the difference is 5 dB as already observed before.

Summarizing, NMPB-1996 apparently presents better results for the cases where diffraction occurs, and CNOSSOS-EU predicts better values when only the ground attenuation is taken into account.

Since the CNOSSOS-EU propagation model is very similar to the NMPB-2008 one, and seeing the NMPB-2008 results for the diffraction cases, it is possible to say that the existent differences are resulting from the emission part.

[2] $\%\ error = (|real\ value - aproximated\ value|/real\ value) \times 100$

5. CONCLUSIONS

As described in the introduction, the objective of this dissertation is the assessment of the CNOSSOS-EU model.

For that purpose an analysis has been made between CNOSSOS-EU and NMPB-1996, which intended to realize what were the main differences in the key elements of the models and how significant they are. A computer program in MATLAB that implemented the CNOSSOS-EU, NMPB-1996 and NMPB-2008 models for road noise was fully implemented in order to obtain comparable data, once no software was available (by the start date of the dissertation) that allowed to do simulations with the newly developed CNOSSOS-EU model. The developed computer program implementing these models constitutes a significant work of this dissertation, since it was necessary to fully program those models, both their emission and propagation parts, based on the public documents available. The implemented programming code was used to simulate a conceptual base scenario, associated parameters variation and for the replication of the considered scenarios. For these scenarios, acoustic measurements were made with a sound level meter for assessing the validity and accuracy of the models developed. In addition, in order to evaluate the validity of the implemented models and therefore the conclusions retrieved from their results, a replication of the scenarios was undertaken in the commercial software CADNA A. The percentage differences between the CADNA A and the MATLAB's results are very small, so one can assume that the MATLAB developed code yields accurate data, therefore being considered accurate, at least for the cases here reported.

A first analysis of the CNOSSOS-EU model allows concluding that it requires a more detailed information in terms of the characterization of the traffic composition because it has more vehicle categories than those required by the GdB 1980. In the CNOSSOS-EU model, sound power level calculation takes into account the two main components of traffic noise, namely rolling and propulsion noise, which did not happen with the power level values found in GdB 1980 abaques. In these abaques, total sound power level is considered instead of being separated in these two components. Also, CNOSSOS-EU takes into account the road surface effect that was overlooked in GdB 1980.

In terms of sound propagation it was identified that the ground effect and that the path difference calculation under favourable (downwards) conditions, may constitute possible factors for potential differences (besides the different frequency band resolution), but after calculations one verified that the resulting path differences between the CNOSSOS-EU model and the NMPB-96 model are only in the order of hundredths.

The simulations done for the conceptual base scenario using the base parameters values allowed one to retrieve some conclusions like the ones described in what follows.

For the CNOSSOS-EU model one concludes that an increase of 20% of the motorcycles' weight in the light vehicles share does not bring a significant change in the noise levels. However, it is relevant if the heavy vehicles are ascribed to the medium or heavy tonnage categories once the obtained sound levels are approximately 2 dB higher when defined as category m=3, corresponding to heavy tonnage vehicles, than when defined as category m=2, corresponding to medium tonnage vehicles. For diffraction scenarios there are not significant differences when considering 3 metres or 4 metres height barriers.

CNOSSOS-EU predicts always lower values than NMPB-1996, and also than NMPB-2008, for all the simulated scenarios no matter the ground absorption factor, and as expected the noise levels are lower when the ground absorption is higher. Ground absorption factor has a fixed influence that is independent from the other parameters, that is, it changes the sound level but not the overall behaviour. For the diffraction scenarios the differences are smaller when increasing the heavy vehicles percentage and the insertion loss caused by the barrier presence is higher for

CNOSSOS-EU. Increasing the ground absorption has more relevance in the NMPB-1996 model and this relevance is somewhat amplified by a presence of a barrier, which results in a higher attenuation in the noise levels.

The differences between CNOSSOS-EU and the other models are more pronounced for the diffraction cases (~6 dB) than for the non-diffraction cases (~4 dB). The difference between CNOSSOS-EU and NMPB-1996 is also approximately the double of the difference between CNOSSOS-EU and NMPB-2008.

The main conclusions that can be drawn from the section on parameters variation of the simulated scenarios are that the overall behaviours are always similar between the models, although there are some significant differences that can be found for particular parameters.

When comparing the computed NMPB-1996 and CNOSSOS-EU noise levels, one can see that CNOSSOS-EU levels are always considerably lower than NMPB-1996 ones (On average 5,3 dB lower). The insertion loss of barriers calculated with CNOSSOS-EU model is somewhat higher than that calculated with NMPB-1996 model.

The main conclusions that can be retrieved from the experimental evaluation, for which acoustic measurements were made at three different locations, are that NMPB-1996 presents better results for the cases where diffraction occurs, while CNOSSOS-EU predicts better values when only the ground attenuation is taken into account. The differences between computed values to measured values for scenarios with diffraction, are very significant in CNOSSOS-EU model compared to the NMPB-1996 model which may indicate a limitation of the CNOSSOS-EU model for such scenarios. For the scenarios with diffraction the predicted values with CNOSSOS-EU are approximately 4.7 to 5.8 dB lower than the measured levels, while the corresponding NMPB-1996 values are in one case approximately 0.9 higher and in another case approximately 0.5 dB higher.

For the non-diffraction cases the CNOSSOS-EU model predicted values are only approximately 2 dB higher than the measured ones, while NMPB-1996 predicts values approximately 6.5 dB higher than the measured ones.

Since the CNOSSOS-EU propagation model is very similar to the NMPB-2008 one, and seeing the NMPB-2008 results for the diffraction cases, it is possible to say that the existent differences are mainly resulting from the emission part.

Resuming, there is a notary difference between CNOSSOS-EU model and the NMPB-1996 model results although a similar behaviour for most of the parameters is found. For the lower speeds (until 50km/h), CNOSSOS-EU emission part presents values that are more correlated to the vehicle fleets existent nowadays. This might indicate that CNOSSOS-EU model yields more correct predictions, despite the extra work needed for the traffic characterization since it uses more vehicle categories. The presence of a barrier produces, as expected, a reduction on the sound levels in every models, but this computed attenuation is higher in CNOSSOS-EU model.

One conclusion of this dissertation is that the CNOSSOS-EU model does not present a considerable improvement towards the other existing models, because the main changes concerned mostly the emission part, which results in noise levels on average 5 dB lower than NMPB-1996 ones.

The results obtained with this new model are thought to be more accurate compared to reality once a more detailed traffic characterization is implied and once a more actual and complete knowledge about outdoor noise serves as a basis to the developed model.

However, the value of that assertion is unclear because the CNOSSOS-EU model simulated results when compared with the values resulting from the acoustic measurements done (which is not enough to portray reality), are sometimes better, but sometimes worse, compared to the existing models, depending on the specific case.

If CNOSSOS-EU model results are in fact correct, which has not been completely proven in this dissertation with the conjunction with the acoustic measures done, then a reassessment to noise mitigation actions taken in the recent past should be made, since this lower emission values at source will affect the level of demand of those actions to be lower, which will mean significant costs savings. These mitigation actions arise from the need to comply with existing legislation regarding the noise levels to which humans may be subject in order to protect their quality of life and health.

CNOSSOS-EU implementation is still essential and it is justified in order for all EU member states to be provided with an official common model thus allowing the creation of a comparable database and the development of a more structured and consistent European noise policy.

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