The revision of the French method for road traffic noise prediction

Guillaume Dutilleux[a], Jérôme Defrance[b], Benoit Gauvreau[c] and Francis Besnard[d]

[a]Lab. Régional des Ponts et Chaussées, 11, rue Jean Mentelin, BP 9, 67035 Strasbourg Cedex 2, France
[b]CSTB, 24 rue Joseph Fourier, 38400 Saint-Martin-d'Hères, France
[c]Laboratoire Central des Ponts et Chaussées, Centre de Nantes - Route de Bouaye, BP 4129, 44341 Bouguenais cedex, France
[d]Lab. Reg. Régional des Ponts et Chaussées de l'Est Parisien, Rue de l'égalité prolongée, BP 34, 93352 Le Bourget, France
guillaume.dutilleux@equipement.gouv.fr

A revision of the French method for road traffic noise prediction (NMPB-Routes-2008) is about to be released. The major principles of NMPB-Routes-2008 are outlined. The most important modifications regarding the source are the reduction of its height and the introduction of two different spectra. In this complete revision, the main change is the replacement of the ISO 9613-2-based ground attenuation formula in downward conditions by the formula for ground attenuation in homogeneous conditions of NMPB-Routes-1996 with corrected heights in order to take into account the mean curvature of rays (refraction) and its spreading (turbulence). The revised NMPB adds an attenuation term for an occasional cutting embankment. Regarding diffraction the Δ_{dif} formula is now suitable for low height barriers. The validation of the revised NMPB with respect to experiment is presented. It is based on measurement campaigns on 6 sites with complex geometries and shows that the predicted noise levels obtained from the revised NMPB are significantly closer to experimental results than in the case of the original method.

1 Introduction

The current French method for road traffic noise prediction (Nouvelle Méthode de Prevision du Bruit des Routes - NMPB) was designed and published in 1996 [?]. NMPB is imposed by the French regulations for distances to the road larger than 250 m. A French standard for both rail and road was first published in 2001 on the basis of NMPB [?]. NMPB is the official interim noise prediction method for roads in the implementation of the European Directive on Environmental Noise 2002/49/CE [?].

The predictions of NMPB-Routes-96 have been validated on a large experimental campaign featuring acoustical and meteorological data on real sites with complex topography. The agreement between measurement and prediction is good, although NMPB-Routes-96 tends to overestimate levels in downward conditions. This is positive for neighbors but costly for the authorities because it leads to noise abatement solutions that are larger than necessary.

The revision of NMPB-Routes-96 started in 2000 under the request of Sétra[1]. Besides Sétra, 5 different administrations of the French ministry of transportation have been involved in this process which is now completed.

The present paper introduces the revised NMPB called NMPB-Routes-2008. First the principles of NMPB are outlined. Second, the changes with respect to NMPB-Routes-96 are outlined, with a focus on the salient points of the source definition, definition of occurrences of downward propagation, ground effect in downward conditions, reflection on embankment slopes and diffraction formula for low-height barriers. The third part deals with the comparison of the method to experiment.

2 Principles of NMPB

2.1 Long term sound level

The method is based on the concept of propagation path. Several paths between a source and a receiver can exist, depending on topography and obstacles. A long term sound level $L_{Ai,LT}$ is associated to each path i. This long term level is derived from 2 computations on each path, one for homogeneous conditions and one for downward conditions.

[1] http://www.setra.equipement.gouv.fr/English-presentation.html

The sound level in homogeneous atmosphere $L_{Ai,H}$ is essentially a safe-side estimate of the level in upward conditions, because it is well known that homogeneous conditions are only a transient state of the atmosphere at the scale of the day-night cycle. The downward level $L_{Ai,F}$ is obtained assuming a *standard* atmosphere with an invariant sound speed gradient. The site- and orientation-dependent probability p_i of occurrence of downward conditions allows to compute

$$L_{Ai,LT} = 10 \log_{10} \left(p_i 10^{0.1 L_{Ai,F}} + (1 - p_i) 10^{0.1 L_{Ai,H}} \right) \quad (1)$$

2.2 Attenuations

On each path, 3 attenuations are computed : the geometrical spreading A_{div}, the atmospheric absorption A_{atm}, and the attenuation to the boundary A_{bnd}. This term is different for homogeneous and downward conditions. The boundary is composed of the ground and the occasional obstacles like noise barriers and buildings. Part of A_{bnd}, the ground attenuation is not derived from reflected paths on the ground but by a term of ground effect based on the concept of mean ground plane between source and receiver as shown on figure 1.

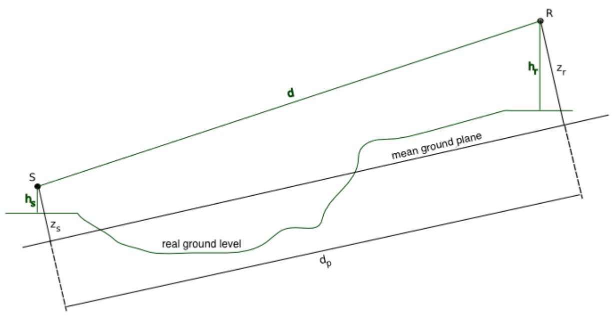

Figure 1: concept of mean ground plane.

The ground effect is computed under this simplified geometrical frame. The same approach is used when a diffraction takes place, except that 2 mean ground planes are considered, *i.e.* one on each side of the diffraction point.

The local absorption of the ground is represented by a frequency independant adimensional parameter G. G equals 0 for a reflecting ground and 1 for an absorbing one. However, G must be seen more as a normalized flow resistivity than as an absorption coefficient. G_{path} is derived as the average of G along the propagation between source and receiver. When source and receiver are close to each other, it is assumed that the reflection on the ground takes place on the road. So a G'_{path} is introduced as follows :

$$G'_{path} = \begin{cases} G_{path} & 30(z_s + z_r)/d_p < 1 \\ G_{path} d_p / [30(z_s + z_r)] & \text{otherwise} \end{cases} \quad (2)$$

See figure 1 for the notations.

3 The NMPB-Routes-2008

3.1 Source

For a simulation the incoherent source line representing a road is broken down in point sources. NMPB-Routes-96 places each point source at 0.5 m above the ground. Different experiments have shown that the equivalent source height of vehicles is close to the ground (see for instance [?]). In NMPB-Routes-2008 the height is set to 0.05 m. This low value corresponds to the dominance of tyre/road noise and also to the fact other noise sources like the engine cannot be seen as point sources.

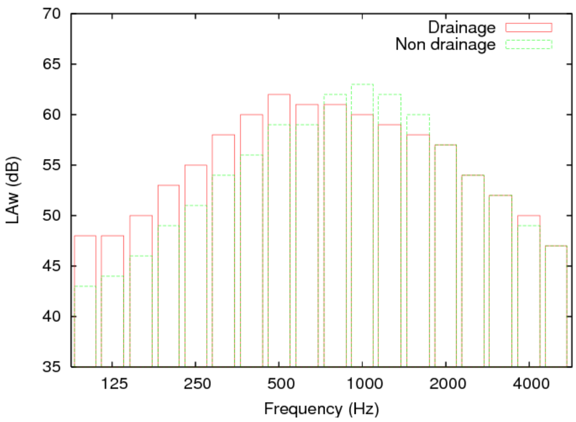

Figure 2: normalized A-weighted spectra for drainage and non drainage asphalt in NMPB-Routes-2008.

In order to take into account the diversity of road pavements on the French territory, two noise spectra are available in NMPB-Routes-2008 : one for drainage asphalt, and one for non drainage asphalt (Cf 2). These spectra are the result of the parallel work on the revision of the French *Guide du bruit* [?]. The source spectra are provided in third-octave bands in NMPB-Routes-2008, instead of octave bands in the previous method. This implies that all the computations in NMPB-Routes-2008 are done in third-octave bands.

3.2 Propagation conditions

NMPB-Routes-96 came with a set of pre-computed occurrences for more than 40 locations over France and 20° wide sectors. They were based on qualitative analysis of meteorological data.

A method has been developed to provide statistical information on propagation conditions between source(s) and receiver(s) in the atmosphere. This method is based on meteorological, vegetation and soil parameters. The hourly or daily micrometeorological data (wind, temperature, relative humidity, solar radiation, etc.) are provided by a huge experimental database from French national meteorological stations - about 40 Météo-France synoptic stations distributed on the whole territory. They yield surface temperature and fluxes, but also components of the soil water and radiative budgets. Those parameters are integrated on an hourly basis over time scales of years through a suited procedure which has been validated and called MAGRET [?, ?].

The vertical gradients of mean horizontal wind and air temperature are next estimated every hour from the standard Monin-Obukhov similarity theory [?]. In order to take into account the vectorial effect of the wind, the output data of the model are given for several source-receiver directions (20° sampling rate as before). This leads to an estimation of the mean vertical gradient of sound velocity for each hour and each station.

All these hourly meteorological results are next synthesized for providing statistics representative of "long term" periods (up to 30 years) for each synoptic station. Thus this method gives access to a representative estimation of the occurrences percentage of downward conditions on typical periods, e.g. 6h-18h, 18h-22h, 6h-22h, 22h-6h, etc. Those values are tabulated and directly implemented in the NMPB-Routes-2008.

It must be noticed that those tabulated values are rigorously only valid for the sites which match the Météo-France criteria and the MAGRET model assumptions :

- Open and flat field, almost without any bush, tree or obstacle
- Grassy ground (maximum vegetation height : 10 cm)
- No large water masses in the vicinity, like lake, river, sea
- Altitude lower than 500 m, mountain areas are excluded

4 Ground effect in downward conditions

In NMPB-Routes-96, the attenuation due to the ground in downward conditions $A_{ground,F}$ is the same as in ISO 9613-2 [?]. However, for our purpose it has been seen that equivalent road traffic noise source appears to be very close to the asphalt when ISO expressions for ground attenuation have been developed for industrial sources sufficiently high. It is why it has been decided to develop a new formulation of $A_{ground,F}$ based on $A_{ground,H}$, the ground attenuation in homogeneous conditions [?] given in Eq. 3 hereafter, and valid for any height of the source. To do so, three phenomena have been taken into account: the atmospheric refraction, the multiple-reflections on the ground and the atmospheric turbulence.

$$A_{ground,H} = -10\log_{10}\left[4\frac{k^2}{d_p^2}\left(z_s^2 - \sqrt{\frac{2C_f}{k}}z_s + \frac{C_f}{k}\right) \times \left(z_r^2 - \sqrt{\frac{2C_f}{k}}z_r + \frac{C_f}{k}\right)\right] \geq -3(1-G'_{path}) \quad (3)$$

where k is the wavenumber, d_p is the horizontal distance, z_s and z_r are the source and receiver heights (Cf figure 1), G'_{path} is defined in Eq. 2 and C_f a coefficient depending on k, G'_{path} and d_p.

The atmospheric refraction in downward conditions is taken into account by means of height corrections terms δz_s and δz_r derived from the analogy between flat ground with curved rays / curved ground with straight rays [?] and written as:

$$z_s = \frac{a_0}{2}\left[\frac{d_p z_s}{z_s + z_r}\right]^2,\ z_r = \frac{a_0}{2}\left[\frac{d_p z_r}{z_s + z_r}\right]^2 \qquad (4)$$

where a_0 is the vertical celerity gradient taken to be equal to $2 \times 10^{-4}\ m^{-1}$ in our purpose.

This approach gives good results as long as there is only one reflection on the ground. To take into account multiple-reflections phenomenon, the right term of the inequality in Eq. 3 is replaced by

$$(1 - G'_{path})\left[-3 - 6\left(1 - 30(z_s + z_r)/dp\right)\right] \qquad (5)$$

for $30(z_s + z_r)/d_p \leq 1$.

Turbulence is taken into account in the same way as refraction, *i.e.* through a height correction δz_T added to z_s and z_r, allowing to model the coherence loss between direct and reflected rays, in the case of a propagation above a flat impedant ground. It will also enable to shift the first interference towards low frequencies with a lower amplitude. This searched behaviour imposes δz_T to be identical for z_s and z_r. Comparisons with Daigle results from [?] have led to the following expression of δz_T for a value of $\langle \mu^2 \rangle = 2 \times 10^{-6}$:

$$\delta z_T = \frac{6 \times 10^{-3} d_p}{z_s + z_r} \qquad (6)$$

The final expression of $A_{ground,F}$ is given by:

$$A_{ground,F} = -10\log_{10}\left[4\frac{k^2}{d_p^2}\left(\tilde{z}_s^2 - \sqrt{\frac{2C_f}{k}}\tilde{z}_s + \frac{C_f}{k}\right) \times \left(\tilde{z}_r^2 - \sqrt{\frac{2C_f}{k}}\tilde{z}_r + \frac{C_f}{k}\right)\right] \qquad (7)$$

with $\tilde{z}_s = z_s + \delta z_s + \delta z_T$ and $\tilde{z}_r = z_r + \delta z_r + \delta z_T$, $A_{ground,F}$ being limited by

$$(1 - G'_{path})\left[-3 - 6\left(1 - 30(z_s + z_r)/d_p\right)\right] \qquad (8)$$

for $30(z_s + z_r)/d_p \leq 1$ and limited to $-3(1 - G'_{path})$ for $30(z_s + z_r)/d_p > 1$ (lower limit as in Eq. 3).

5 Reflection on an embankment slope

The NMPB-Routes-96 takes into account ground effect by considering an mean ground plane, calculated between two points, or on both sides of a diffraction. However it often happens that a reference microphone located a few meters away from the road and a few meter high is installed at the top of an embankment - the road being lower than the natural ground where measurements take place, see figure 3. It is then of major interest to know exactly whether the embankment brings some extra acoustic energy to the receiver R since measurements at R often characterize the sound power level of the road.

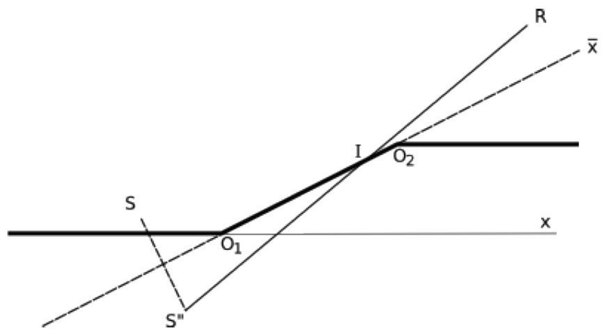

Figure 3: notations used for the embankment slope reflection in NMPB-Routes-2008.

The calculation of the attenuation A_{emb} due to the embankment slope is carried out only if:

- The slope $(\overrightarrow{O_1x}, \overrightarrow{O_1O_2})$ is between 15 and 45°,
- R can "see" O_1.

If so, A_{emb} is estimated as follows:

- Determination of S'' image-source of S referred to O_1O_2,
- Determination of intersection point I between $S''R$ and O_1O_2,
- Calculation of the half-length e of the intersection between the Fresnel ellipsoid and O_1O_2:

$$e = \frac{1}{\cos\theta}\sqrt{\frac{\lambda}{2}\frac{S''I \times IR}{S''I + IR} + \frac{\lambda^2}{16}} \qquad (9)$$

where $\theta = (\overrightarrow{O_1x}, \overrightarrow{O_1O_2}) + (\overrightarrow{O_1x}, \overrightarrow{S''R})$

- Calculation of the abscissa $\bar{x}_l$ of I on the slope ;
- Calculation of ϵ the proportion of the ellipsoid coinciding with the slope:

$$\epsilon = \begin{cases} 0 & \bar{x}_l \leq -e \\ \min\left(\frac{l_emb}{2e}, \frac{\bar{x}_l - e}{2e}\right) & -e < \bar{x}_l < l_{emb} + e \\ 0 & l_{emb} + e \leq \bar{x}_l \end{cases} \qquad (10)$$

where $l_{emb} = O_1O_2$,

- A_{emb} finally writes

$$A_{emb} = -1.5\epsilon(2 - G_{emb}) \qquad (11)$$

where G_{emb} is the ground factor for the embankment slope.

6 Diffraction by low barriers

The case of low barriers is not treated in the NMPB-Routes-96. However the presence of small but long obstacles along roads may occur (for instance 80 cm high concrete protection devices). To take them into account in the sound propagation calculations, we propose to add to the classical diffraction expression a corrective term C_h making tend the total attenuation Δ_{dif} towards zero:

$$\Delta_{dif} = 10 C_h \log_{10}(3 + 20N) \qquad (12)$$

with $C_h = \min\left(\frac{h_0 f_m}{f_{m0}}, 1\right)$, where f_m is the mid-frequency of the third-octave band, f_{m0} is the reference frequency of C_h (250 Hz) and h_0 is the largest value of height between the diffraction edge and the two mean ground planes, on source and receiver sides.

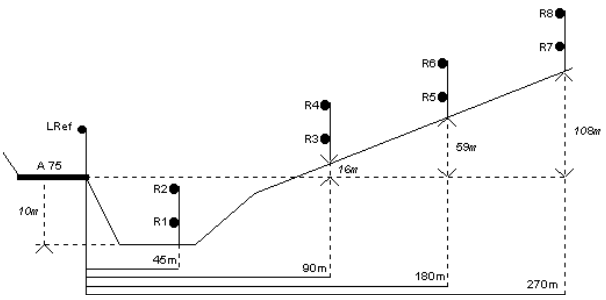

Figure 4: vertical cut for the site of Massiac and position of the receivers.

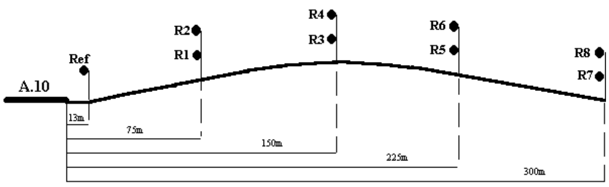

Figure 5: vertical cut for the site of Mer and position of the receivers.

7 Other aspects

The room is missing here to give all the changes introduced in NMPB-Routes-2008 with respect to NMPB-Routes-1996. The sections above have only mentioned the most remarkable changes. Other modifications concern diffraction. In NMPB-Routes-2008, the path length difference in downward conditions is computed assuming rays with constant curvature.

In NMPB-Routes-1996, A_{bnd} had 2 mutually exclusive forms, one with diffraction, one without. For each path the form was chosen from a path length difference calculation at 500 Hz. The choice would apply to all octaves. In the new method, the path length difference is computed for each third-octave band. Therefore, the transition from an attenuation due to ground effect to an attenuation due to diffraction is mode gradual than before, more in agreement with physics.

8 Validation

8.1 Measurement campaign

Beside unit tests on the different terms of the attenuation that have been carried out with reference methods like BEM, PE or ray theory, the validation of NMPB-Routes-2008 is based on a set of 6 measurement cam-

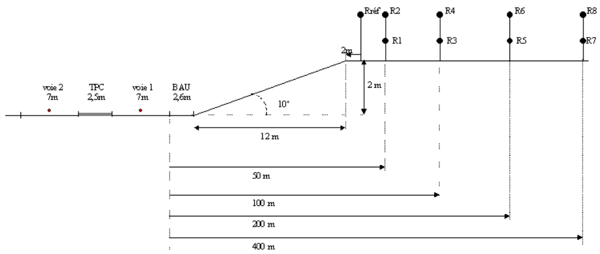

Figure 6: vertical cut for Mulhouse test site and position of the receivers.

paigns carried out from 1996 to 1998 on sites with complex topography, including noise barriers, hilly terrain, trenches (Cf figures **??**,**??** and **??**).

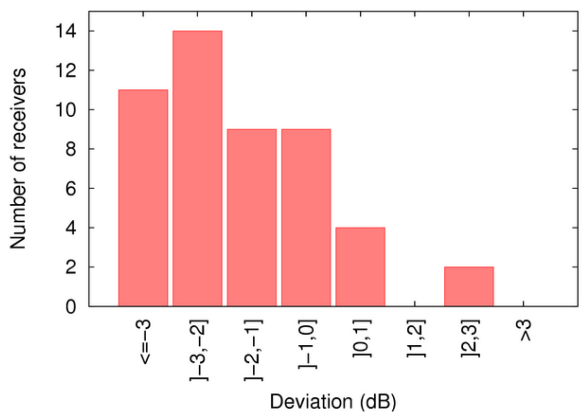

Figure 7: deviation between measured and NMPB-Routes-1996 simulated attenuations. A negative deviation means that the calculated attenuation is lower than the measured attenuation.

Sound levels were recorded in third-octave bands L_{eq} 1s at 9 points in parallel to meteorological data acquisition, for at least 2 weeks. The meteorological data allowed to calculate the occurrences of downward conditions as a function of direction. So it is possible to calculate "medium-term" equivalent levels on Day (6h-22h) and Night (22h-6h) intervals, intervals defined by the french regulations, from levels in homogeneous and downward conditions. The noise measurements give the attenuations on the Day and Night intervals.

Despite all the attention paid to the measurement protocol, obtaining valid measurements for propagation distances above 400 m is difficult, at least when using the traffic as the noise source, which was the case for all sites studied here. After filtering out the data, the measurements provide 49 validated attenuations with respect to a reference receiver. The reference receiver is usually the closest point to the infrastructure.

8.2 Simulation software

The topography of each site has been recorded with good precision. It is reproduced in the NMPBLRS2 simulation code written in Scilab language for the needs of the revision of NMPB. NMPBLRS2 handles 3D sites that can be specified by a 2D vertical cut. Only one propagation path is considered for a given (source, receiver) pair. This is enough for the current application. NMPBLRS2 implements both NMPB-Routes-1996 and -2008.

8.3 Results

The comparison of the simulated attenuations to the measured ones shows that the average of deviations is reduced from -1.7 to -0.6 dB(A) by the new method (Cf. figures ?? and ??). Among the 49 pairs of receivers considered, only 9 exhibit a deviation between measurement and computation larger than 2 dB.

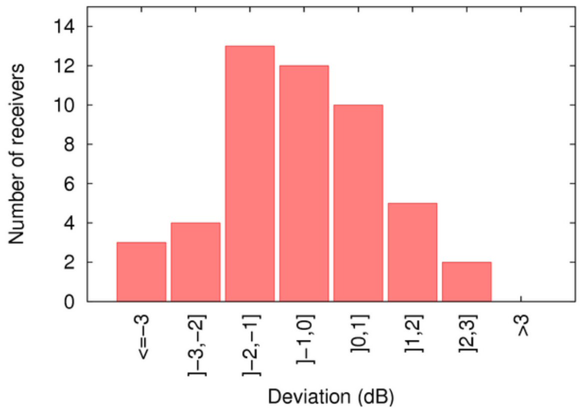

Figure 8: deviations between measured and NMPB-Routes-2008 simulated attenuations. A negative deviation means that the calculated attenuation is lower than the measured attenuation.

9 Conclusion

NMPB-Routes-2008 introduces a lot of changes with respect to NMPB-Routes-96. The most important one is certainly the formula for ground effect in downward conditions. The result is a more coherent formulation regarding ground effect, with the same formula for homogeneous and downward conditions. The occurrence values are now based on a quantitative analysis instead of a qualitative one as before. The diffraction formula can now cope with low barriers.

Compared to NMPB-Routes-96, NMPB-Routes-2008 exhibits a more moderate trend to the overestimation of noise levels in downward conditions.

NMPB-Routes-2008 appears to be a good trade-off between precision, CPU time, the skills required to handle the method properly and the effort to collect the data necessary for a simulation.

An outstanding feature of NMPB-Routes-2008 with respect to Nord2000 or Harmonoise/Imagine projects is that NMPB-Routes-2008 benefits from a large effort of experimental validation on real sites with complex topography.

10 Perspectives

The standardization of NMPB-Routes-2008 in a revision of AFNOR NF S 31-133 is in progress. As before, the standard will cover both road and rail. There seems also to be an interest for an extension of the scope of the standard to prediction of industrial noise.

It is planned by Sétra to publish an english translation of the description of NMPB-Routes-2008.

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