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CNOSS OS and indus trial no ise

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Summary
The CNOSSOS calculation scheme is tested with regard for industrial noise in this research against measurements and the Dutch calculation scheme HMRI, which has much in common with the ISO 9613-2. The results were disturbing, with noise levels increasing on average with 7 dB. This was only partly due to the lack of no foliage and industrial sites attenuation are present in CNOSSOS, and because sound power calculations are based on the inverse propagation from the HMRI. Calculations in residential areas showed that no screening was present according to CNOSSOS, while the HMRI screening was well above 10 dB. This was discovered in other Dutch tests for road and rail traffic as well. But the main difference can be explained by the ground reflection attenuation and meteorological correction. An overview will be given on these matters.

1. Introduction

In this paper we reflect on the findings of our research commissioned by the RIVM (in English: National Institute for Public Health and the Environment) in report "Research on the CNOSSOS calculation method involving industry" [1]. The main question to be answered in this research was: Can the Commision Directive (EU) 2015/996 'Establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council' from May 19, 2015 (further refered to as CNOSSOS [2]) be used instead of the "Guide for measuring and calculating industrial noise" (Dutch: "Handleiding meten en rekenen industrielawaai" , abbreviated HMRI [3]). The HMRI is used in the Netherlands for setting maximum noise values for large factories and zoning of industrial areas. Although there are differences, the ISO 9613-2 [4] is in many ways similar to the HMRI.
To research the differences, several topics were raised. The main topics are given below:

- Determination of sound power
- Influence of 31,5 Hz octave band
- Influence of forest and industrial sites on sound propagation, how can these be incorporated into CNOSSOS
- Comparison between measurements and calculations
- Impact on zoning

In this paper we consider these questions and state the answer to the main question.

2. Determination of sound power

In the HMRI six methods are described to determine the sound power level of all kinds of industrial noise sources. The one that is most comely used is the concentrated source method. In this method the dimensions of noise source are at least 1,5 times less than the distance from the source to the microphone. To determine the sound power, an inverse propagation model is used, based on the HMRI. Using this sound power in a different propagation model is only allowed when the inverse propagation gives the equal answers. Above a reflecting plane within 20 meters from source to receiver, the difference is inverse propagation between the HMRI and CNOSSOS results in a 1 dB difference. The sound power level for CNOSSOS will be 1 dB lower.
We researched the percentage this method was used on two mayor industrial sites and found that in 63% of the performed measurements this method was used. So, the influence of the method concentrated sources in CNOSSOS is there but has practically little effect (smaller than 1 dB).

3. Influence of 31,5 Hz octave band

The HMRI described that calculations on noise propagations must be performed in the octave bands ranging from 31,5 up to 8000 Hz. In CNOSSOS the octave bands reach from 63 up to 8000 Hz. The omittance of the 31,5 Hz could lead to differences in the calculation results, with low frequency noise components and or over calculations over large distances.

We found that in most cases the 31,5 Hz octave band can be omitted without compromising the results. Only when the noise level of the 31,5 Hz octave band is less than 16 dB under the total noise level, the 31,5 Hz octave band influence cannot be discarded.

4. Influence of forest and industrial terrain on sound propagation

The correction terms for vegetation attenuation and terrain attenuation used for industrial noise are absent in CNOSSOS, but are present in the HMRI. How can these correction terms be implemented within CNOSSOS?

1.1. Forest

In case of the industry, vegetation is seen as strips of vegetation consisting of trees, bushes or shrubs that are so dense they block the view according to the HMRI. The path of the curved sound ray should be at least one meter lower than the height of the vegetation. The attenuation is frequency dependent, as can be seen in table I. Multiple vegetation strips can be used if they fulfil the requirement of not being see-through, see figure 1. It is mentioned this only holds true in exceptional cases. A maximum of four strips of vegetation may be considered.If in winter the vegetation becomes translucent, only half of the attenuation can be accounted for.

Table I. noise reduction of a strip of vegetation in dB.

Octave band	31	63	125	250	500	1k	2k	4k	8k
A_{veg}	0	0	0	1	1	1	1	2	3

The effect of a strip is generally around 1 dB; the maximum effect (4 strips) is 4 dB (at 500 Hz).

Figure 1. Examples of vegetation, the vegetation on the right side does not qualify, while the image on the left does

In practice A_{veg} is applied with some regularity but not on a large scale. The use of strips is a complicating factor. It allows the effect of the vegetation to be direction dependent, see figure 2. Depending on the source-receiver combination the sound path crosses 1 or 3 strips of vegetation, while the intersecting path through a single strip is longer.

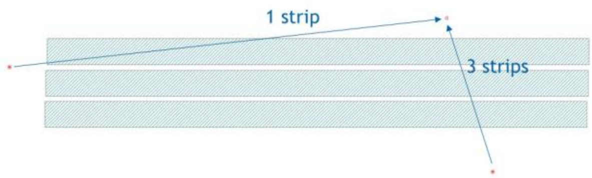

Figure 2. examples of the use of vegetation strips

The use of ISO 9613-2 is widely spread for calculating of industrial noise. This method has operated as interim-method for industrial noise during the development of the END Noise maps. The approach to vegetation attenuation is slightly different in the ISO 9613-2 ANNEX 2 compared to the HMRI. The actual distance of the curved sound ray through the vegetation is considered. For the first 20 metres, the attenuation is the same as that of the HMRI. Onwards, extra attenuation is computed per metre, with a maximum of 200 metres, this is seen in table 2.

Table II. noise reduction due to vegetation attenuation according to ISO 9613-2

Octave band	63	125	250	500	1k	2k	4k	8k
10 ≤ df ≤ 20 m	0	0	1	1	1	1	2	3
20 ≤ df≤ 200 m	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.12

After 200 metres, the noise reduction at 500 Hz is 10 dB. It is striking that at the 20 metres limit the attenuation is not continuous. At the 125, 2,000 and 8,000 Hz octave band the difference is 0.6 dB.

The NORD 2000 [5] uses another approach. The average tree density (per m^2), the average trunk thickness, and the distance through the vegetation is taken into account. Next to that, the absorption and the objects' mean vertical heights/width is implemented, although this often is of minor importance. In the NORD 2000 model ground impedance is considered as well. The impedance is considered very soft due to leaves and branches and the effect of turbulence because of higher temperatures in the forest. These are the factors that are included into the computation of the vegetation attenuation. For different types of forests, the attenuation is determined and represented in table III. We assume that the curved sound ray completely travels through the vegetation.

Table III. noise reduction because of vegetation attenuation according to NORD 200 in dB (path distance = 50 m, α (trunk absorption) = 0.2)

	Density [trees/m_2]	Trunk [m]	h [m]	500	1k	2k	4k	8k
Poplars	0.04	0.27	9	0	0	0	0	0
Oak	0.20	0.20	4	5.1	7.9	9.4	10.	10.4
Conifero	0.03	0.15	10	0	0	0	0	0
Dense coniferous forest	0.40	0.10	10	0	5.1	7.9	9.4	10.1

In an article about vegetation attenuation in forests that NORD 2000 refers to by Tarrero[6], measurements were made, the upper three examples of table III. In this article, it is noted that the ground attenuation is decisive to the propagation of sound through forests up to 40 metres. A limited part of the noise reduction upwards from the 500 Hz octave band at larger distances is derived from the trees themselves. The article states that calculations with tree attenuation is only slightly more accurate compared to the measurements, than the calculations without tree attenuation.

The results of the attenuation according to ISO 9613-2 and NORD 2000 depicted in figure 3 are not directly comparable, but do show results where the effects are not highly contradictory.

With frequencies lower than 500 Hz, the ISO 9613-2 approach produces slightly higher attenuation, above 500 Hz, the NORD 2000 yield greater attenuation. Further research is needed into the effects of ground impedance and turbulence to apply NORD 2000 within CNOSSOS if these prove to be relevant.

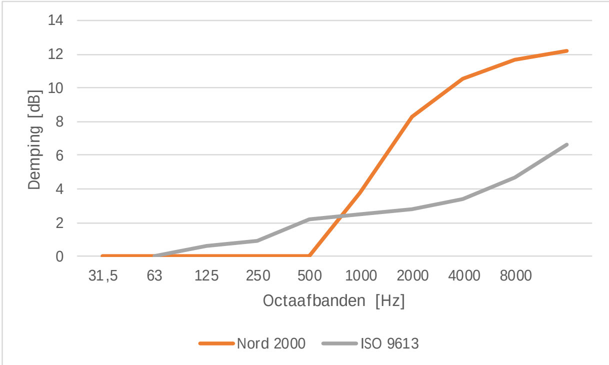

Figure 3. Attenuation due to 50 m of forest (density 0.3 trees/m^2, trunk section 0.15 m)

Based on the above, the recommendation is to model vegetation attenuation according to the ISO 9613-2 methodology. Overall, the attenuation yields similar results as the HMRI does with vegetation strips.

1.2. Industrial terrain

The HRMI describes how the presence of installations and objects on an industrial terrain can attenuate the propagation of sound. Preferably, the degree of attenuation ($A_{terrain}$) is deduced from measurements. In practice, however, this is not often achieved.

The HMRI describes three types of terrain.

- Type A: Open process installations with a coverage of circa 20% for every 30 metres.
- Type B: Open process installations with a coverage of more than 20% for every 30 metres.
- Tank (reservoir) parks: Open process installations where many storage tanks are placed.

The calculation of $A_{terrain}$ is as follows:

- $A_{terrain} = t(f).r_t.$
- $A_{terrain} \leq A_{max}.$
- With:
  - $t(f)$ as a frequency dependent attenuation factor caused by the industrial terrains, in table 1 some indicative values are represented.

- R_t is the part of the curved sound ray that passes through the 'open' installations. If the curved sound ray is mostly located above the installations, then this part is not within the R_t computation.
- A_{max} is the maximum type-depending attenuation value, as can be seen in table 1.

Table IV. indicative HMRI attenuation coefficients *t(f)* in dB/m (31,5 and 63 octave band are 0 dB/m)

Octave bands	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**D_{max} [dB]**
Type A	0.02	0.03	0.06	0.09	0.1	0.1	0.1	10
Type B	0.04	0.06	0.11	0.17	0.2	0.2	0.2	20
Tank parks	0.002	0.005	0.015	0.02	0.02	0.02	0.02	10

Screen diffraction may not be implemented when $A_{terrain}$ is being applied.

In general practice $A_{terrain}$ is mostly applied when there are open process installations. These installations produce sound themselves, but attenuate the sound of neighbouring process installations or sound sources. The size of the process installations can differ from tens to hundreds of metres. From around 175 metres at 500 Hz the effect of an open process installation is limited by the A_{max}. Tank parks can be even larger and can reach up to 1,500 metres. Tank parks reach their limit around 700 metres. Around such distances the curved sound ray is elevated at least 10 metres. With the average height of the reservoir tanks being 20-30 metres, it is still possible that these maximum values are obtained. In common practice $A_{terrain}$ is not often used for tank parks. It is possible to model reservoirs as a diffraction object, where the diffraction can cause up to 20 dB attenuation, in exceptional cases when the source is close to the receiver even 40 dB according to the HMRI.

These values are based on research conducted by Consultancy Peutz 'Bepaling inplant-screening, IL-HR-13-01'[7]. This report shows that a mean terrain attenuation was used. The spread of the noise measurements was wide, the variation at 500 Hz was between -0.04 and 0.75 with an average of 0.35. This emphasises the notion that these are only indicative measurements, see figure 4.

The ISO 9613-2 applies the terrain attenuation in a similar way as mentioned in the HMRI, but the

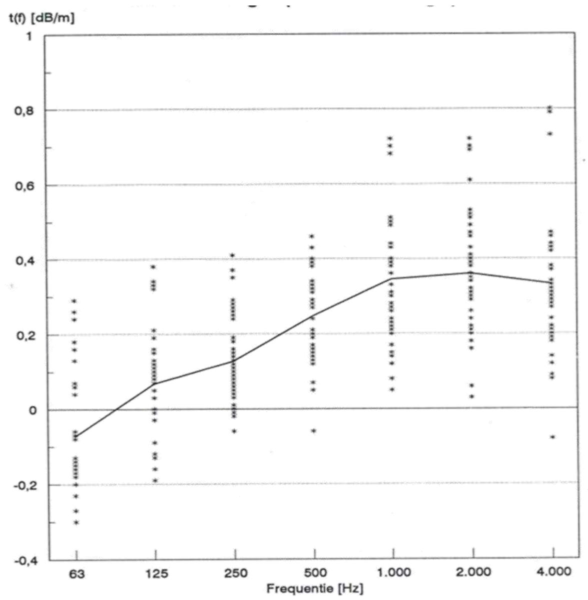

Figure 4. *t(f)*/km as function of octave bands, report R 705-1

attenuation values per meter are approximately half the values from IL-HR-13-01, and consequently much lower compared to the HMRI.

The CONCAWE [8] model 'The propagation of noise from petroleum and petrochemical complexes to neighbouring communities' does mention 'inplant screening', but does not quantify the attenuation because of the great uncertainty.

The IMAGINE model [9], based upon the HARMONOISE model, refers to the HMRI for the influence of process installations, but also to the NORD 2000 model. The NORD 2000 model, latest version from 2006, does not describe the influence of process installation or tank parks but a more general description about the scattering from objects such as a forest.

The concluding remark is that the most recent data about the effect of process installations and tank parks in calculation methods are derived from the HMRI. Therefore, this is a (unsecure) starting point from which to continue the extension of CNOSSOS concerning this topic.

5. Measurements and calculations

The Province of Noord-Brabant performed a long-time noise measurement [10] of one year near the industrial terrain of Moerdijk, see figure 5.

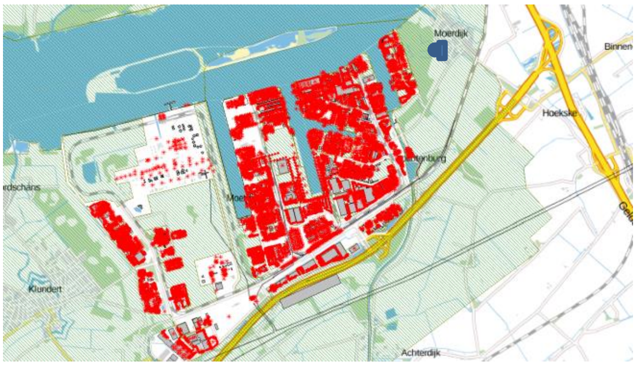

Figure 5. Industrial terrain Moerdijk and measuring point in bleu

This terrain over a surface of 15 km^2 has petrochemical, transhipment, where housing industry and the like. A Geonoise [HMRI] model based on the licenses of each company was available to compare calculations to the measurements. Since in CNOSSOS the effect of forest and industrial terrain are not incorporated, these effects are separately stated, see table V.

Table V. Comparison between measurement and calculations, equivalent noise levels in dB(A)

Situation	Method	Level
Measured		35,0
Original model	HMRI	33,8
Original minus effects of forrest and industrial terrain and 31,5 Hz oct.b.	HMRI	36,1
Favourable	CNOSSOS	44,3
Homogeneous	CNOSSOS	30,7
50% Favourable	CNOSSOS	41,5

Table V shows that the measured and HMRI calculated noise levels agree reasonably. The effect of especially the industrial terrain is about 2 dB and therefore important in this model.

The difference between favourable and Homogeneous is quite large, about 14 dB. The yearly averaged situation, assumed to be about 50% favourable, is almost about 3 dB lower than just favourable.

The table also shows that CNOSSOS calculated outcome compares poorly with the measurement.

6. Impact on zoning

Zoning in the Netherlands regulates the maximum total noise levels of all licensed industrial noise on an industrial terrain. The 50 dB(A) noise contour (max of day; evening+5 and night+10 dB) shows the limit of the impact of an industrial terrain.

The industrial zone for Botlek/Pernis is calculated according to the HMRI and CNOSSOS both with Geonoise. The Botlek/Pernis area is about 25 km^2. The results are presented in figure 6.

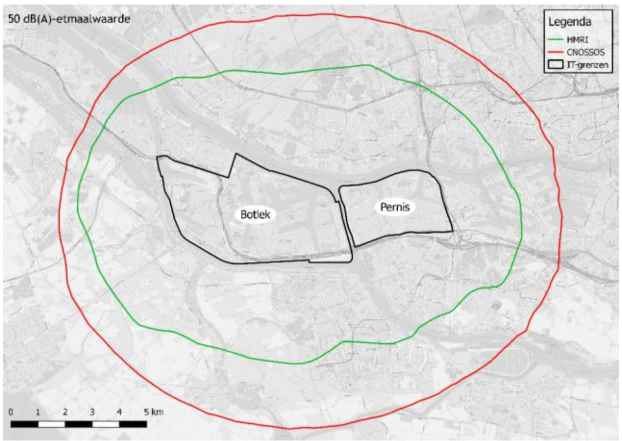

Figure 6. 50 dB(A) contour HMRI (green) and CNOSSOS (red).

Figure 6 shows that the 50 dB(A) contours increase significantly, to an unrealistic distance of over 5 km from the border of Botlek/Pernis. If CNOSSOS is introduced without changing the maximum allowed noise levels inside a house, large sums of money must be invested to isolate the houses within the contours.

Further detail is given in figure 7, where results are presented on individual calculation points on various distances from the Botlek/Pernis area, and some on this area.

This figure shows that almost all calculation points result in a higher noise level when calculated with CNOSSOS. The lower the noise levels (longer distances) the higher the difference becomes. On average noise levels increase from 5 till 10 dB.

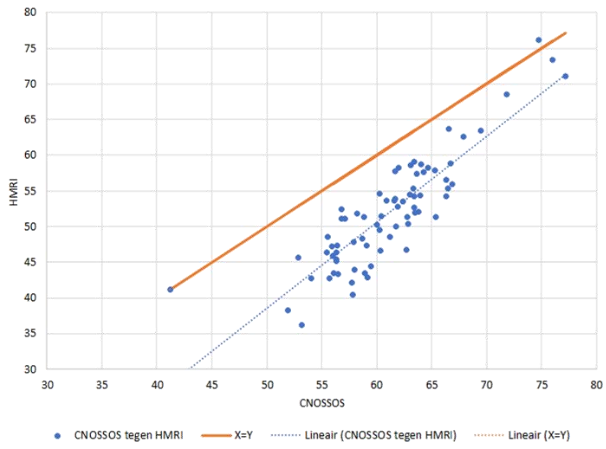

Figure 7. Results from CNOSSOS and HMRI on the same calculation points in dB(A), on and around Botlek/Pernis.

Part of the difference originates from the improperly incorporated attenuation of multiple screens in CNOSSOS [11].

Another influence is the ground reflection. The calculation demands that in favourable conditions the location of the source and receiver is moved upwards to calculate the ground attenuation. This results in an increase of the source height from 1 meter to 10 meters at 1500 meters distance.

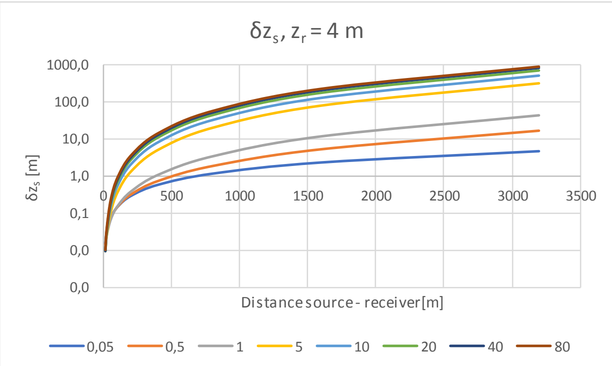

Figure 8. Curves for different original z_s (coloured lines) based on distance between source and receiver. Receiver (z_r) at 4 m height.

The effect is that for any kind of ground type the ground attenuation is in many cases independent of frequency in favourable conditions with a receiver at 4-meter height. This results generally in a ground attenuation far below that is found in the HMRI or ISO 9613-2.

The meteorological correction C_m found in HMRI and in ISO-9613-2 leads also in higher noise levels. C_m is in many cases on larger distances 5 dB. To reach in CNOSSOS a meteorological effect of 5 dB is not realistic. The favourable situation over large distances is dominant over the homogeneous situation. With a small error, one could say that the meteorological influence in this case is equal to the -10log(favourable%/100%). To reach an outcome of 5 dB, the percentage favourable will be about 30%. This low percentage of favourable conditions will be seldom realized, as can be seen from the French NMPB [12]. It shows that in Dunkerque, a place near the sea in flat country that could be considered as representative for the Dutch situation, the minimum percentage favourable is 39%, the minimum is 63%. This results in a meteorological effect of maximal 4 dB, minimal 2 dB. The average favourable percentage is about 50%, resulting in an averaged 3 dB meteorological effect.

The above gives us the main reasons for the differences between CNOSSOS and the HMRI:

- Multiple screen calculations (effect up to 10 dB)
- Ground attenuation (effect up to 8 dB)
- Meteorological influences (effect up to 3 dB)

7. Conclusions

The conclusions are as follows

- Determination of sound power: small influence
- Influence of 31,5 Hz octave band: very small influence
- Influence of forest and industrial sites on sound propagation, how can these be incorporated into CNOSSOS: suggestions of extension on CNOSSOS are given
- Comparison between measurements and calculations: CNOSSOS calculates far worse than the HMRI
- Impact on zoning: disastrous effects of CNOSSOS

The above leads to the main advise: don’t use CNOSSOS for licensing and zoning in the Netherlands.

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