Approaches to determining and the effects of utilising Favourable Propagation on CNOSSOS-EU calculated levels

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ABSTRACT

This study has analysed the consequence of modelling favourable meteorological (met) conditions for sound propagation of sound in line with the CNOSSOS-EU:2020 and identified the most feasible methodology for the calculation of yearly average probability of occurrence of favourable propagation. Literature reviews have allowed the identification of two methodologies and their met data requirements. The analysis on the availability of the met data at the met stations across UK have shown that the only feasible methodology is the NORD2000 methodology. English meteorological data have been processed to obtain long term means for relevant meteorological variables. Once the meteorological data was extracted and processed, a computer program was written to implement the NORD2000 methodology and, therefore, derive the percentages of favourable propagation (%Pf). Calculated %Pf are presented in tables and in the form of meteorological roses for all the available met sites across England. Furthermore, an analysis of the effect of meteorological conditions on CNOSSOS-EU calculated noise levels have been undertaken via the implementation of a test model in LimA and also a comparison of the results of different scenarios. The analysis of the results has indicated that compared to the NORD2000 model, all other models produce an under/over estimation of the results.

1. INTRODUCTION

The Department for Environment, Food and Rural Affairs (Defra) commissioned a series of studies investigating the sensitivity of the CNOSSOS-EU noise assessment method. These studies were commissioned to support the data governance and quantify potential uncertainties in Defra's noise model. As part of these studies, this paper seeks to identify the requirements for met data within CNOSSOS-EU, a suitable methodology to determine the occurrence of favourable meteorological conditions, and its effect on the propagation of sound outdoors.

CNOSSOS-EU:2020 [2][3] does not include a description of how the occurrence of favourable propagation is to be determined. Therefore, as there is currently no official methodology to develop the occurrence of favourable propagation, and the potential effect of the value on the results is unknown, both aspects were covered as part of this study.

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2. LITERATURE REVIEW

After literature review, two methodologies were identified as feasible for the calculation of the speed of the sound gradient and, consequently, the %Pf. The two methodologies identified are described in the following documents:

- Sétra, Road noise prediction - Noise propagation computation method including meteorological effects (NMPB 2008), 2008 [1]; and
- Raimo Eurasto, NORD2000 for road traffic noise prediction: Weather classes and statistics, Vtt Technical Research Centre of Finland, 2006 [4].

The first document describes the French national methodology for calculation of outdoor sound propagation, on which the CNOSSOS-EU:2020 point-to-point propagation methodology is based.

The second methodology is also cited within the NMPB 2008 method as a valid methodology for the calculation of the %Pf. This method requires air temperature, wind direction and velocity, and cloudiness.

2.1. Meteorological Data available from Met stations across England

Meteorological data in England is primarily collected, aggregated and managed by the UK Met Office, for the purposes of weather forecasting and provision to stakeholders. Hourly average data for various meteorological variables have been acquired for this study, spanning the time period 2015 to 2020. Following review of meteorological data, the parameters: wind direction; wind speed; temperature; cloud cover; and relative humidity; were found to be widely available within meteorological data recorded at English meteorological stations.

The majority of meteorological variables required by each of the proposed methodologies are measured at most of the meteorological stations for which data are available. However, some of the inputs required by the methodology described in the Sétra document for use with NMPB 2008 are not widely available. These include solar radiation and terrain moistness, which are parameters that are rarely measured at English meteorological stations.

Therefore, due to the complexity in acquiring and determining some of the meteorological data required by the methodology described in the Sétra document for NMPB 2008, the NORD2000 methodology was identified as the most feasible and practical way to calculate the occurrence of favourable propagation in England.

3. METHODOLOGY

3.1. NORD2000

Within NORD2000, the effect of the meteorological conditions on sound speed gradient is calculated using Equation 2:

$$C = A\,ln\left(1 + \frac{z}{z_0}\right) + B_z + C(0) \qquad (1)$$

Where:

- z height above ground surface
- z_0 the roughness length
- A coefficient of the logarithmic term (m/s)
- B coefficient of the linear term (1/s)
- C(0) sound speed at height z = 0 m (m/s).

The effect of meteorological conditions on the propagation of sound can then be derived by the combination of logarithmic and linear sound speed profiles. The A and B coefficients are a function of the aerodynamic and thermal conditions, see Equation 3 below, and are themselves a function of three other parameters and wind direction in respect of sound propagation direction:

- friction velocity (u*)
- Monin-Obukhov length (L)
- temperature scale (T*)

These three parameters can be derived, provided three characteristics are known and are available from annual average meteorological data from local meteorological stations. These characteristics are:

- wind speed at 10 m above ground, V (z = 10 m);
- cloud cover in oktas; and
- time of the day (day/night).

The three characteristics above allow the derivation of two meteorological propagation classes, wind speed class and atmospheric stability class.

The friction velocity (u*), the Monin-Obukhov length (L) and the temperature scale (T*) parameters can be derived by the classes above.

Once all the parameters are assessed, the A and B coefficients can be calculated using Equation 2, 3 and 4:

- During day (stability classes S_1, S_2 and S_3)

$$B = \frac{u_* \cos\alpha}{C_{vk} L} + \left(\frac{1}{2}\ \frac{C_0}{T_{ref}}\right)\left(0.74\ \frac{T_*}{C_{vk} L} - \frac{g}{C_p}\right) \qquad (2)$$

- During night (stability classes S_4 and S_5)

$$B = 4.7\ \frac{u_* \cos\alpha}{C_{vk} L} + \left(\frac{1}{2}\ \frac{C_0}{T_{ref}}\right)\left(4.7\ \frac{T_*}{C_{vk} L} - \frac{g}{C_p}\right) \qquad (3)$$

$$A = \frac{u_* \cos\alpha}{C_{vk}} + \left(\frac{1}{2}\ \frac{C_0}{T_{ref}}\right)\left(0.74\ \frac{T_*}{C_{vk} L}\right) \qquad (4)$$

Where:

- u_* is the friction velocity in m/s, given by Figure 3
- T_* is the temperature scale in K, given by Figure 4
- L is the Monin-Obukhov length in m, given by Figure 5
- C_{vk} is the Von Karman constant = 0,4
- g is the Newton's gravity acceleration = 9,81 m/s
- C_p is the specific heat capacity of air at constant pressure, 1005 J/kg K
- T_{ref} is the reference temperature = 273 K
- α is the angle between wind direction and the direction of sound propagation

The range of values for the A and B coefficients are divided into five classes each (from 1 to 5).

The combinations of these two parameters generate 25 different sound propagation conditions, based on the resultant sound speed gradient.

3.2. Extracting Meteorological Data from English Met Stations

The bulk of hourly meteorological data available in England is recorded at 'synoptic' stations for the purposes of weather forecasting, as part of the UK land surface observing network. These measurements are supplemented by hourly observations made at over 50 airports across the UK, which are issued for a more limited set of meteorological elements, in an encoded format known as 'METARs'. This information is available from the data provisioning and transport teams at the UK MET Office, and has been obtained for the years spanning 2015 to 2020.

Before this data can be used it must be subject to a multistage processing procedure and QA process (not described in this paper).

The METARs data were subject to initial pre-processing to parse the data into a similar columnar timeseries format to that of the synoptic data. Once this was completed, the following processing has been undertaken:

- Extract relevant measurements from the raw data which includes observation datetime, wind direction, wind speed, temperature and cloud cover fields.
- Datetime checking, alignment and resampling – i.e. measurements taken at a time of HH:50 represent the hour beginning HH+1. Some meteorological stations may record measurements against non-standard timestamps (i.e. HH:53) or on the hour. Where duplicate measurements exist for the same hour in the raw datasets, this processing step has been designed to always retain the first available value in the set. Finally, measurement sites that have very low data capture (<5% on an hourly basis) have been removed.
- Additional checks are made to verify the identity of remaining sites against a metadata list. Sites are grouped by location (i.e. synoptic data and METARs data may be recorded at the same location), and measurement data is then stored in a standardized clean format.
- These data are subject to quality checking, which includes filtering out erroneous values and outliers. A process of linear interpolation is used to fill missing contiguous periods of up to 7 hours for most measurement variables.
- The hourly data from grouped measurement sites (i.e. synoptic and METARs stations at the same location) are merged into a single hybrid site, in a process prioritizing synoptic hourly data.
- Finally, a process is used to improve the overall data capture at each site by considering hourly data at other nearby meteorological stations to "fill-in" periods of missing data.

The approach outlined above resulted in the production of processed meteorological data from a total of 123 stations. These stations provide a broadly even geospatial coverage across England, as shown in Figure 1.

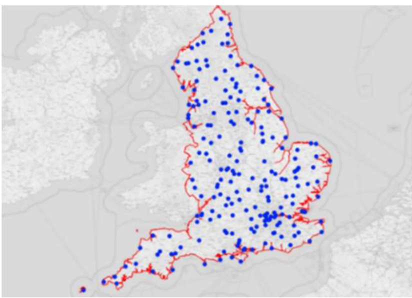

Figure 1 Location of meteorological sites in England used in this study

3.3. Applying the NORD2000 methodology

Once the met data had been extracted and processed, a computer program was written to implement the NORD2000 methodology, which has been based on the process described in the (Raimo Eurasto,2006) paper.

Following the approach outlined in (Raimo Eurasto,2006), the coefficients of the logarithmic term A and linear term B were derived for each hour. These were classified into intervals to derive a total of 25 different sound propagation conditions (i.e. 25 unique combinations of A and B) as described in (Raimo Eurasto,2006). This process was repeated for angular deviations in the hourly average wind direction and the direction of sound propagation, in 20-degree sectors between 0 and 340 degrees.

The occurrence of each meteo-class has then been divided by the total number of occurrences and presented as percentages.

The meteo-classes can be re-classified using the methodology described in (Birger P.,2007) [9]. In order to re-classify the classes, the speed of sound gradient resulting from each class were plotted. The plot clarifies which class can identify the favourable condition and which one the upwind/homogeneous condition. The plot of the meteo-classes is presented in Figure 2.

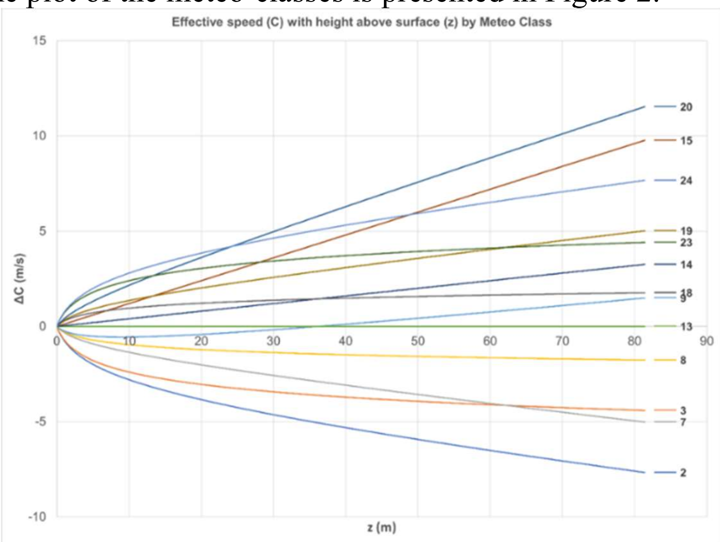

Figure 2 Sound Speed Gradient by Meteo-Class

Using the definition of favourable condition, it can be seen that the classes that identify a condition of favourable to propagation are 14, 15, 18, 19, 20, 23 and 24.

The yearly average number of occurrences were summed across the seven classes identifying conditions favourable to propagation. These values were then divided by the total number of occurrences and presented in percentages, which are the percentages of favourable propagation (%Pf) required by the CNOSSOS-EU:2020 methodology.

3.4. Sensitivity Testing

A sensitivity test was undertaken via the implementation of a test model in LimA to consider the effect of meteorological corrections on long term average road traffic noise levels to help identifying the consequences of different modelling approaches to implementing met corrections under CNOSSOS-EU:2020.

The met correction approaches which were considered as part of this sensitivity testing are indicated below:

- 100% Homogeneous propagation;
- 100% Favourable propagation;

- WG-AEN GPG v2 [6] Default values of %Pf (50% Day, 75% Evening and 100% Night); and
- Manchester meteorological station %Pf, calculated according to NORD2000 methodology.

The first three methodologies have assumed reference values of temperature and humidity [8] (15° C and 70%, respectively) as they are the default values designated in Directive 2015/996 [2] when long term meteorological data is not known.

Two areas, Area 1 (a rural area of 20km^2) and Area 2 (an urban area of 4 km^2) were selected as testing areas. Calculations were undertaken on a 200m-by-200m grid. These areas were selected for the following reasons:

- They include a good mixture of rural, urban and suburban locations;
- They contain a good mixture of road classes, including the M6 motorway; and
- They include a good mixture of different types of ground cover.

The presence of a motorway and the other main roads, and the different type of terrain (i.e. rural and urban areas) will help identify the effect of met correction on the propagation of road traffic noise in different conditions and at different locations from such sources.

4. RESULTS DISCUSSION

4.1. %Pf across UK using NORD2000 methodology

An example of the %Pf for the Manchester meteorological is shown in Figure 3.

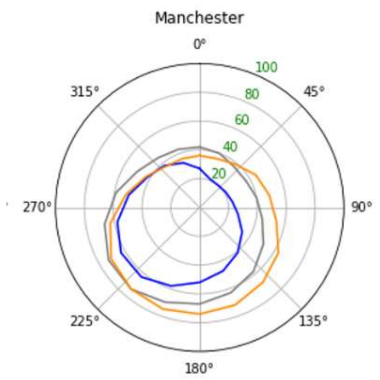

Figure 3 %Pf presented around a 360-degree meteorological rose of the Manchester Met Station site

The calculated %Pf can be used in accordance with the CNOSSOS-EU:2020 methodology.

The results of this implementation were compared with the results presented in NMPB 2008 [1], in the paper “CNOSSOS-EU Sensitivity to Meteorological and to Some Road Initial Value Changes” [5] and with the default values presented in WG-AEN GPG v2 for validation purposes.

The occurrences of favourable propagation resulting from the implementation made in this study have patterns comparable with those presented in the first two documents above.

An example of these patterns is given by the highest favourable propagation values. The results across England presented in this study, the ones across France, and across Finland, all follow the yearly average prevailing wind direction.

Another pattern in common between the results of this study and the ones already published in the literature is that the evening and night-time period have generally higher probability of favourable propagation when compared to the day-time period. This phenomenon is expected, and is due to the fact that during the night the temperature gradient tends to be positive (temperature increase with altitude), which will improve the sound propagation [7].

4.2. Sensitivity Test

The analysis of the comparison between 100% favourable and 100% Homogeneous condition models has confirmed how the occurrence of favourable propagation conditions has a great impact on the overall results of the sound propagation model as shown in Table 1 below.

Table 1 Statistic Results Across the Overall Grid for Favourable Vs Homogeneous Scenario

Scenario	Indicator	Mean difference (dB)	Standard Deviation	95% Coverage Interval (dB)	$q_{0,1}$ to $q_{0,9}$ Range (dB)	Range (dB)
Favourable Vs Homogeneous	L_{day}	-8.6	6.0	18.3	16.2	19.0
	$L_{evening}$	-8.4	6.0	18.1	16.1	18.8
	L_{night}	-8.9	6.1	19.1	16.3	19.1
	L_{den}	-8.7	6.0	19.0	16.2	19.0

The analysis of the results has indicated that compared to the model using the data for the Manchester met station calculated using the NORD2000 method, all other models produce either an under or over estimation of the results, as indicated in Table 2.

Table 2 Statistic Results for NORD2000 Vs WG-AEN v2 Default Values Scenario

Scenario	Indicator	Mean difference (dB)	Standard Deviation	95% Coverage Interval (dB)	q0,1 to q0,9 Range (dB)	Range (dB)
NORD2000 Vs WG-AEN v2 Default Values	Lday	-0.1	0.4	1.7	0.8	1.3
	Levening	-0.3	0.4	1.4	1.0	1.5
	Lnight	-2.6	2.0	6.5	4.3	13.0
	Lden	-1.3	1.2	3.8	2.3	9.1

5. CONCLUSIONS

This study has investigated the requirements for meteorological data within the CNOSSOS-EU:2020 methodology for the calculation of propagation of sound outdoors.

The study identified a methodology which can be used to determine the required met data, including the percentage occurrence of favourable propagation, based on data commonly collected and available for English met stations.

The analysis on the availability of the met data across the met stations across UK has shown that the only feasible methodology is the one indicated in (Raimo Eurasto, 2006) following the guidance of NORD2000 methodology.

Using the available meteorological data across England, it was possible to implement the NORD2000 methodology for the calculation of %Pf, at met site level. For the purposes of this study, six years of meteorological data were used in order to demonstrate the methodology identified, and data processing steps employed.

The analysis of the comparison between 100% favourable and 100% homogeneous condition models has confirmed how the occurrence of favourable propagation conditions has a great impact on the overall results of the sound propagation model.

The analysis of the results has indicated that compared to the model using the data for the Manchester met station calculated using the NORD2000 method, all other models produce either an under or over estimation of the results. The greatest magnitude of the differences varies between rural and urban locations, depending upon whether the comparison is with mainly homogeneous or mainly favourable propagation.

Furthermore, since the %Pf can vary greatly across the country, it is expected that using the default values for the whole country could potentially introduce inconsistency in the uncertainty of the results across the country.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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