Matching directive 2015/996/EC (CNOSSOS-EU) and the French emission model for road pavements

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Summary
The member states of the EU will have to implement CNOSSOS-EU from 01.01.2019 on. This requires to adapt existing emission databases to this new framework. In particular, road pavements are often country specific. CNOSSOS-EU offers a set of 9 coefficients per vehicle category to account for a particular pavement but with little guidance about how to tune these coefficients. In the French context, the noise emission model for road traffic was updated in 2009 in relation to the publication of NMPB 2008. It is based on a large database of statistical pass-by measurements on a representative set of national pavement formulations for the two categories of light and heavy vehicles. The emssion model introduces a classification in 6 categories {R1, R2, R3} x {Drainage, Non Drainage} that is extensively used in the context of strategic noise mapping. Since the propagation part of CNOSSOS-EU is very close to NMPB 2008, the approach taken here for a particular pavement formulation is to match sound power levels and adjust the available 9 coefficients so that the discrepancy is as small as possible. Although they both combine an engine noise component and a rolling noise component the emission models of CNOSSOS-EU and NMPB 2008 differ significantly in terms of formulation and input parameters. Therefore an exact analytical resolution was not possible and simplifying assumptions were necessary. Moreover, the focus was put on aged pavements on horizontal roads. In addition, we considered only steady speeds above 50 km/h. The results presented illustrate that with the coefficients obtained, a good agreement is observed on L_{Aw} both for CNOSSOS-EU category 1 and 3, with discrepancies lower than 1 dB(A) in most of the cases. The procedure works better on Non Drainage than on Drainage pavements.

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1. Introduction

The French current noise prediction framework for roads was released in 2009. It features an emission model [1] and a propagation model [2] named NMPB2008. In France, the implementation of 2002/49/EC directive (END) [3] has been relying on it since round 2 of END.

A common noise prediction method was adopted by the member states (MS) of the European Union in 2015. It is specified in directive 2015/996/EC [4] which is the outcome of the so-called CNOSSOS-EU project. This directive is meant to substitute for the original Annex II in END. In short one can say that CNOSSOS-EU and the current French prediction framework have the propagation model for terrestrial noise sources in common, although the propagation part of directive 2015/996/EC is only a subset of NMPB2008. But the emission model defined in CNOSSOS-EU is significantly different from its French counterpart.

Directive 2015/996/EC will be mandatory from 01.01.2019 on. For several MS, this means that country-specific emission values must be obtained in due time in order to account for the specificity of national pavements, among other aspects. A similar exercise is to be carried out for rail emissions. For the MS, evaluating the consequences of the model shift is also of interest. This paper focuses on road emission.

The French emission model is based on a large database of statistical pass-by measurements on a representative set of national pavement formulations for the two categories of light and heavy vehicles.

The emssion model introduces a simplified classification in 6 categories {R1, R2, R3} x {Drainage, Non Drainage} that is extensively used in the context of strategic noise mapping.

This paper summarizes the work carried out toward adapting the harmonized EU framework and the French one [5] for light vehicles and heavy vehicles. Medium heavy vehicles deserve a specific approach and are adressed elsewhere at Euronoise 2018 [6]. The paper is organized as follows. Section 2 outlines the European noise emission model for roads and road traffic. Section 3 is the counterpart of the previous section for the FR model. Section 4 describes a first method used to identify pavement-specific coefficients. It is based on rolling noise only. Since the results obtained with this approach are not completely satisfactory, an alternative identification on the total sound power is proposed in Section 5.

In this paper, the following notations are used :

- EU for the EUropean model [4],
- FR for the FRench model [1],
- v, the mean vehicle speed (in km/h),
- Octaves from 63 to 8000 Hz are indexed by $i \in \{1, \ldots, 8\}$,
- $\oplus$ stands for the energy sum:

$$L_1 \oplus L_2 = 10 \log_{10}(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}}) \quad (1)$$

2. European road emission model

The most detailed specification of the EU model for road emission is given in 2015/996/EC [4]. The EU model is expressed in octave bands from 63 to 8000 Hz and considers 4 clearly defined vehicle categories and a fifth open one. Category 1 corresponds to light vehicles (LV), category 2 to medium heavy vehicles, category 3 to heavy vehicles and category 4 to powered two-wheelers. In the EU model emission values are not A-weighted. The sound power level is given by the sum of so-called *rolling noise* and *propulsion noise* components:

$$L_{w,EU,i}(v) = L_{r,EU,i}(v) \oplus L_{m,EU,i}(v) \quad (2)$$

where $L_{r,EU}(v)$ is rolling noise power, $L_{m,EU}(v)$ the engine noise power and v is vehicle speed. Eq. 2 is valid for the whole range of vehicle speeds, except that that $L_{W,EU,i}(20)$ is used for $v < 20\ km/h$.

Except for category 4 (powered 2-wheelers) where rolling noise is negligible, rolling noise is given by:

$$L_{r,EU,i} = A_{r,EU,i} + B_{r,EU,i} \log_{10} \frac{v}{v_{\text{ref}}} \quad (3)$$
$$+ \Delta L_{r,EU,i} \quad (4)$$

where $A_{r,EU,i}$ et $B_{r,EU,i}$ are tabulated for each octave band and for each vehicle category at the reference speed $v_{\text{ref}} = 70\ km/h$. $\Delta L_{r,EU,i}$ is the sum of various corrections for deviations from a *reference* situation. where among other aspects constant vehicle speed, horizontal road, a *virtual reference pavement* made of a combination of DAC 0/11 and SMA 0/11. These two pavement formulations hardly exist in France if at all although the first one is close to the French BBSG 0/10. In our study we can assume that the correction of interest corresponds to the deviation from the reference pavement $\Delta L_{r,\text{pav}^t,EU,i}$ so that:

$$\Delta L_{r,EU,i} = \Delta L_{r,\text{pav}^t,EU,i} = \alpha_i + \beta \log_{10} \frac{v}{v_{\text{ref}}} \quad (5)$$

where α_i is the spectral correction in dB at v_{ref} for octave i. β is meant to adjust for the influence of speed on the variation of rolling noise and it does not depend on frequency.

To summarize we have:

$$L_{r,EU,i} = [A_{r,EU,i} + \alpha_i] \quad (6)$$
$$+ (B_{r,EU,i} + \beta) \log_{10} \frac{v}{v_{\text{ref}}} \quad (7)$$

Propulsion noise is a linear function of vehicle speed:

$$L_{m,EU,i} = A_{m,EU,i} + B_{m,EU,i} \frac{v - v_{\text{ref}}}{v_{\text{ref}}} \quad (8)$$
$$+ \Delta L_{m,EU,i} \quad (9)$$

where $A_{m,EU,i}$ and $B_{m,EU,i}$ for octave i are tabulated for each vehicle category and $\Delta L_{m,EU,i}$ accounts for the deviations from the reference conditions relating to road gradient, acceleration and pavement type. The latter correction is named $\Delta L_{m,pav^t,EU,i}$ and accounts for the influence of the absorption factor of the pavement on propulsion noise. The other factors can be ignored in our case.

$$\Delta L_{m,EU,i} = \Delta L_{pavt,EU,i} = \min(\alpha_i; 0) \quad (10)$$

So that the expression of propulsion noise can be summarized by:

$$L_{m,EU,i} = A_{m,EU,i} + B_{m,EU,i} \frac{v - v_{\text{ref}}}{v_{\text{ref}}} \quad (11)$$
$$+ \min(\alpha_i; 0) \quad (12)$$

A complete software implementation of this emission model in Scilab was developed in the framework of this study. Its validity was checked against the official EU reference software [7, 5]. It was used in relation to the optimization tasks described in Sections 4 and 5.

3. French road emission model

The FR model is specified in [1] and its *rationale* outlined in [8]. The model expressed in third octave bands from 100 to 5000 Hz. In our study the third octave bands were combined into octaves $i \in \{2, \ldots, 7\}$. The FR model accounts for two vehicle classes: light vehicles (LV) and heavy vehicles (HGV). LV corresponds to category 1 in the EU model and HGV to EU category 3. The FR model distinguishes 6 pavement classes made of the product of 3 noise level classes R1, R2 and R3 and 2 spectral distributions (Non drainage and Drainage). R3 is the noisiest category.

The FR model is A-weighted and assumes that the emission spectrum does not depend on vehicule speed nor on vehicle category (Figure 1). The emission spectrum is indeed a traffic noise spectrum where 15% HGV is assumed.

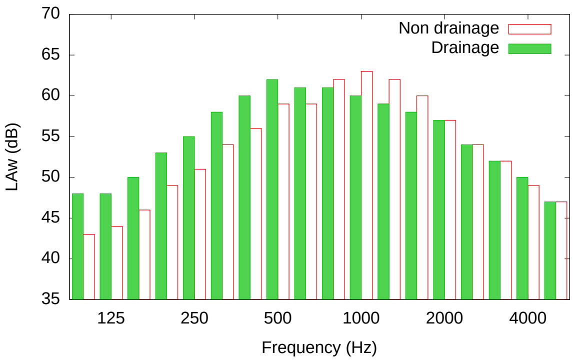

Figure 1. Fixed frequency distribution R_i for Drainage and Non drainage pavements.

The maximum A-weighted pass-by sound level at frequency i is the energy sum of two components with the same notations as for the EU model for vehicle speed, rolling and engine noise components:

$$L_{\text{Amax},FR,i}(v) = L_{r,FR}(v) \oplus L_{m,FR}(v) + R_i \quad (13)$$

where R_i is spectral distribution. Although vehicle speed is the main parameter, the FR model that also depends on age, flow type (constant speed, decelerated or accelerated) and on the road gradient.

The rolling noise component is expressed as follows.

$$L_{r,FR}(v) = A_{r,FR} + B_{r,FR} \log_{10} \frac{v}{v_{\text{ref}}} \quad (14)$$

where $A_{r,FR}$ and $B_{r,FR}$ are tabulated for LV, HGV and R1, R2 and R3 [1]. $v_{\text{ref}} = 90\ km/h$ for LV and $v_{\text{ref}} = 80\ km/h$ for HGV.

The formulation for engine noise is similar

$$L_{m,FR}(v) = A_{m,FR} + B_{m,FR} \log_{10} \frac{v}{v_{\text{ref}}} \quad (15)$$

where $A_{m,FR}$ and $B_{m,FR}$ are the corresponding set of tabulated values for LV and HGV[1]. For $v < 20\ km/h$ the model assumes $L_{m,FR}(v) = L_{m,FR}(20)$.

The sound power level of a vehicle $L_{w,FR}$ is related to its maximum pass-by sound level by

$$L_{W,FR} = L_{Amax,FR} + 25.6 \quad (16)$$

.

To summarize:

$$L_{W,\text{FR},i}(v) = L_{r,\text{FR}}(v) \oplus L_{m,\text{FR}}(v) \quad (17)$$
$$+ R_i + 25.6 \quad (18)$$

In Sections 4 and 5 the implied numerical calculations were performed with the Scilab software used to generate the graphic appendix in [1].

4. Matching FR and EU models on rolling noise only

4.1. Modelling

In order to account for the characteristics of a particular pavement formulation in the CNOSSOS-EU emission model, we need to obtain suitable values for the 9 coefficients α_i $i \in \{1, \ldots, 8\}$, and β for each vehicle category. To do so a possible approach is to identify the FR and the EU model. We can at least try to solve

$$L_{W,FR,i} - L_{W,EU,i} = 0 \quad (19)$$

for $i \in (2 \ldots 7)$ and EU vehicle categories 1 and 3. For $i = 1$ a linear extrapolation from the lower end of the spectrum is acceptable. For $i = 8$ we can do the same with the higher end of the spectrum. About vehicles, there is no close match for category 2 in the FR model. For category 4 the pavement correction is not relevant.

We assumed here a horizontal road, constant vehicle speed and a 10-year old pavement. This assumption is typical in the context of strategic noise mapping.

$$L_{r,FR} \oplus L_{m,FR} + R_i + 25.6 \quad (20)$$
$$= L_{r,EU,i} \oplus L_{m,EU,i} + A_{w,i} \quad (21)$$

where $A_{w,i}$ is A-weighting for octave i.

At higher speeds, a common approximation is that rolling noise dominates. Therefore one can simplify Eq. 20 and write:

$$L_{r,FR} + R_i + 25.6 \approx L_{r,EU,i} + A_{w,i} \quad (22)$$

or more explicitly

$$A_{r,FR} + B_{r,FR} \log_{10}\left(\tfrac{v}{90}\right) + R_i + 25.6 \quad (23)$$
$$= [A_{r,EU,i} + \alpha_i] + (B_{r,EU,i} + \beta) \log_{10}\left(\tfrac{v}{70}\right) \quad (24)$$
$$+ A_{w,i} \quad (25)$$

This leads to the following system of equations:

$$\begin{cases} \alpha_i = & A_{r,FR} + B_{r,FR}\log_{10}\left(\frac{70}{90}\right) \\ & +R_i + 25.6 - A_{w,i} - A_{r,EU,i} \\ \beta = & B_{r,FR} - B_{r,EU,i} \end{cases} \quad (26)$$

Unfortunately it is not possible to solve for β in Eq. 26 since $B_{r,EU,i}$ is frequency-dependent. But we can try to minimize the cost function

$$f(x) = \int_{v_{\min}}^{v_{\max}} E(x,v)dv \quad (27)$$

where

$$E(x,v) = \Big| A_{r,FR} + B_{r,FR}\log_{10}\frac{v}{90} + R_i + 25.6 \quad (28)$$
$$-\ [[A_{r,EU,i} + \alpha_i] \quad (29)$$
$$+\ (B_{r,EU,i} + x)\log_{10}\frac{v}{70} + A_{w,i}]\Big| \quad (30)$$

and $[v_{\min}, v_{\max}]$ is a category-specific speed range. For instance we used $[50, 130]$ km/h for LV.

4.2. Results

This section summarizes the results from the minimization defined in the previous section. The reader shall refer to [5] for more details.

For EU category 1, the matching of sound power levels in dB(A) is systematically better for non drainage pavements than for drainage ones. This is preferrable to observing the opposite, because drainage pavements are much less frequent than non drainage ones. Whatever the pavement category the maximum deviation is 1.7 dB(A) whatever the speed considered and lower or equal to 0.5 dB(A) for speeds above 50 km/h. The matching is best for pavement R2 (Figure 2). The largest discrepancies are observed for R1 Drainage class (Figure 3). The overall adjustment seems satisfying. However the values obtained for α_i at the octaves from 63 Hz to 500 Hz are quite large. β is always negative with absolute values lower than 2.5.

Like for EU category 1 the adjustment for category 3 is systematically better for non drainage pavements. For EU category 3 vehicles, the discrepancy between EU and FR models can reach 1.8 dB(A) on the total sound power level whatever the speed. It remains below 1.3 dB(A) for speeds above 50 km/h. The best match is shown in Figure 4 and the worst one in Figure 5. As shown in these figures, the discrepancy originates from the propulsion/engine components between the two models that are significantly different.

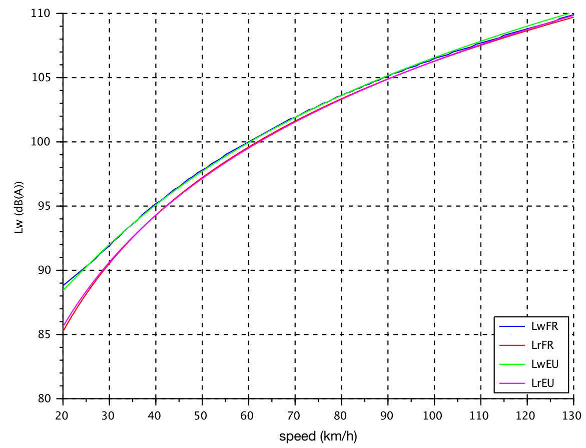

Figure 2. Best fit of the EU model against the FR model based on L_r for LV and R2 Non drainage pavement.

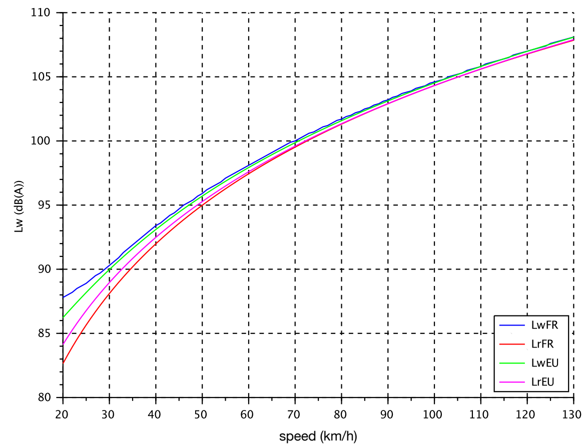

Figure 3. Best fit of the EU model against the FR model based on L_r for LV and R1 Non drainage pavement.

5. Matching FR and EU models on total sound power

5.1. Modelling

The matching on rolling noise only that was just presented is not totally satisfactory for EU vehicle category 3 where the propulsion component of the EU model is stronger than in the FR model. This suggests that rolling noise only dominates at very high speeds in the EU model for this category and that the matching should be performed on the total sound power instead. This time we tried to solve Eq. 19 without assuming any dominance of rolling noise.

This equation has no analytical solution but can be considered as a minimization problem. For a vehicle category and a pavement category, we can rely on the coefficients obtained in section 4 and use them as initial guesses $\alpha_{0,i}$ et β_0. Let us introduce the 9-

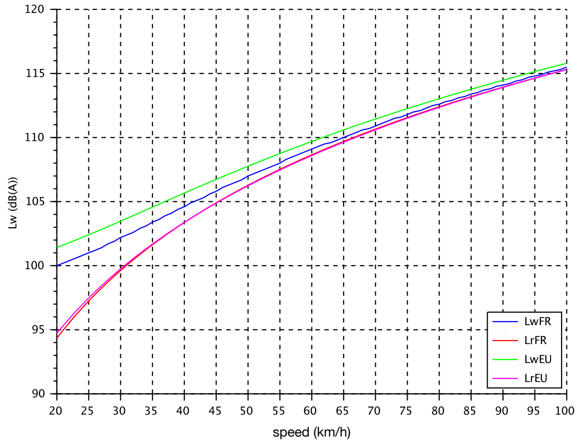

Figure 4. Best fit of the EU model against the FR model based on L_r for HGV and R2 Non drainage pavement.

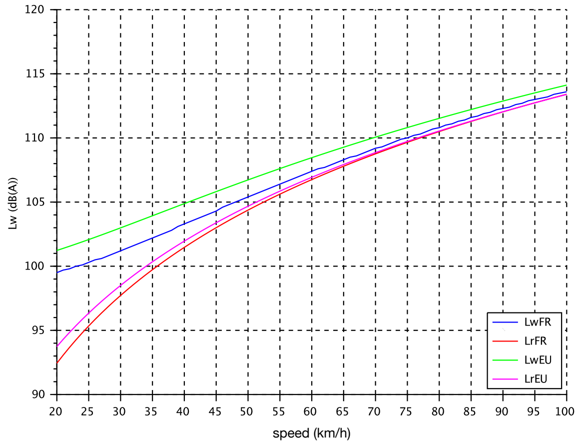

Figure 5. Best fit of the EU model against the FR model based on L_r for HGV and R1 Drainage pavement.

dimension vector $X = [\delta\alpha_i, \delta\beta]$ and rewrite Eq. 5 and 10 as follows:

$$\Delta L_{r,EU,i} = \alpha_{0,i} + \delta\alpha_i \quad (31)$$
$$+ (\beta_0 + \delta\beta) \log_{10} \frac{v}{v_{\mathrm{ref}}} \quad (32)$$

and

$$\Delta L_{m,EU,i} = \min(\alpha_{0,i} + \delta\alpha_i; 0) \quad (33)$$

Solving Eq. 19 means finding X_{opt} such that:

$$X_{\mathrm{opt}} = \operatorname{argmin} ||L_{W,FR} - L_{W,EU}(X)|| \quad (34)$$

A preliminary parametric study on α_i and β indicates that the optimization problem is convex and that a gradient descent method can be used. Since calculating the gradient of the cost function is tedious, the gradient of the function to be minimized was approximated by finite differences.

5.2. Results

The optimization on total sound power brings a significant improvement for category 3. The maximum deviation is 1.1 dB(A). If only speeds above 50 km/h are considered then the maximum deviation is 0.4 dB(A). Figures 6 to 8 illustrate the results obtained for category 3.

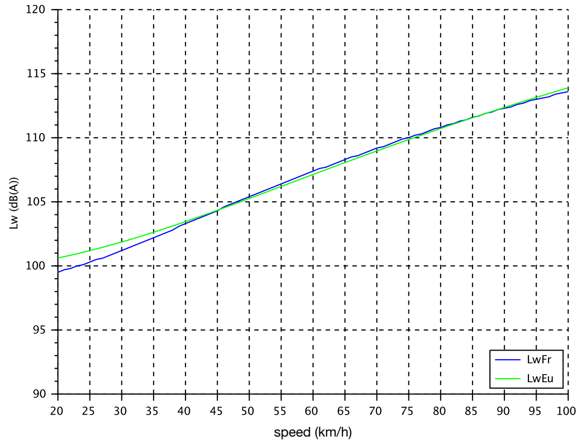

Figure 6. Best fit of the EU model against the FR model based on L_W for HGV and R1 Drainage pavement.

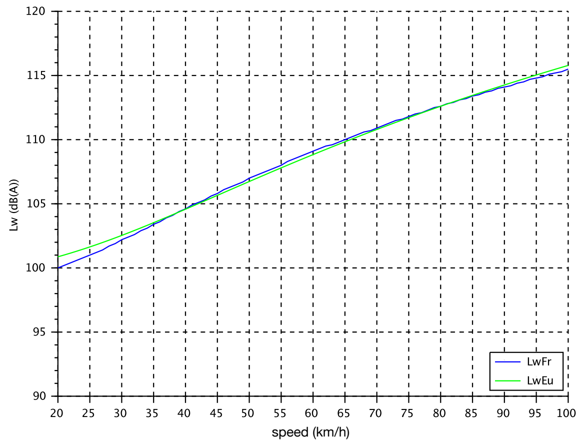

Figure 7. Best fit of the EU model against the FR model based on L_W for HGV and R2 Non drainage pavement.

6. Conclusion

In the perspective of the implementation of 2015/996/EC directive we tested two approaches to account for the specificities of pavements in the

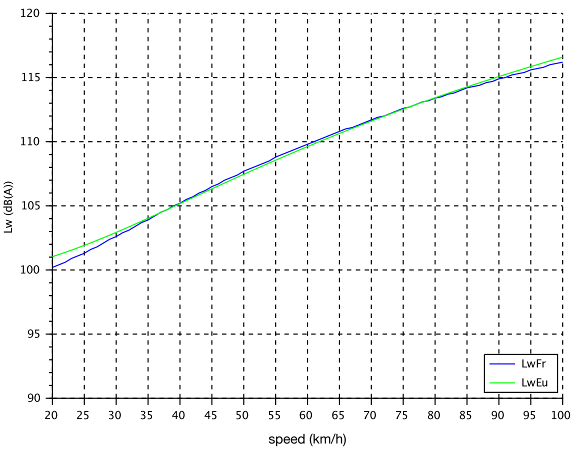

Figure 8. Best fit of the EU model against the FR model based on L_W for HGV and R3 Non drainage pavement.

French context. They both harness the available official French emission model the use of which is mandatory for noise impact studies of road infrastructures. The first approach is based on the adjustment of α_i and β coefficients on the rolling noise component in the spirit of the definition of these coefficients in the EU directive. A very good match was found for EU vehicle category 1, an acceptable one for category 3. A much better agreement was obtained when adjusting the coefficients with respect to the total sound power level. The results from this second approach are currently retained in the candidate transposition of 2015/996/EC directive into the French law.

We have shown that for EU vehicle categories 1 and 3 a good agreement between the EU model and the FR model can be achieved for the 6 different pavements families considered by the FR model under the assumptions of constant speed, horizontal road and 10 year-old pavement. Nevertheless, it remains that the two models are significantly different in the way they account for pavement ageing, road gradients and unsteady flow types. Therefore large deviations on L_W between the two models may occur in some configurations.

Although both models are based on separate rolling noise and propulsion/engine noise components, the balance between the two components is somewhat different from one model to the other. For category 3 the engine noise component is much larger in the EU model than in the FR one.

Morevover the two models differ in their categorization of vehicles. Since EU vehicle category 2 has no equivalent in the FR model, a different approach than for EU categories 1 and 3 is required. A first approximation can be to use the coefficients obtained here for category 3. This is the choice of the current candidate French transposition. But more accurate coefficients can be obtained from direct pass-by measurements. The estimation of coefficients for EU category 2 in the French context is discussed in another paper presented at Euronoise 2018 [6].

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