UNCERTAINTIES IN ENVIRONMENTAL NOISE MODELING

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Abstract

With sound level meters the measurement uncertainty is fixed and transparent, depending on the class of the instrument. The counterpart of the measurement, the noise simulation, has many more uncertainties. The uncertainties stem from the calculation standard used, the application of the model's theoretical basis in a computer program and the construction of the data model. The uncertainty of the simulated results is the sum of the uncertainties of the applied standard, the computer program and the physical representation of the reality in a computer model. The end user only has influence upon the creation of the data model and most likely is not aware of the other uncertainties. The assessment of the sources sound power is also an uncertainty but will not be discussed in this paper. This paper is concentrating on the use of popular standards and their built in systematic errors and shortcuts in the evaluation of propagation parameters. Special focus is given to the evaluation of the ground effect. Discussed standards include CoRTN, CoRRN, CONCAWE, ISO9613, GPM (Nordic) and Nord 2000. Testing routines and procedures both listed in the standard and external are to be shown and comments made. Other sources of uncertainty are the transition from area and line sources to the evaluated point sources and the acceleration techniques in the modeling software. In the near future one can hope that the shortcomings in today's standards are avoided with the next generation of noise models conceived at the moment in Europe.

Introduction

Sound level meters, analyzers, microphones and other similar equipment are all standardized in their accuracy. When someone purchases a class one instrument, he is guaranteed a defined accuracy of the measurements as long as he observes certain conditions. It is a reasonable assumption that a measurement of environmental noise taken with a class one meter is +/- 1 dB from the true value. The total error in the measurement is the sum of errors of the microphone, the cable and the noise level meter itself.

With environmental noise predictions, the user is not so lucky to get a standardized product where he knows the total error is one or two dB. Like the noise level meter, the total uncertainty is derived from several sources. The assessment of the sources sound power is built into most models for road and railway traffic. For industrial noise, it is entirely the user's responsibility to correctly evaluate the source. Often the evaluation of the sound power of an area source is done from a single spot measurement assuming a single distance to the source. Reflections on the ground and other horizontal surfaces are most often ignored. Thus, a non definable error is made right at the source.

The propagation of noise from source to receiver depends on the correct representation of the geometry in the model, on the correctness of the propagation model, on the definition of the correct environmental parameters and on the implementation of the rules in the computer software. As the evaluation of the source model is being discussed at large within the measurement circles, this paper concentrates on the uncertainties of the propagation model.

Uncertainties of existing noise models with special regards to the models used in Australia

Most of the propagation models used today were designed decades ago and are no longer state of the art. They were conceived at a time when hand calculations were the normal means of performing them. Now the same formulas are executed on fast computers and everyone tends to treat a computer program as a black box and believe the results.

As part of the ever ongoing quality control process, the software is checked against hand calculations with allowable differences of less than 0.2 dB. Some standards have built-in test questions, others leave this open. Some organizations even set tolerances. Here, the German Umweltbundesamt (German EPA) is probably the most stringent, demanding the tolerance shall not be greater than 4/10 000 of a dB.

Currently the computer processing speed is not fast enough to calculate all details of noise maps. The calculation speed is stretched by evaluating which of the sources is important and which is not. Less important sources are suppressed by the programs. The algorithms determining which source is less important and therefore can be ignored, are not standardized, nor are they published. They are the trade secrets of the noise models. These details can be very subtle but are nonetheless important. In SoundPLAN, for example, industrial sources can be assigned to be active on a per hour basis so the loudest hour at night can be computed. This makes it necessary that all 24 hours of the day are included in the question if a noise source is significant or can be ignored. The pre-calculations do not simply eliminate sources after a set distance.

The biggest contribution to the overall uncertainty is rooted in the standards themselves. Many standards do not detail the conditions they are supposed to model. The ISO 9613 [1] claims to model average downwind situations. For the assessment of power plants and other industrial facilities, it seems appropriate to use the worst case situation of the meteorology which marks the never to be exceeded criterion. The widely used CONCAWE [2] standard allows setting the meteorological parameters to reflect a distinctive meteorological situation and thus represents one episode of the entire years worth of meteorological cases. In SoundPLAN, it is also possible to apply the worst case downwind situation to all sources and pretend the wind is blowing from all source directions towards the receiver. For other standards, such as the CoRTN [3] and CoRRN[4], the meteorological conditions are not explicitly mentioned. For most infrastructure projects the annual average conditions are more desirable. In any case, there will always be problems combining contributions from different noise sources and calculation standards into a comprehensive noise map if the meteorology base assumptions are not the same. Calculations with CoRTN do not pose much of a problem. The results are L_{10} and therefore not comparable with any other calculation standard. Triggered by the EU Noise mapping initiative, the CoRTN standard now has three different correction methods to post-correct the L_{10} into the L_{eq}. With this addition, the person doing the noise modeling and the client interpreting the noise map have to be aware that adding noise contributions from these different standards will add results that might be describing different meteorological base situations.

Another serious point of uncertainty in noise modeling for industrial sources is the directivity and the assessment of the addition for non-spherical propagation. Most often directivity data is not available and is estimated. For openings in buildings such as doors, windows and ventilation ducts, reliable data of the directivity is available. Corrections for non spherical propagation can be broken down into the half sphere representing the ground and sources close to walls. The assessment of the ground proximity needs only to be performed for CONCAWE; ISO9613 and the Nordic General Prediction Method [5] (GPM) have the non spherical transmission built into the ground effect.

CoRTN and CoRRN both have some problems with their source descriptions. The methods state a noise level for the entire line source and adjust segments in accordance to its angular size. An observer positioned at the extended source line will see a line segment of zero degrees, creating a singularity for the segment. The authors of CoRTN knew this and suggested rotating the receiver to a new position where the equations would not generate this infinity error. As CoRTN was devised as a hand calculation standard, this “as you can see” method is not suitable for a computer program. First, there are no clear boundaries where to start rotating, nor does the standard specify how far to rotate. Secondly, it is very difficult to move the receiver and one must cope with the fact that the intervening ground might be completely different than what should be modeled. For a computer program, it would be a nightmare if the receiver would end up in a building. For these reasons, SoundPLAN rotates the road segment as soon as the enclosed angle becomes shallower than one degree.

In CoRTN, the location of the source is 3.5 meters in from the curb position. For small single lane roads as can be found in England, the source position may already be on the other side of the road and inside the next building. There are no provisions in CoRTN to deal with this, so SoundPLAN fixed the case so that the source cannot be farther away than the opposite curb. CoRTN only calculates the noise as a single line source 3.5 meters from the curb position unless the highway is divided by a central reservation of at least 5 meters or if the horizontal alignment of the lanes differs by more than 1 meter. These generous simplifications will create a significant difference near roads over the individual calculation of each lane.

In general, the ground effect is a big source of uncertainty. The early calculation methods were all derived from empirical data. The phase shift on softer ground and the phase correct addition of the direct and the ground reflected wave can not be simulated with the simplified approach most standards have taken. In the GPM and subsequently in the ISO 9613, the formulas for the ground effect simulate the physical phenomenon as much as possible in an empirical model. *Consequentially*, the GPM never talks about ground absorption; it calls it the ground effect. Standards such as CoRTN that do not simulate a spectrum with octaves or third octaves could never get this effect right. In CoRTN, the ground effect and the screening are evaluated from a projection of the geometry upon the perpendicular position. For the screening, this procedure will never be able to work correctly. In a shallow intersection with a road, where the perpendicular position may be 20 meters, the real intersection with the screen may be 500 meters away and the road 600. In real life, there is hardly a measurable screening in this case; projected to a perpendicular position the screening can be anywhere, all the way to the maximum of 20 dB. Evaluating the ground effect only for the perpendicular position will always produce undesirable effects with the extended source line from a road.

In general, screening and ground effect influence each other. In the ISO9613, receivers that are in the shadow zone of a screen will have the ground effect set to zero and only have the screening attenuation. The ground type on both sides of the screen becomes irrelevant. In the standard that can be viewed as one of the parents of the ISO9613, the GPM, the ground attenuation is evaluated and combined with the screening. If significant screening occurs, source and receiver heights above the reflection plane are raised, diminishing the influence of the ground effect. For the screening itself, the GPM first evaluates the natural curvature of a noise "ray" in a neutral atmosphere and computes the extra path length beyond this natural curvature. The insertion loss is then computed from the adjusted extra path length and the secondary path around the screen.

Additional uncertainties in the models stem from the interpretation of the physics of a reflected wave. Most of the standards allow for reflections to be accounted that observe the law of the mirror. The CoRTN standard, however, has a variety of shortcuts in the evaluation. First of all, reflections can only occur on structures on the opposite side of the road. Noise levels on streets where the entire opposite side is reflective will only add 1.5 dB to the results, regardless of the geometry and the structure of the opposite facades. The standard does not state how far the reflector can be away from the road. The sample questions in the back of the CoRTN book, however, state that the reflection shall only be evaluated for the far side lane; the near side lane does not receive the reflection addition (Annex 2). Reflections within a u-shaped building, for example, do not count as reflections. They occur on the "own" side of the street. In CoRTN, the material of the reflector or the height of the reflector is not evaluated. Most other standards evaluate reflections with the mirror principle. Some limit the reflections to objects that are at least 1/2 wave length in size, some limit the reflection to a distance from the source/receiver. Noise maps with single and multiple reflections, as has become standard in Europe, often show reflected sectors from multiple reflectors as sharply defined segments. Interpreting the results from noise sensitive receivers in areas where multiple reflections are present is only possible with consulting the noise map depicting the reflections.

In CoRTN, another added element of insecurity is the fact that the results are L_{10} instead of the now customary L_{eq}. If multiple roads are present within the calculation, it is mathematically questionable if the results of the calculation can be summed up with a simple logarithmical level addition. In the new procedure developed by TRL for the EU Noise mapping, there are now three different methods of converting the L_{10} to a L_{eq}, thus further adding to the uncertainty.

Having tested the SoundPLAN interpretation of many of the standards, the author has checked many test questions, and in the cases of CoRTN and CoRRN, found that some of the test questions are inconsistent with the rules set forth in the standards texts. As mentioned before, the limitation of the reflection addition in Annex 2 of CoRTN is an open question. The simplifications of Annex 17 with reducing a 3D building into a simple line will also cause some deviation from the real answers. The railway test examples also contain errors concerning the handling of the air absorption for diesel locomotives under power.

Call for a new beginning

Most of the existing standards were written for hand-calculations and were derived by means of curve fitting measured data. Often these standards are applied via commercially available software without understanding what the standard wanted and where the standard set limitations. When multiple standards are used to create a comprehensive noise map from multiple noise types, the results are not as reliable as they should be. It is the author's opinion that only a method which can be applied to road, rail and industry sources with uniform propagation conditions can result in reliable noise predictions. Such a standard must consider phase effects of ground reflections and absorption, a more physically correct description of reflections at walls and buildings and must allow for a better control of the environmental parameters such as wind and temperature distributions. If the environmental control over the calculation is guaranteed, it would be possible to simulate annual average conditions for a project and design suitable noise barriers. With the same model and worst case meteorological conditions, it would still be possible to assess how much more it would cost to design the protection for the inversion conditions during the very early morning rush hour.

Contenders for a new beginning

There are already some attempts to start over with new models. The ASJ [6] models, TNM [7] and the Nord2000 [8] are all based on interpreting the wave equation rather than curve fitting measured data. Of these models, the Nord2000 is the only one designed for road, rail and industry noise with emission models for road and rail that can be customized to local fleets. The conventional ground effect has been replaced by a series of reflections and diffractions with the influence zone evaluated by a frequency dependant Fresnell zone. The equations are all a solution of the complex wave equation. Reflections gradually phase in on the sides and the end of their range. Environmental parameters allow for the calculation of a dedicated wind and stability situation as well as the calculation of the worst case. The new approach has one big draw back; the equations are so complicated that quick checks by hand are almost impossible. As plausibility checks are very difficult, the emphasis on testing and verification of the computer models will become much more difficult and time intensive.

Developments in Europe with the European Noise Directive, Harmonoise [9] and Imagine [10] indicate that the older European models in the short and medium term will be replaced with a single, uniform model. At the moment, it appears the main contender for the future European model will be a slightly modified version of the Nord2000.

With the new phase correct propagation, the demands on the calculation engine are increasing dramatically. Comparisons between the execution speed of simple models such as the German RLS 90 and TNM have shown that the implementation of these algorithms take a toll on computation speed. Using the same data, the RLS in SoundPLAN carried out the calculations by a factor of 3500 faster than TNM. With careful implementation, SoundPLAN has reduced the speed overhead with the Nord2000 to a factor of 10, proving that a complex physical model such as the Nord2000 is feasible. A native implementation of the ASJ model and the TNM in SoundPLAN will attempt to result in similar execution speeds.

References

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