Sensitivity of Input Parameter on CNOSSOS-EU Road Emission Levels

Jonathan Phillips[1], James Trow[2]
Noise Consultants Limited
6 Bankside, Crosfield Street, Warrington, WA1 1UD, United Kingdom

Simon Shilton[3]
Acustica Limited
3000 Aviator Way, Manchester, M22 5TG, United Kingdom

ABSTRACT

The UK's Department for Food and Rural Affairs (Defra) commissioned a series of studies investigating the sensitivity of the CNOSSOS-EU noise assessment method. CNOSSOS-EU presents challenges in terms of data accuracy and availability. These studies were commissioned to support data governance and quantify potential uncertainty in Defra's national noise model. The quality framework in Directive 2015/996 requires that uncertainty in road emission source levels is limited to ±2 dBA. Emissions calculated across a range of scenarios with fixed and variable input parameters, performed separately for each of the CNOSSOS-EU vehicle categories and a selection of hypothetical composite flows, were used to indicate which input parameters emissions are most sensitive to. The results identified that, to meet the quality framework, traffic speed has a tolerance of ±11 km/h for cars and two-wheelers and ±24 km/h for HGVs, traffic volumes should be within a factor of 1.6 of their true value, while changes in air temperature have a limited effect. Significant variation in emissions across road surface types indicate the importance of obtaining representative surface data. The effect of road gradient is dependent on direction and speed. Assumptions about proportions of HGVs become more important on lower speed roads.

1. INTRODUCTION

Large-scale adoption of the CNOSSOS-EU road traffic noise emission source model presents challenges in terms of the availability and accuracy requirements of input data. Adopters of the CNOSSOS-EU method are often unlikely to have access to precise and comprehensive data on road traffic flow characteristics and road surface conditions within a model area. Models covering small areas may obtain relevant data through measurement or monitoring, however models covering large areas, such as cities, states or countries, may have to use incomplete data, use modelled estimates, or make

[1] jonathanphillips@noiseconsultants.co.uk

[2] jamestrow@noiseconsultants.co.uk

[3] simon.shilton@acustica.co.uk

assumptions. Furthermore, the CNOSSOS-EU database default parameters [1, 2] may not be representative for all use cases, e.g. [3].

This study presents a parametric sensitivity analysis of the CNOSSOS-EU road traffic source model input terms, with the aim of quantifying the acoustic accuracy implications of variations to these parameters on overall source emission levels. This paper will identify which input parameters have the greatest influence on CNOSSOS-EU road traffic noise emissions, and quantify the potential uncertainties that may exist at the point of emission within a CNOSSOS-EU road traffic model. The findings of this report can be used to support the drafting of data collection guidelines, and could be used by stakeholders to support future campaigns of data collection.

2. METHOD

A Python script was developed to implement the CNOSSOS-EU road source emissions calculation methodology, and prepare and run the sensitivity analyses. The script implements the methodology as presented within Directive 2015/996 [1] as amended by the 2020 Delegated Directive [2]. It was validated against the CNOSSOS-EU source model C++ code developed by DGMR [4].

Source emissions were calculated while varying a given parameter across a dense range of values (i.e., 'sweeping' the parameter) for each of the five CNOSSOS-EU vehicle categories. Various scenarios were designed in which all other parameters were kept constant (see Table 2). The total sound power emission of a traffic flow for each vehicle category, m, is represented by a line source with an A-weighted sound power level per metre length of $L_{WA',m}$.

Table 1 presents the 'sweep range' for each of the parameters considered in this study. These ranges were chosen to match, or slightly exceed, the expected range of UK road and traffic data.

Table 1: Chosen parameters to sweep and their ranges

Input parameter	Modelled parameter ranges [start, stop, step]	Rational
Hourly traffic flows, $\boldsymbol{Q}$	$Q = [1, 7000, 1]$ vehicles per category, per hour	Test very low traffic flows and exceed equivalent of max AADF in England [5].
Vehicle speed, $\boldsymbol{v_m}$ [km/h]	$v_m = [0,\ 130, 0.1]$ km/h	Test full range of traffic speeds typical to English roads, with 130 km/h slightly exceeding the highest national speed limit.
Type of surface vs v_m	14 road surface types	Test each surface type in [2] and allow assessment of trends with speed.
Road gradient, $\boldsymbol{s}$ [%]	$s = [-15, 15, 0.1]$ %	Exceed the ranges stated within CNOSSOS-EU equations at different speeds.
Air temperature, $\boldsymbol{\tau}$ [°C]	$\tau = [-5,\ 30, 0.1]$ °C	Test reasonable range of air temperatures in England.
Composite flow scenarios [%HGV] vs v_m	(0, 4, 12, 24, 44) %HGV	HGV volume split 50/50 between categories 2 and 3 [6]; with 0.5% category 4a and 0.5% category 4b [7]; and category 1 takes remaining %.
Proximity to junctions, $\boldsymbol{x}$; and type of junction, $\boldsymbol{k}$ (traffic light-controlled crossing, or roundabout)		The application of the junction correction was not considered in this study.

Number of months over the year during which studded tyres are used, $\boldsymbol{T_s}$; and ratio of light vehicles equipped with student tyres, $\boldsymbol{Q_{stud,ratio}}$	Not considered as studded types are illegal in the UK.

The sensitivity of air temperature, τ, and road gradient, s, on emissions is affected by speed, v_m. Therefore, parameter sweeps for these were produced for a selection of default v_m values which represent typical road speeds in the UK. However, only the speeds at which greatest sensitivities were observed are presented below: 16 km/h and 97 km/h for road gradient and 97 km/h for air temperature.

Default parameter values shown in Table 2 have been determined from the CNOSSOS-EU reference conditions [1], supplemented by typical conditions where none are specified therein.

Table 2: Default values for study when parameter is not the sweep parameter.

Parameter	**Default value**	**Rational**
Hourly traffic flows, $\boldsymbol{Q_m}$	250 vehicles	WG-AEN GPGv2 [8] default hourly traffic flows for a "main road"
Vehicle speed, $\boldsymbol{v_m}$	70 km/h	Reference speed, v_{ref}, in Directive 2015/996 given for the road surface correction term
Type of surface	Reference road surface	Reference surface type with flat 0 dB coefficients from 2020 Delegated Directive
Gradient, $\boldsymbol{s}$	0%	Reference condition in Directive 2015/996
Distance to junction, $\boldsymbol{x}$	150 m	Results in zero correction for junctions
Air temperature, $\boldsymbol{\tau}$	20 °C	Reference condition in Directive 2015/996

3. RESULTS

3.1 Traffic Flows

Emission levels and traffic flow volume have the same logarithmic relationship for all vehicle categories. For every doubling / halving in the traffic flow the $L_{WA',m}$ changes by ±3 dBA.

Figure 1 provides an indication of the relative influence of the respective vehicle categories which demonstrate a consistent behaviour with regards to changes in road traffic flow and shows that there is approximately a 10 dB difference in emissions between category 3 and category 4 vehicle types.

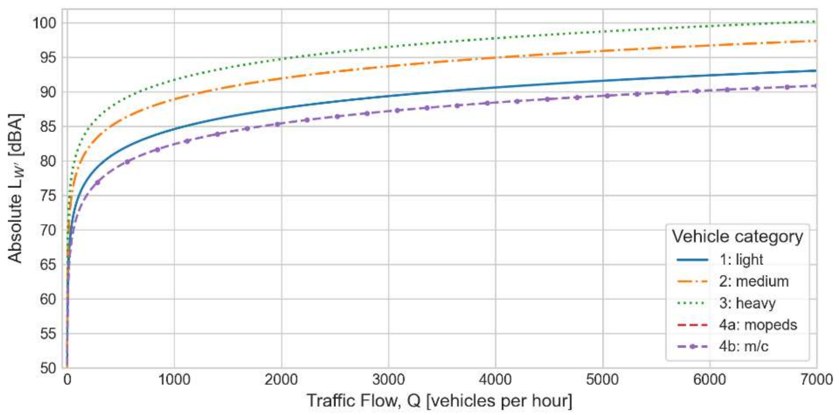

Figure 1: Traffic flow sensitivity sweeps

The $L_{WA',m}$ is more sensitive to absolute changes in traffic flow where the flow is low (i.e., small roads), and less sensitive to the same absolute changes when the traffic flow is high (i.e., motorways). This introduces a greater risk for lower trafficked roads, where reasonably small absolute changes in traffic flow values will form a larger proportion of the total flow, as well as for roads for which reliable sources of traffic data are less likely to be available. Where default values may be required, this finding will need to be considered alongside the approach to the development of default values, and estimations of the expected confidence levels of those flows.

3.2 Vehicle Speed

Speeds less than 20 km/h are to have the same sound power level as defined by the formula for v_m = 20 km/h [1]. Therefore, sound power emissions are not sensitive to changes in speed below 20 km/h, resulting in zero change between 0 km/h and 20 km/h. The analysis for category 3 and category 4a vehicles are also restricted within the legal UK speed limits: 97 km/h and 45 km/h respectively.

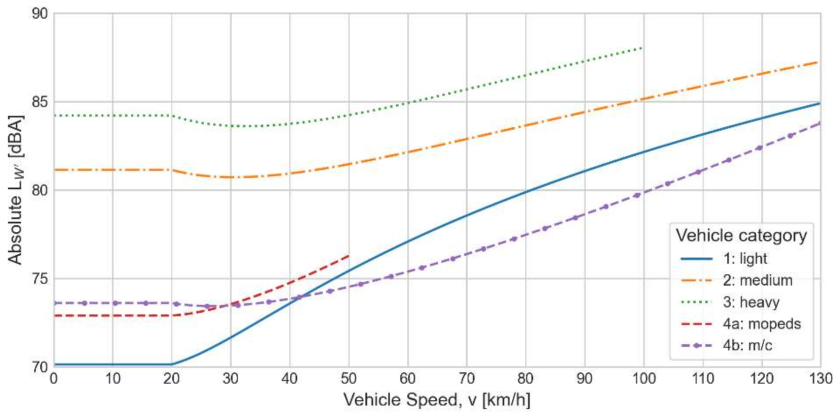

Figure 2: Vehicle speed sensitivity sweeps

Figure 2 shows that in absolute terms, the dominance of certain vehicle categories varies where speeds are less than 50 km/h. Above 50 km/h, an increase in vehicle speed leads to a near-linear increase in $L_{WA',m}$ for all categories.

Across all speeds, categories 2 and 3 generate more noise than other categories. In the range of 20 km/h to 50 km/h their sensitivity to speed is relatively low, with emissions decreasing slightly in this range, due to the dominance of propulsion noise, before beginning to increase. Category 2 and 3 emissions are most sensitive to changes in speed above 50 km/h. Category 1 emissions increase quickly as speed increases, being most sensitive to changes between 20 km/h and 50 km/h. As speed increases above 50 km/h, light vehicle emissions see slightly decreasing sensitivity. Category 4b emissions below 50 km/h remain relatively flat with a change of less than 1 dBA. As speed increases above 50 km/h, sensitivity to speed increases slightly, being most sensitive to changes in speed between 50 km/h and 100 km/h. The change in emission level for category 4a exceeds 3 dBA below 50 km/h, with the highest sensitivity as it reaches its maximum legal speed around 45 km/h.

Assuming linearity, the approximate steepest variation in speed for each category, such that a change of ±2 dBA is obtained, are: ±11 km/h for cat. 1; ±25 km/h for cat. 2; ±24 km/h for cat. 3; ±15 km/h for cat. 4a; ±18 km/h for category 4b. These results may differ if alternative road gradients, air temperatures, or flows within 100 m of a junction, were considered.

3.3 Road Gradient

CNOSSOS-EU includes corrections for the effect of the road gradient for category 1, 2 and 3 vehicles. Where the road surface is considered relatively flat the gradient correction is zero. This is between -6% and +2% for category 1, and between -4% and 0% for categories 2 and 3. The maximum gradient correction is limited at ±12%. The correction is dependent on speed, except for category 1 vehicles on a negative / downhill gradient.

Figure 3 shows that while the category 1 negative gradient correction is not speed dependent, emissions become less sensitive as speed increases. Below 20 km/h, category 1 emissions increase linearly by nearly 5 dBA. As speed increases, the maximum negative gradient sensitivity decreases, and is no more than +1 dBA above 97 km/h. The category 1 positive gradient correction is dependent on speed, seeing maximum sensitivity at +12% becoming larger at higher speeds. At low speeds maximum sensitivity to positive gradient correction is approximately +1 dBA, while at high speed this is close to +1.5 dBA.

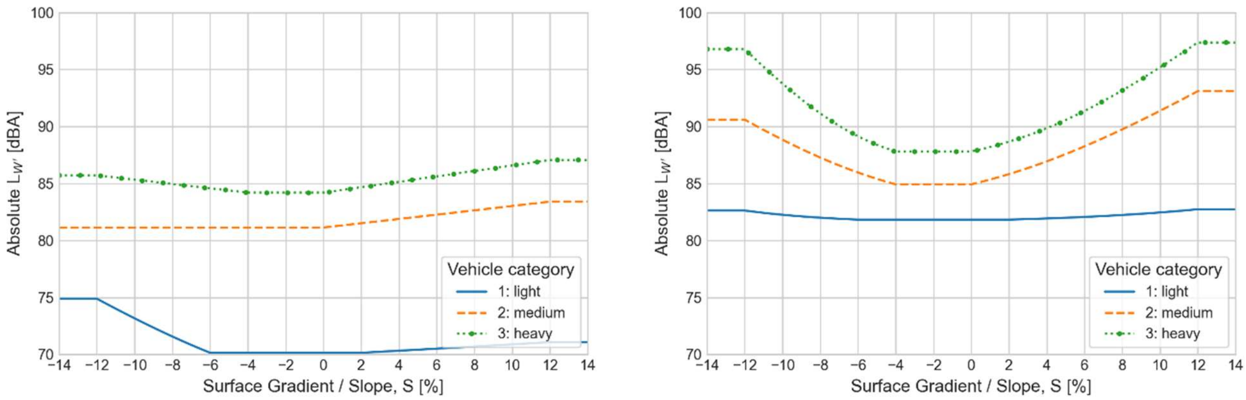

Figure 3: Road gradient sensitivity sweeps. (left) at 16 km/h; (right) at 97 km/h.

Categories 2 and 3 see a maximum positive and negative gradient corrections at +12% becoming larger at higher speeds, where emissions change by approximately +7 dBA and +9 dBA respectively for positive gradients, and +10 dBA for negative gradients. At low speeds the maximum change in emissions is within +1.5 dBA for negative gradients, and for positive gradients this is around +2 dBA for category 2 and +4 dBA for category 3 vehicles. Category 2 and 3 emissions are far more sensitive to road gradient than category 1, both in terms of the maximum change in emissions, but also the smaller range of gradients consider to be flat.

This indicates the importance of including the gradient correction within a CNOSSOS-EU road noise model, as uncertainty in emissions can be significant. There is a need to determine and calculate the corresponding gradients of source emission lines.

3.4 Air Temperature

Figure 4 shows that air temperature primarily affects category 1 vehicles, with the effects on categories 2 and 3 being consistently within ±1 dBA across the temperature range considered at all speeds. For low speeds, the sensitivity of category 1 emissions is approximately ±1 dBA across the temperature range, however, at the highest (most sensitive) speeds emissions may change by ±2 dBA for every 25 °C change in air temperature.

CNOSSOS-EU road traffic noise emissions are relatively insensitive to air temperature. Nevertheless, an approach to adopting air temperature during calculation is necessary. This could take the form of a default value representative of averages across a country, or a more localised approach. Average temperatures for each of the modelling periods will also be required to consider diurnal trends.

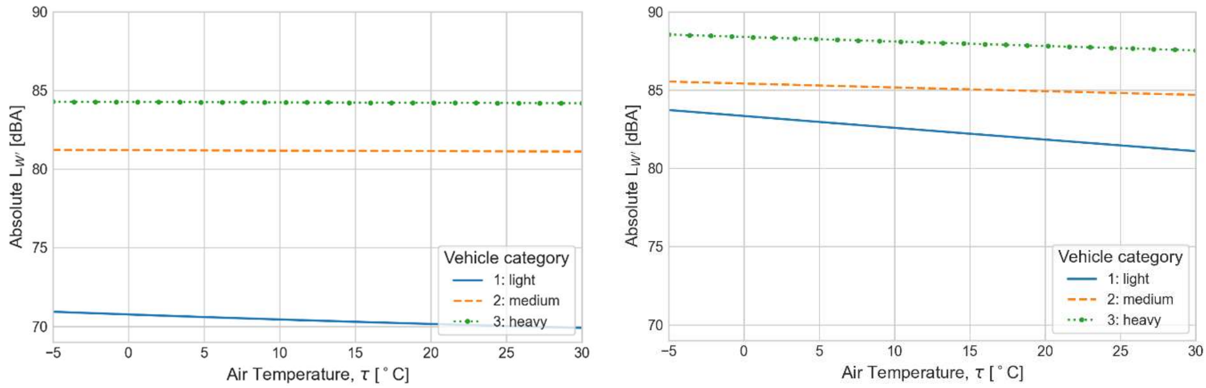

Figure 4: Air temperature sensitivity sweeps. (left) at 16 km/h; (right) at 97 km/h.

3.5 Surface Types

The curves presented in Figure 5 are cut off where the speed exceeds the minimum or maximum valid speed [2] for the given surface type, and maximum legal speed in case of category 3.

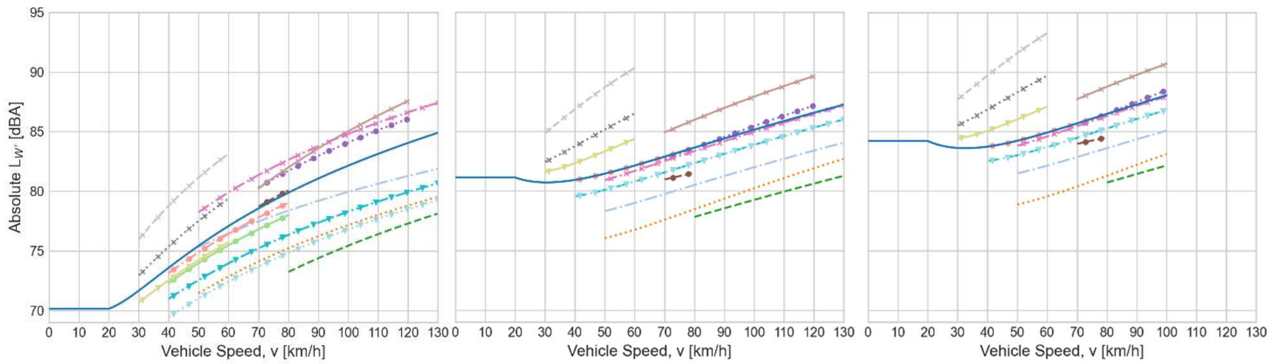

Figure 5: Surface type emissions against vehicle speed sweeps. (left) category 1; (mid) category 2; (right) category 3. Reference surface is solid blue line extending to 0 km/h. Other types are unlabelled since the purpose here is only to demonstrate variation in sensitivity.

The sensitivity of emissions to speed follows a similar trend irrespective of surface type, i.e., as speed increases, so do noise emissions with each surface type showing a similar rate of change. Generally, the curves run approximately parallel to the curve of the reference type, although some of the curves do deviate significantly from the reference curve as speed increases, indicating that road noise sources with those surface types are more sensitive to changes in speed.

What is clear from these figures is that the surface type itself has a significant influence on emissions for all vehicle categories. Where surface information is unavailable and traffic speeds are likely to be below 30 km/h, the default surface type (no surface correction) may be assigned. This is because all other surface types are only valid above this speed [2], and the difference between most surface types for category 1 decreases as speed decreases towards 20 km/h. However, at speeds above 30 km/h assigning the wrong surface type could have a significant impact on the calculated road traffic noise emission level.

As such, decisions relating to how surface types are determined becomes an important factor, and is more significant than any other parameter considered. This needs to be carefully explored as part of two cases: (1) where surface type information is available and a CNOSSOS-EU surface type is to be assigned; and (2) where traffic speeds are above 30 km/h yet there is no surface information available, an appropriate assumption needs to be made having regard for typical surfacing and the available surface types for CNOSSOS-EU, ideally considering the range of possible outcomes available. However, where roads have traffic speeds of greater than 30 km/h and no surface type is available, a carefully considered assumption may be sufficient to manage the uncertainty.

3.6 Composite Flows against Vehicle Speed

Figure 6 shows that with increasing vehicle speed, the sensitivity of emissions to the flow composition reduces. Above the national speed limit for category 3 vehicles, 100% of the HGV flows are assigned to category 2, hence the discontinuity at 97 km/h.

At > 90 km/h, emissions are within ±3 dBA between 0% – 44% HGV, and less for smaller intervals. At lower speeds, the proportion of HGVs has a significant effect of road noise emissions with over 2 dBA difference between consecutive proportions and almost 10 dBA between 0% – 44% HGV at 20 km/h. For low-speed roads where traffic flow compositions are unknown, a nominal assumed proportion of between 12% and 24% HGVs may be used to keep emission uncertainty at an acceptable level; however, this may seem a high level of HGVs for minor roads.

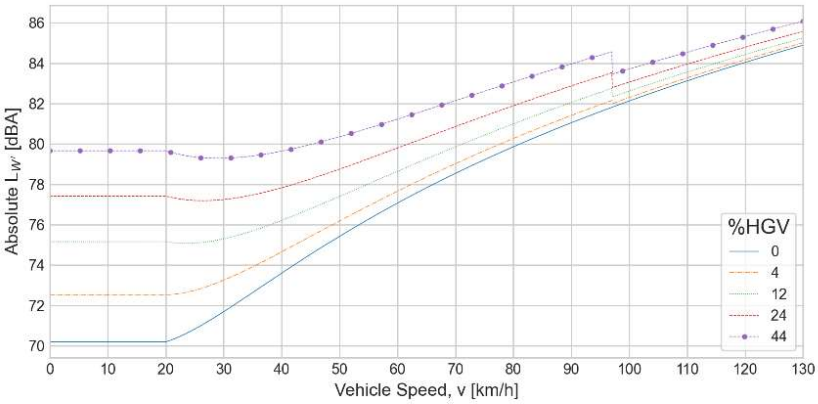

Figure 6: Vehicle speed sensitivity sweeps with composite flows: %HGV

4. CONCLUSIONS

Key findings and recommendations are made regarding the sensitivity of the calculated sound power emission level to variance in the input parameters of the CNOSSOS-EU road emissions calculation model. The results presented for each of the parameters investigated can be used to help to inform input data quality requirements for noise modelling, for example in the context of the ±2 dBA accuracy requirement at the point of emission within the CNOSSOS-EU quality framework [1], or in the context of noise modelling for other purposes, which may have a different quality objective.

The analysis indicates a logarithmic relationship between road traffic flow and emission level for all vehicle categories. Changing flow volume by a factor of 2 (i.e., ×2 or ÷2) results in a change of emission level by ±3 dBA; changing flow by a factor of 1.6 changes emissions by ±2 dBA; and, changing flow by a factor of 1.25 changes emissions by ±1 dBA. The results also indicated a difference in absolute emission levels across the tested vehicles of approximately 10 dBA.

The effect of road traffic speeds on emissions is near linear as speed increases. At lower speeds (<30 km/h) only emissions from category 1 and 4a vehicles are sensitive to speed. Given that traffic volumes are generally dominated by cars [5], it is recommended that the required accuracy of overall traffic speeds consider the sensitivity of category 1 vehicle emissions, such as ±11 km/h to remain within ±2 dBA at the point of emission. The composite flows analysis shows that assumptions regarding the proportion of HGVs becomes more important on lower traffic speed roads.

A linear relationship exists between air temperature and road traffic noise emissions, the gradient of which depends on the traffic speed. Emission levels change the most for roads with higher traffic speeds (e.g., >100 km/h) at a rate of 2 dBA per 25 °C. As such road traffic noise emissions are relatively insensitive to air temperature. However, it is recommended to include day, evening, and night-time annual average temperatures within a model as there can be differences between these which may affect the emissions by around 1 dBA between sources.

The sensitivity of road gradient is largely dependent on speed but is significant at low speeds for category 1 vehicles, and at high speeds for category 2 and 3 emissions. This indicates the importance of including the gradient correction within a CNOSSOS-EU road noise model.

Road surface type has a significant influence on road traffic noise emissions. Therefore, it is recommended that deriving relevant road surface correction coefficients should be considered for each use case. Uncertainty is significantly lower where traffic speeds are less than 30 km/h, however, so as such, many residential streets may be modelled with a carefully selected default road surface rather than surface coefficient derivation.

5. ACKNOWLEDGEMENTS

We gratefully acknowledge Defra for commissioning the study.

6. REFERENCES

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