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2021:00990 - Unrestricted

Report

Methods for calculating maximum levels in Norway using Cnossos-EU.

For miljødirektoratet

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2021-11-08

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KEYWORDS:
Cnossos-EU,
Maximum levels

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VERSION
1.0

DATE
2021-11-08

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CLIENT(S)
Miljødirektortet

CLIENT'S REFERENCE
Merete Gynnild

PROJECT
102024869-1

NUMBER OF PAGES AND ATTACHMENTS
17

ABSTRACT
Cnossos-EU is a new European calculation method for noise levels from road traffic, railway traffic, industry- and aircraft sources. Its objective is to ensure more uniform noise level calculations across Europe. Cnossos-EU in its original state does not support the calculation of maximum levels. This report describes how maximum levels can be introduced to Cnossos-EU to fit current Norwegian policies.

REPORT NUMBER
2021:00990

ISBN
978-82-14-07687-5

CLASSIFICATION
Unrestricted

CLASSIFICATION THIS PAGE
Unrestricted

Document History

VERSION	DATE	VERSION DESCRIPTION
0.2	22.09.2021	First draft for internal review
0.3	27.09.2021	First draft for client review
1.0	08.11.2021	Final edition

Contents

1 Introduction

Cnossos-EU is a new European calculation method for noise levels from road traffic, railway traffic, industry- and aircraft sources. The method is described in the EU Directive 2015/996 [1], and its objective is to ensure that a uniform method is used throughout Europe to calculate noise levels for area planning and action plans to protect the health of the population from excessive noise levels [2].

Both equivalent and maximum values are calculated when estimating road, rail, industry and aircraft noise levels in Norway. While the maximum values represent the maximum noise level likely to occur, the equivalent values represent a measure of the total noise exposure. The choice of measures was based on their wide use and simplicity and their good correlation with noise effects on humans. While the equivalent level such as L_{den} is a good predictor of annoyance [3], a good correlation has been found between maximum levels and sleep disturbance in the form of an increased number of awakenings and related unfortunate health effects [3]. Therefore, the combination of both an equivalent and a maximum value is helpful for specialists when planning noise reduction measures as it allows for better control of the noise exposure to surrounding noise-sensitive areas. Combined, maximum and equivalent noise levels provide a more detailed description of the noise produced by a source than each unit of measure would alone.

While the equivalent value is commonly used worldwide, the maximum value is only used in a few countries, such as the Norway and Sweden. The new European calculation method for noise levels from road traffic, railway traffic and industry sources, Cnossos-EU, does not support the calculation of maximum levels in its current state [1]. For the computation of noise levels according to current Norwegian regulations, Cnossos-EU must therefore be adapted also to include the computation of maximum levels. This report describes how maximum levels can be introduced to Cnossos-EU to fit current Norwegian policies.

2 Maximum sound pressure levels

At first glance, the term "Maximum level" appears to be self-explanatory and easy to define: it is the highest sound pressure level observed. However, both instrumental settings and measurement time will affect the resulting level. For example, with increased measurement time, the probability of observing an atypically high level increases. Further, the noise level observed will rely on various effects such as meteorology and which vehicles that pass and the time weightings of the measurement equipment.

The convention for measuring maximum noise level is that it can be evaluated with a 1s time constant, denoted "Slow" or a 0.125s time constant, denoted "Fast". Both time constants dampen the reaction of the displayed level to a sudden change in the sound level. If the time constant is "Fast", the shorter time window used for averaging results in a greater probability that a higher level will be observed than if the time constant "Slow" is used. Thus the definition of maximum noise level is the level **measured** by an instrument with a particular setting over a specific time window. Both time constants are used in Norway, but which constant is used depends on the source in question. For more information, see section 4 and [4]. Another complication is that different frequencies will have their maximums at different times and that the time weighting for each of these also should be included in the analysis to get the correct maximum level.

An exact definition of the maximum levels hence requires a more elaborate definition for all common practices. Various statistical approaches are used to make the results more reproducible and uniquely defined, such as the maximum noise level exceeded by 5% of the vehicles or the n^{th} highest level averaged over a given frequency range. As a result, different authorities can have different definitions of maximum levels, and they can be different for different sources to best capture the characteristics of the relevant source. For Norwegian conditions, this is further described in section 4.

3 Methodology for computing maximum levels for the Norwegian adaptation of Cnossos-EU

Cnossos-EU describes four noise sources: road traffic, rail traffic, industry and aircraft. The propagation model is identical for the three terrestrial sources, as the physics behind the sound propagation is the same, but the source model varies significantly. Therefore, it is necessary to detail how to compute maximum levels for the different sources separately. How this should be done, according to Norwegian policies, are described for the three terrestrial sources in the following sections. The aircraft methodology differs greatly from that of the terrestrial sources, and computation of maximum levels is already described in the method [1]. This methodology is therefore not rendered here.

3.1 Road traffic noise

When estimating road traffic noise using Cnossos-EU, each vehicle is represented by a moving point source that radiates uniformly. The sound power emission from each point source depends on the vehicle category, its speed and various corrections due to the road surface, studded tyres, acceleration, and the road's gradient. For a vehicle of category m driving at a speed $v(m)$, the total source sound power level in frequency band i is given as:

$$L_{W,i,m}(v_m) = 10 \times \lg(10^{L_{WR,i,m}(v_m)/10} + 10^{L_{WP,i,m}(v_m)/10}), \tag{1}$$

where $L_{WR,i,m}$ is the sound power level contribution due to rolling noise and $L_{WP,i,m}$ is the sound power level contribution due to propulsion noise [1]. In Cnossos-EU, a road is represented by a line source consisting of a chain of such moving point sources, and the equivalent level will be the summed and time-averaged level from each moving point source, as illustrated in Figure 1.

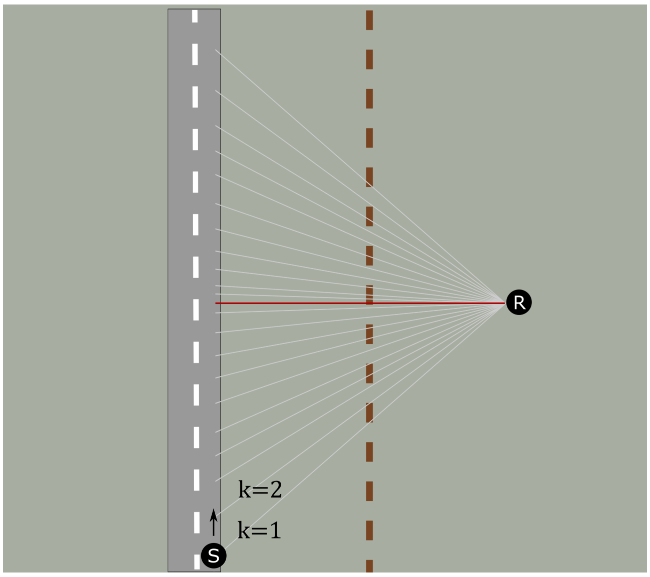

Figure 1: The figure illustrates a road-traffic source S in position k. The sound rays that reach the receiver R when seen from above is illustrated in gray. The red line illustrates the position and ray path that will give the maximum level in this specific symmetrical case. The brown stippled line is an infinitely long noise barrier parallel to the road.

In Figure 1, the light gray rays indicate the contributions from each part of the road, which combined give the equivalent level in the receiver position after the propagation effects from each path is included. In the case of maximum levels, the highest contribution, and the propagation effects from that point source, should be stored instead of summing and time-averaging all contributions. In the symmetrical case on Figure 1, the highest contribution will be from the part of the road closest to the receiver. The contribution from this segment is illustrated by the red ray on the figure. The sound power level per frequency band in the receiver position from this segment is then the maximum spectrum.

It should be noted that the point source representation is a simplification, which is valid when the receiver is further from the vehicle than the length of the vehicle itself. For smaller vehicles, this is an accurate representation. For longer vehicles this is not ideal [5]. It is, however, the current practice in Nord 2000 [6] and the Nordic prediction method for road traffic noise [7]. This practice is therefore continued here.

Cnossos-EU considers two standard atmospheres: a homogeneous atmosphere and a downward-refraction atmosphere named favourable conditions. Both atmospheres are illustrated on Figure 3. As we are interested in the maximum level, and a favourable and homogeneous atmosphere can not co-occur, we only consider the favourable atmosphere. This simplification will provide conservative results, for example when the nth highest values are computed.

Using the Cnossos-EU notation described in [1], the sound level in position R from the source in position k from one path is then given as:

$$L_F(k) = L_{W,0,dir} - A_F, \tag{2}$$

where A_F represents the total attenuation along the propagation path in favourable conditions and $L_{W,0,dir} = L_{W,i,m}(v_m)$ for road traffic noise. The attenuation A_F includes the attenuation due to geometrical divergence, atmospheric absorption and the attenuation due to ground effects or diffraction effects. The maximum level in the receiver position R from a source position k is then given as

$$L_{F,max,energy} = max(L_F(k)) = \max\left[10 \cdot \lg \sum_{n=1}^{N} 10^{(L_{W,i,m}(v_m,k,n) - A_F(k,n))/10}\right], \tag{3}$$

where the sum $\sum_{n=1}^{N}$ corresponds to the sum over all the various propagation paths N from source position k. This is illustrated in Figure 2, where two propagation paths are included due to a reflecting building close to the receiver. There will also be paths in the vertical plane if the ground is reflecting, which isn't shown in the figure.

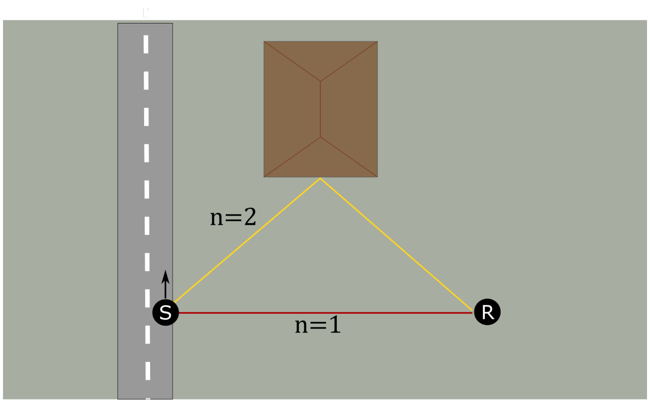

Figure 2: The paths n from a source S to a receiver R seen from above when a reflecting building induces an additional path $n = 2$. There will also be paths in the vertical plane, which are not shown in the figure.

When calculating noise from road traffic, the prediction method contains empirical data, ensuring the source strength to be the same for a certain vehicle type at a certain speed. Hence, the source level before including the propagation effects will be the same for all the rays on Figure 1. Therefore, when estimating time-averaged values, such as $L_{A,eq,24h}$, where the traffic flow is averaged over a 24-hour window, average values for source strength is sufficient for a correct representation. When estimating maximum levels, however, we rely on the value of one single vehicle. Therefore, it is necessary to account for the typical variance s^2 in the source strength to predict an "atypical" high level.

The source strength variance s^2 is found from measurements of a large variety of vehicles and driving conditions, which combined describe the expected variance of a representative vehicle fleet. Cnossos-EU, in its current state, provides no such additional knowledge about the expected source strength variation. Therefore, it is necessary to include the variance described in other noise prediction methods. The variance described in Nord 2000, and Nor 96, are the same, and are based on measurements published in 1994 and 1996 [7, 8, 9]. The standard deviations are given for light and heavy vehicles and are speed-dependent, as defined by the following equations:

$$s(heavy) = 4.1,\ 30 \leq v \leq 50\ \text{km/h} \tag{4}$$

$$s(heavy) = 10 \cdot e^{-0.9\frac{v}{50}},\ v > 50\ \text{km/h} \tag{5}$$

$$s(light) = 5.5 \cdot e^{-0.7\frac{v}{50}},\ v \geq 30\ \text{km/h} \tag{6}$$

As seen from equation (4) to (6), these standard deviations are only given for two vehicle classes: "light" and "heavy". Cnossos-EU operates with five vehicle classes in total. In addition to "Light motor vehicles" and "Heavy vehicles" a category for medium heavy vehicles and two categories for powered two-wheelers are included. Data describing the standard deviations for the missing classes have not been found. We, therefore, recommend new investigations before the additional vehicle classes are used in Norway.

Sound exposure calculations of equivalent values come from so-called *energy averaging* across the variation of noise within a vehicle class. This is done for sound pressure square (p^2), not dB numbers. The statistical variance s^2 described here, however, is only valid for dB levels. Therefore, to compute the correct maximum levels, it is necessary to add a correction in order to move from the calculated sound exposure $L_{F,max,energy}$ to the maximum level as a dB-average:

$$L_{F,max} = L_{F,max,energy} - 0.115 \cdot s^2. \tag{7}$$

This equation is based on empirical data, and is further described in Nord 2000 for road traffic noise [10].

3.1.1 Calculation example

To verify that maximum levels can be calculated for road traffic noise using the presented methodology, a test calculation has been performed. Figure 1 and Figure 3 present the setup for the calculation in the horizontal and vertical plane, respectively. The vehicle speed is set to 50 km/t, and the number of vehicles is set to AADT 4000 (annual average daily traffic).

The terrain is modelled as flat (no elevation) with a soft/absorbing surface. The calculation example has taken air absorption into account and presuppose favourable atmospherical conditions. A 2-meter high noise barrier has been placed 4.5 meters from the roadside. The sound pressure level is calculated for both $L_{A,max}$ and

$L_{A,eq,24h}$ for distances from 1 to 100 meters, where the receivers are placed at $h = 1.5$ meters. The results from the calculation are shown in Figure 4.

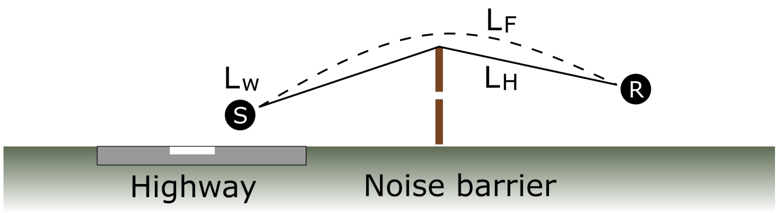

Figure 3: Illustrates the setup for the computational example for road traffic noise. The source is denoted S and the receiver R. Both paths for favourable and homogeneous atmosphere is illustrated, but only favourable atmosphere has been used in the example.

As one can observe from the results, the noise level decreases as a function of distance. As expected, $L_{A,max}$ is declining slightly faster than $L_{A,eq,24h}$. The effect of the noise barrier is clearly noticeable as the sound pressure drops immediately after the barrier.

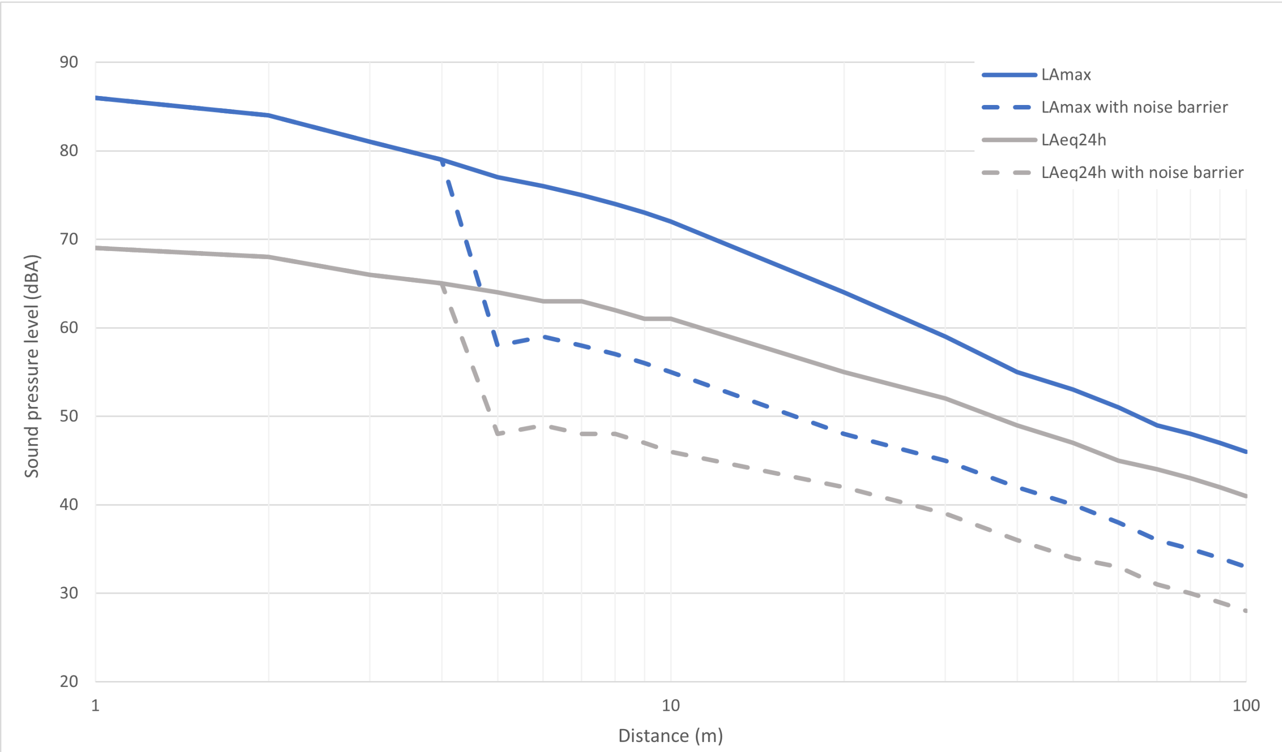

Figure 4: Source height: 0.05 m, Receiver height 1.5 m, Ground condition: soft surface. In this example a 2 m high noise barrier has been placed 4.5 meter from the roadside. The speed of the vehicle is set to 50 km/t with AADT 4000. The car's sound power level is set to 100 dB and its frequency spectrum has been taken from HB 47 [11].

3.2 Railway noise

Unlike road sources, trains can not be approximated to be moving point sources, as they can be more than 700 m long, and buildings within 700 meters from the railroad is not uncommon. Further, the expected noise source level will vary along the train and the tracks. There will be contributions from various parts of the train depending on the vehicle type, rail conditions, and other parameters. This is also the case in the Cnossos-EU description. Two source heights are to be used, one at 0.5 m and one at 4.0 m, to represent the different noise sources as illustrated in Figure 5. When evaluating the noise emission of a traffic flow, each track shall be represented by a set of 2 source lines characterized by its directional sound power per metre. Hence, railway sources are far more complex than road traffic sources, and no simple measured variance, as described for road traffic, can be used.

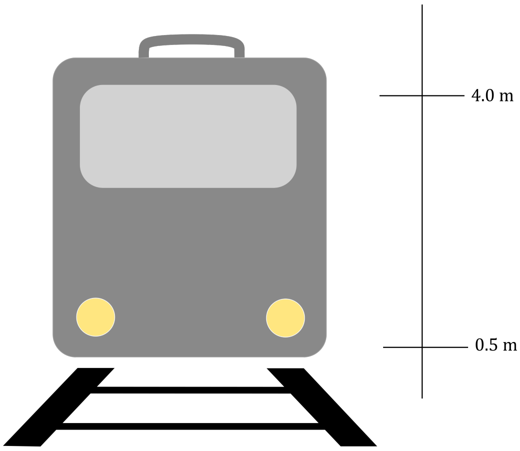

Figure 5: Illustrates the two source positions for a railway source in Cnossos-EU.

In total, five physical source types are identified in Cnossos-EU for the railway sources: rolling and impact noise, curve squeal, traction noise, aerodynamic noise and additional effects. The directional sound power from each specific source is given as

$$L_{W,0,dir,i(\psi,\phi)} = L_{W,0,i} + \Delta L_{W,dir,vert,i} + \Delta_{dir,hor,i}, \tag{8}$$

in frequency band i, where $\Delta L_{W,dir,vert,i}$ and $\Delta_{dir,hor,i}$, is the vertical and horizontal directivity correction respectively. $L_{W,0,i}$ is the sound power level of the specific source.

The directional sound power per metre sums over all combinations X of various sources, vehicle types, speeds and running conditions and the directional sound power per metre is given in Cnossos-EU [1] as

$$L_{W',eq,T,dir,i} = 10 \cdot \lg\left(\sum_{x=1}^{X} 10^{L_{W',eq,line,x}/10}\right), \tag{9}$$

where:

$$L_{W',eq,line,i}(\psi,\phi) = L_{W,0,dir,i}(\psi,\phi) + 10 \times \lg\left(\frac{Q}{1000v}\right), \tag{10}$$

constant speed is assumed, Q is the average number of vehicles per hour and v the vehicle speed in km/h.

As Cnossos-EU doesn't give any additional information about how to compute maximum levels, it is natural to look to existing methods. The Nordic Prediction Method for Railway Traffic Noise [12] calculates maximum levels from equivalent values. Nord 2000 calculates maximum levels for railway traffic based on measurement data from 1994 [13] and will form the basis for how maximum levels from railway traffic should be computed in Norway in combination with Cnossos-EU.

In Nord 2000, $L_{F,max}$ is calculated from the sound power levels $L_{W,j}$ of the J sub-sources of the noisiest train. According to Cnossos-EU, the available data is the sound power level per meter train $L_{W',eq,T,dir,i}$. This sound power has to be distributed between a finite number of sources. If the train is very long, only parts will contribute to the maximum sound pressure level at short distances. In practice, the sound power distribution, and the selection of number of sources, can be done in many ways. To only account for the relevant part of the train, we define the length $l_p = \min(l, 15 \cdot d)$, where l is the train length, and d the distance from the loudest part of the train to the receiver. The sound power level relevant for the maximum level of this train is then given in [10] as:

$$L_W = L_{W',eq,T,dir,i} + 10\lg(l_p)\ \text{dB}. \tag{11}$$

As mentioned, a train will have many noise emission points. For simplicity, these will be reduced to seven emission points distributed horizontally along the train's propagation direction: in the middle of the train and at $\pm l_p/2$, $\pm lp/4$ and $\pm lp/8$, as is done in Nord 2000 [10]. Given a train length l in meters, each sub-source will radiate with the sound power level:

$$L_{W,k} = L_W - 10\lg(7)\ \text{dB}, \tag{12}$$

where k is the position of the train along the tracks. The maximum level is then calculated from:

$$L_{max} = \max(L_{max}(k)) = \max\left(10\lg\sum_{j=1}^{J} 10^{(L_{W,j,k}-A_F(j,k))}\right), \tag{13}$$

where j is the source index of one of the $J = 14$ train sources distributed along the train: 7 horizontal locations in two source heights. The conservative assumption of only favourable atmosphere being present when computing maximum levels is used for railway traffic as well.

As further described in Nord 2000, L_{max} is a form of average maximum because it is based on a sound power level which has been calculated from the sound exposure level, which again is a time-integrated measure. In practice, it turns out that this maximum is close to time-weighting "Slow". To calculate $L_{F,max}$ ("Fast"), we have to consider local effects, such as a wheel being noisier than average, which will increase the level further. As the local effects are more pronounced close to the train, they will be distant dependant:

$$L_{F,max} = L_{max} + 3 - 2\lg\frac{d}{10}\ \text{dB}. \tag{14}$$

This is an empirical correction that accounts for variations in the train's radiation pattern. The correction is 0 dB at $d = 300$ meters distance from the center of the train, and +3 dB at 10 meters distance.

For railway traffic, it is not necessary to define a generalized variance s^2 as the one described for road traffic noise as it will be different for various trains, different rails and be affected by local screening effects. The "noisiest train" should therefore be used.

3.2.1 Calculation example

To illustrate that maximum levels can be computed for railway noise sources, using an adaptation of Cnossos-EU, a calculation example has been performed for railway noise as well. The railway example uses the same setup as described for road traffic, see section 3.1.1. In this example, the train has a length of 100 meters, and the train's ten first meters is modelled as a locomotive. The locomotive is given a 10 dB higher noise level compared to the rest of the train.

As one can observe from the results in Figure 6, the sound pressure level for both $L_{A,max}$ and $L_{A,eq,24h}$ is decreasing as a function of distance. Compared to the road traffic results, the maximum sound level from the train acts more like a line source than a point source. The effect of the noise barrier is clearly noticeable as the sound pressure drops immediately after the barrier.

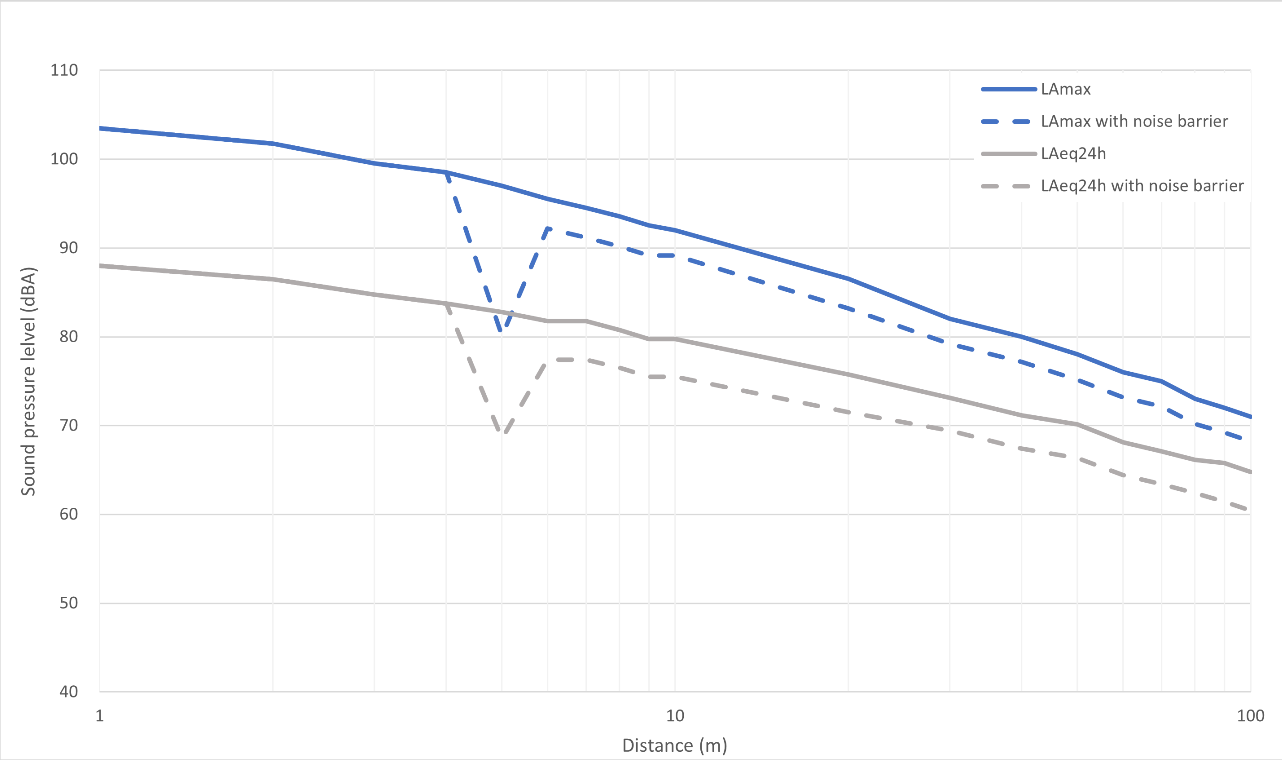

Figure 6: The 10 first meters is simulated to be a locomotive. The source height is 0.5 m, and the receiver height is 4 m. Ground condition soft surface has been used. In this example, a 2 m high noise barrier placed 4.5 meters from the roadside has been implemented. The train speed is set to 120 km/h, and 4000 passes in 24 hours has been used. The train Sound power level is set to 100 dB, and the frequency spectrum was found in HB 47 [11]

.

3.3 Industrial noise

The industrial sources are very often of variable character and variable dimensions. Both large industrial plants and small concentrated sources will fall in this category. Generalizations such as those made for rail- and road traffic sources are, therefore, not possible. Therefore, it is necessary to use an appropriate modelling technique for the unique source in question to find a representative source value. Such a technique will typically include a simple source being modelled as one point source and complex sources to be modelled as a combination of point sources. To quantify the source strength and the source strength variation, measurements must be performed. Cnossos-EU describes the general rules that should be applied when defining the number of point sources to use [1].

3.3.1 Calculation example

The industry source is modeled as a fixed point source 1.5 meters over the terrain. The receivers are placed in 1.5 meter height on a straight line from 1 to 100 meters. 4.5 meter from the source there is a 2 meter high noise barrier.

The results from the calculation are shown in Figure 7.

As one can observe, the sound pressure level is decreasing with approximately 6 dB per doubling of distance. For larger distances, the air absorption will also contribute to increasing attenuation. The effect of the noise barrier is clearly noticeable as the sound pressure drops immediately after the barrier.

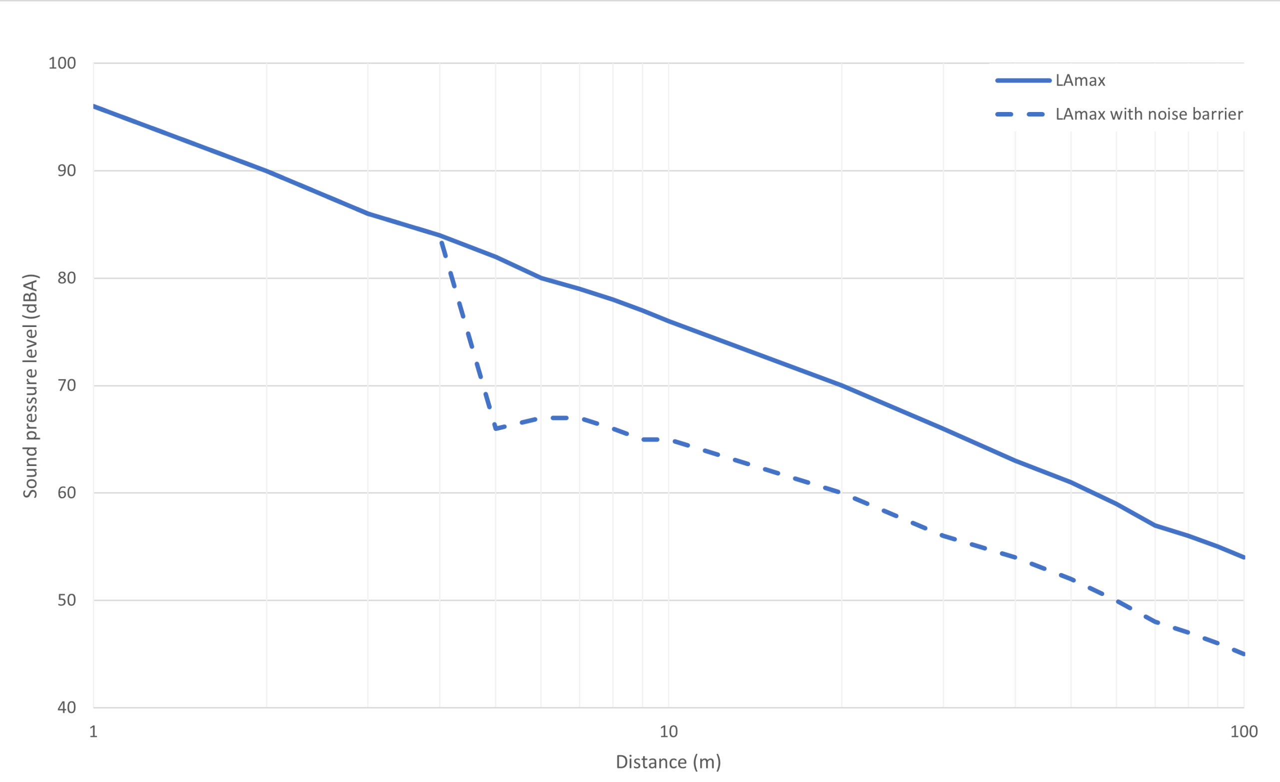

Figure 7: Calculation results from industry source. Source height: 1.5 m, receiver height 1,5 m, ground conditions soft surface. Sound power level 100 dB with flat spectrum.

3.4 Noise from light firearms

Light firearms are not mentioned in the official Cnossos-EU methodology and there is, therefore, no guidelines on how noise from these should be described or modelled. Of the sources mentioned in Cnossos-EU, light firearms have the most in common with industrial noise sources. The biggest difference between these sources are that for light firearms, the duration of each event (each shot) is so short that the source strength not is given in sound effect L_w, but rather in *Sound Exposure Level* denoted L_E or SEL. Under the assumption that a shot is completed within 125 ms, the maximum level is given as:

$$L_{F,max} = L_E + 10\lg\left(\frac{1000}{125}\right), \tag{15}$$

where 1000 and 125 are the reference times from L_E and the time constant "Fast" respectively. In this context, L_E is the level from one shot with the noisiest firearm of the relevant category. As for industrial noise and railway traffic, no general standard deviation can be defined. In general one can assume that L_E is constant for each weapon type and that the level is based on measurements. For each weapon type, the standard deviation can be assumed to be zero.

When computing maximum levels from shooting sources, it is important to account for the variance in sound propagation that can occur due to both meteorological conditions and to the extreme directivity of the source. To ensure that the levels are computed conservatively enough, favourable conditions should also be used for shooting noise.

4 Maximum level metrics used in Norway

While the equivalent value is uniquely defined, the definition of the value representing the maximum level varies between countries and between regulations within the same country. Therefore, it is necessary to give a brief overview of the different metrics used in Norway, their use and their definitions. Two different ways of calculating maximum levels for road traffic noise are suggested for the Nord 2000 prediction model. They will be adapted for the Norwegian version of the Cnossos-EU methodology for computing maximum levels for all three terrestrial sources. One approach calculates the maximum noise level as the noise level exceeded by 5% of the vehicle passings. The other calculates the maximum level as the level exceeded by more than a certain number of events. Both are described in the following two sections and are based on the assumption that the spread of maximum noise level of an individual vehicle passage is normally distributed, and use the mean maximum level and the standard deviation from a large number of measured or individual passages to arrive at a value. The procedure is comparable for industrial sources, except the standard deviation not relying on a passing source but rather the empirically measured highest noise levels. These two ways of calculating maximum levels give different results and are relevant for different parts of Norwegian legislation, as further described in the following sections.

4.1 Maximum level exceeded by 5% of events

The maximum noise level exceeded by 5% of events of a category can be determined by adding 1.65 times the standard deviation s to the arithmetic mean maximum value $L_{F,max}$ presupposing a Gaussian distribution, as shown in equation (16):

$$L_{max,5\%} = L_{5AF} = L_{p,\mathrm{AF,max,95}} = L_{F,max} + 1.65 \cdot s, \tag{16}$$

In the case of road and railway traffic, an event is a vehicle passing. In the case of road traffic, the standard deviation s is described in equations (4) to (6).

4.2 Maximum level exceeded more than a Certain Number of Times

The n^{th} highest maximum noise level $L_{AF,max,n}$ from N events during a specified time period is in the users guide to Nord 2000 [14] given as

$$L_{AF,max,n} = L_{F,max} + P\left(\frac{100 \cdot n}{N}\right) \cdot s, \tag{17}$$

where $P(x)$ is the function shown in Figure 8. This should also be used for the Cnossos-EU computations.

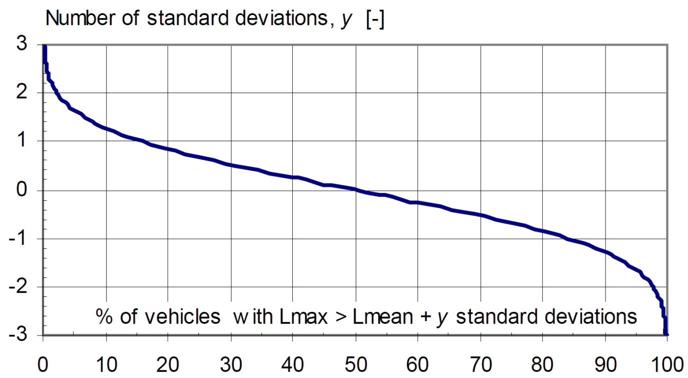

Figure 8: Percentage of single events with a maximum sound pressure level exceeding, by a certain number y of standard deviations, the (arithmetic) mean of a normal distribution of maximum sound pressure levels. The figure and figure text is taken from [14].

4.3 Indoor requirements: NS8175:2012

In Norwegian legislation, the requirements for indoor noise levels are defined in NS8175:2012. The relevant maximum levels are rendered in Table 1.

Table 1: Norwegian metrics describing the requirements to indoor noise levels according to NS 8175

Metric	Description
$L_{p,\mathrm{AF,max}}$	Average A-weighted maximum noise level in dB
$L_{p,\mathrm{AF,max,95}} = L_{5\mathrm{AF}}$	statistical maximum level as described in equation (16) in dB, A-weighted, time constant "Fast"
$L_{p,\mathrm{AS,max}} = L_{5\mathrm{AS}}$	statistical maximum level as described in equation (16) in dB, A-weighted, time constant "Slow"

In addition, NS 8175 specifies that $L_{p,\mathrm{AF,max}}$ only is valid in the case where $n \geq 10$ events in equation (17). For road traffic, the requirement for $L_{p,\mathrm{AF,max}}$ is for the $n = 10$ highest noise event.

4.4 Outdoor recommendations: T1442/2021

In Norwegian regulations, the recommendations to outdoor noise levels are given in T-1442/2021. The relevant maximum levels are rendered in Table 2. The recommendations largely overlap with the requirements described in section 4.3.

Table 2: Norwegian metrics describing the recommendations to outdoor noise levels according to T-1442/2021

Metric	Description
$L_{AF,max}$	A-weighted maximum noise level in dB with time constant "Fast"
$L_{AS,max}$	A-weighted maximum noise level in dB with time constant "Slow"
L_{5AF}	statistical maximum level as described in equation (16) in dB, A-weighted, time constant "Fast"
L_{5AS}	statistical maximum level as described in equation (16) in dB, A-weighted, time constant "Slow"

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