

Modelling techniques applied to the noise prediction of industrial noise

Antonio NOTARIO¹

¹DataKustik GmbH, Germany

ABSTRACT

There is a number of calculation methods widely used to predict the noise from industrial sources such as ISO 9613-2¹ or the recent CNOSSOS-EU² calculation method. In either case, the general problem is to decide about the input data of the relevant industry noise sources, such as emission values or directivities. This paper discusses a number of techniques oriented to tackle common challenges such as the unavailability of source's data, the use of noise measurements to determine Sound Power Levels of noise sources, strategies applied to improve existing methods or the arrangement of the acoustical model with an efficient structure, allowing the fast comparison of different scenarios.

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1. INTRODUCTION

The assessment of noise impact in the vicinity of industrial installations is an important task which normally leads to noise reduction solutions at existing sites or to different layouts at new sites. These noise reduction measures are commonly to be applied at either the noise sources or at receiver positions.

The calculations applied in this assessment make use of calculation standards such as the widely used ISO 9613-2¹ or the recent CNOSSOS-EU², developed by the European Commission. These calculation guidelines are based on the propagation calculation in octave bands, but can also be used with A-weighted levels if no spectral data are available. Regardless the used standard, one of the basic problems is to decide about the right input parameters to define the sound emission of the sources because these are input data for the calculation of sound pressure levels at receiver positions. In some cases these emission data are declared by the manufacturers, but in many cases they must be measured, taken from technical literature or even be estimated using experience from similar cases. In addition the planning of new scenarios should include measures to reduce noise which can be applied to either the receiver positions or directly to the sources. Therefore how to determine a compatible emission within a new industrial site or commercial activity is the challenge that should be addressed.

This paper presents and discusses some software⁴ based optimization techniques that can be applied to successfully optimize planning scenarios and set emission values that are compatible with the limiting values set by the regulations while the activity is restricted as less as possible.

2. CHARACTERIZATION OF INDUSTRIAL NOISE SOURCES

Industrial sources can be defined as point sources, line sources and area sources. For a point source, sound power L_W and directivity as a function of the three orthogonal coordinates (x, y, z) are needed. On the other hand, line sources can be used when the largest dimension is more than $\frac{1}{2}$ of the distance between the source and the receiver. They can be used to represent conveyor belts, pipe lines, etc. therefore the sound power per unit length $L_{W\prime}$ is used. They are also suitable to model vehicles, each associated with the sound power L_W . The sound power per unit length is then derived from the speed and number of vehicles passing by. Finally, area sources are defined by the sound power per unit area $L_{W\prime\prime}$ with a wide range of applications such the definition of multi-source industrial sites, radiating areas – such as windows, machine parts or complete radiating buildings – and industrial activity areas

¹ antonio.notario@datakustik.com

where machines or vehicles are moving randomly.

The Commission Directive 2015/996/EU² establishes the following as the complete set of input data for sound propagation calculations with the methods to be used for noise mapping:

- Emitted sound power level spectrum in octave bands
- Location (coordinates x, y) and elevation (z) of the noise source
- Dimensions and orientation
- Directivity of the source
- Working hours (day, evening, night, on a yearly averaged basis)
- Operating conditions of the source

2.1 Emitted Sound Power Level

With regards to the emitted sound power level, Figure 1 shows the usual assignment workflow in a noise mapping project:

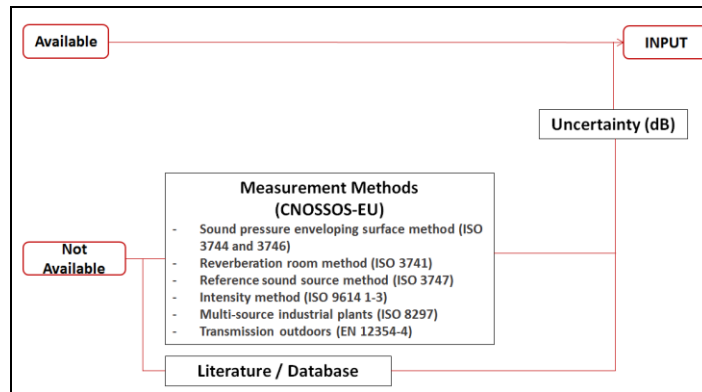


Figure 1 – Input of sound power levels depending on the source of information

The source of data where emission values are obtained from is a key aspect for success and unfortunately depends on the case. Within industrial projects such as power plants or oil platforms, where the industrial company sets the technical requirements for the equipment, the collection of emission data can be easier as manufacturers are asked to declare the emission values of their machinery. Unfortunately this is not the case within noise mapping projects, where more types of sources – such as roads or railways – are present and therefore industrial sites are only a small part of the overall emission. In such cases the use of predefined databases is the usual procedure. CNOSSOS-EU² provides a general database of sound power levels for a variety of industrial devices and machines as shown in Figure 2.

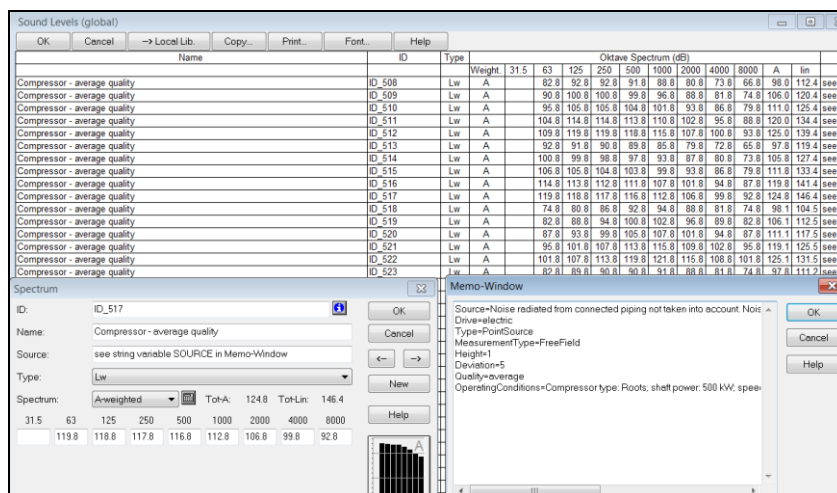


Figure 2 – CNOSSOS-EU² Sound Power Database. The memo window shows the measurement type, height, operating conditions and standard deviation (uncertainty) of the source

2.2 Correction for working hours

The working hours are an essential input for the calculation of noise levels. The working hours shall be given for the day, evening and night period and, if the propagation is using different meteorological classes defined during each of the day, night and evening periods, then a finer distribution of the working hours shall be given in sub-periods matching the distribution of meteorological classes. This information shall be based on a yearly average.

The correction for the working hours, to be added to the source sound power to define the corrected sound power that shall be used for calculations over each time period, C_w in dB is calculated as follows:

$$C_w = 10 \lg \left(\frac{T}{T_0} \right) \quad (1)$$

Where

T: active source time per period based on a yearly averaged situation, in hours

T₀: reference period expressed in hours (day: 12 hours, evening: 4 hours, night: 8 hours)

The correction for working hours has been conveniently implemented in the CadnaA⁴ prediction software by means of the use of diurnal patterns:

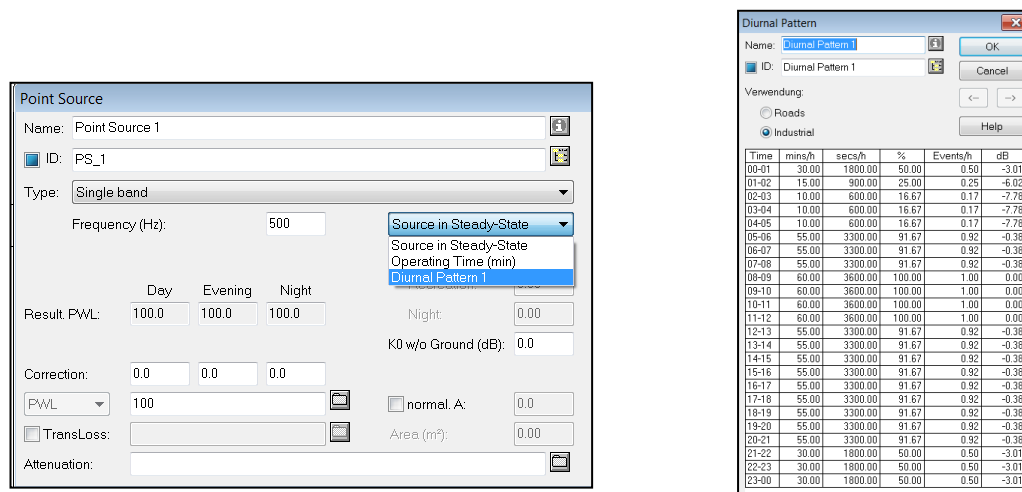


Figure 3 – (Right) Diurnal pattern defined for an industrial machine | (Left) selection in the edit dialog of a point source

The diurnal pattern dialog can be edited by the input of the working minutes (or seconds) per hour, the percentage of time the machine is active, the number of events per hour or the final correction in dB. After a diurnal pattern has been addressed to a source, the additional parameter L_{1hMax} (loudest hourly level per time period D, E, N) can be calculated.

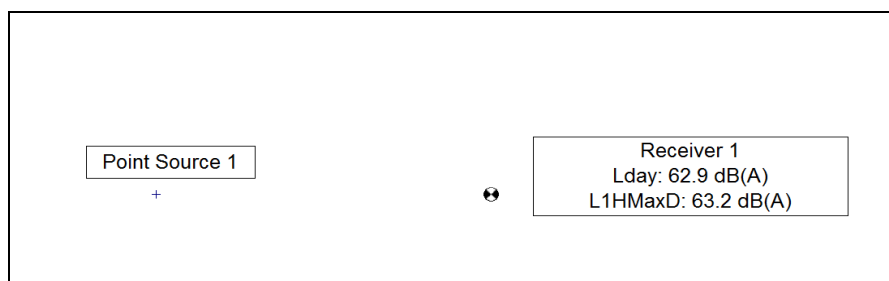


Figure 4 – Calculation of the L_{day} and the loudest hourly level for the day period

2.3 Location, dimensions, Orientation and Directivity

The dimension of the industrial sources can be very variable. They can be large industrial plants as well as small concentrated sources like small tools or operating machines used in factories. Therefore,

it is necessary to use an appropriate modelling technique for the specific source under assessment.

In practice, the calculation of the noise effect is always based on point sources, but several point sources can be used to represent a real complex source, which mainly extends over a line or an area. These sources are known as equivalent sound sources where sum of their assigned sound power level corresponds to the total sound power level of the source. According to the Directive 2015/996² the position of the partial sources cannot be fixed due to the large number of different configurations that an industrial site can have. As far as all the calculation methods used in noise mapping projects are based on ray tracing techniques, a key factor is to obtain a sufficient high resolution to see the gaps between obstacles like buildings, barriers or even terrain. Figure 5 shows the application of a specific technique called projection implemented in a noise mapping software⁴ which avoids limitations caused by the ray tracing method.

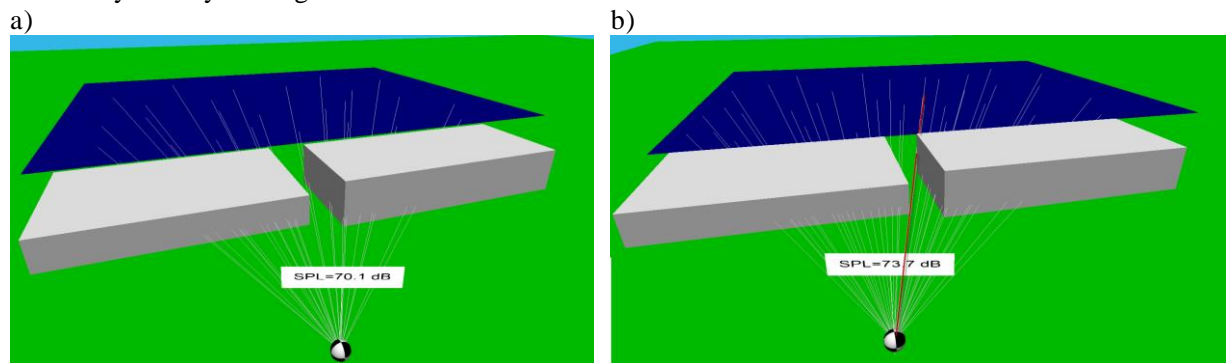


Figure 5 – Sound Pressure Level at the receiver point calculated a) without projection and b) with projection

The application of the projection at extended sources occurs as follows: the area source is first subdivided in screened and unshielded parts by projecting the objects to the source as they are seen from the receiver. The energy of each subpart is then attached to a relevant ray which can also be screened (grey color) or unshielded (red color). This produces the exact energy contribution of the partially screened source at the receiver location. As far as the number of calculation rays and therefore the calculation time explodes with increasing number of objects between receiver and source the projection technique should be applied in those cases where the level difference at the receiver points are expected to be relevant.

Directivity and orientation are also essential parameters in the characterization of industrial sources. Figure 6 shows the level difference at the receiver points between a point source with directivity but different orientation:

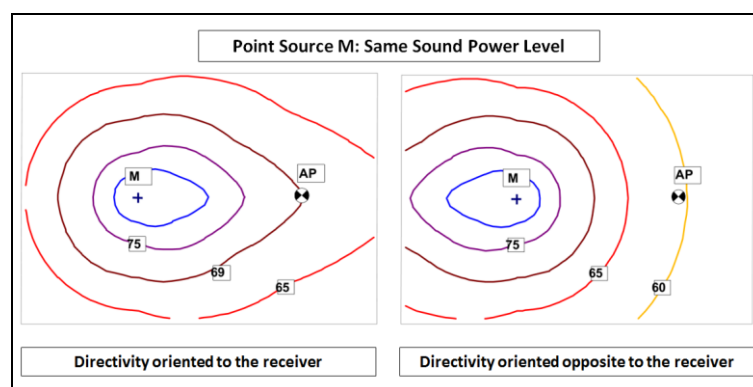


Figure 6 – Sound Pressure Level distribution difference between a directive source (left) oriented to the receiver and (right) oriented opposite to the receiver

It has been demonstrated that the accuracy of a noise map not only depends on the sound power level spectra but also on the correct set of essential input parameters. When those parameters are not available the preferred approach in order to collect data is to perform measurements at the source. In general default input values or assumptions should not be accepted unless collection of real data is associated with disproportionately high costs.

3. OPTIMIZATION OF THE NOISE EMISSION FOR NOISE PLANNING

In case that valid input data sets are available to describe the noise sources which are present in a noise model these are usually applied to obtain the noise map of the current situation. On the other hand, the European Directive 2002/49/EC³ considers the noise mapping as a basis for the adoption of future action plans to preventing and reducing environmental noise and to preserving environmental noise quality where it is good. Therefore, future predictions must include measures to reduce noise which have been planned and approved. These can be applied either to receiver positions or directly to the sources provided the limiting values defined in the regulations are not exceeded. If the noise values are already above the limiting values even in the current scenario then the quality target should be meeting that limiting value.

In any case, there are situations where this task is extremely difficult. For example, new expected industrial or commercial activities that are planned into areas where the limiting values are already exceeded by road noise shall be resized to assure that the regulations are fulfilled while the activity is restricted as less as possible - and therefore it would be still profitable -. Additional techniques are then required to optimize the emission of the new activities from both the acoustical and financial point of view.

3.1 Noise Optimization of Area Sources

The optimization of new activities can be a tedious task due to the fact that usually neither sound power levels nor further information about the new setup is available. For example the prediction for a new power plant site is easier than an industrial or commercial area where a number of trucks and moving machines are working. In most of these cases the overall sound power level of the new activity is unknown.

A procedure to calculate the sound power level is used in prediction software⁴ to calibrate area sources of which the pressure level at different receiver points is known or has been measured while the sound power level L_w or the sound power level per unit area is unknown. This way, even situations with several area sources and receiver points can be handled by applying an optimization strategy defined by the user. The procedure makes use of a special area source – so-called optimizable area source – which is segmented into sub areas in the same way as with the general area source, taking into account both receiver distances and screening objects. As normally these area sources include screening objects inside – such as industry buildings or chimneys – the screening effect of these can be deactivated with regards to the source's own emission. This allows the area source to be considered as a unique source with an overall emission that will be included into the new situation together with other types of sources such as road, railway or even aircraft.

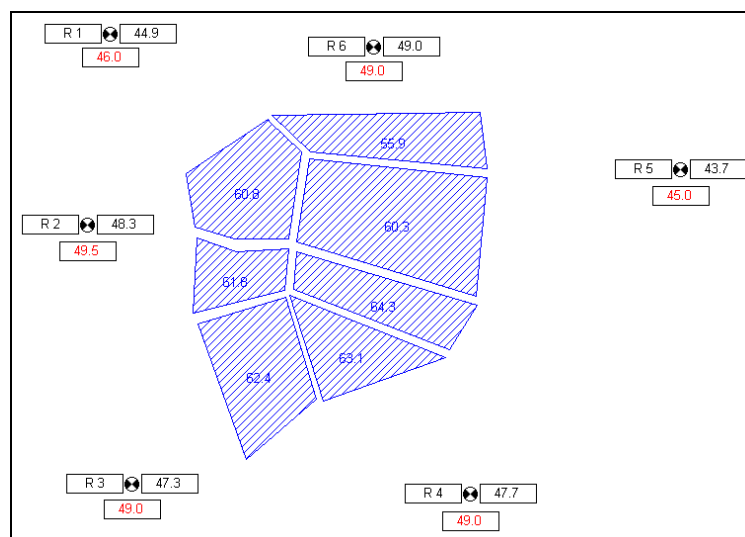


Figure 7 – Optimization of a new industrial activity consisting of seven area sources

Figure 7 shows a simple optimization example. The new activity has been divided into seven optimizable area sources. Receiver points represent critical positions where the sound pressure level must be respected (red color). The automatic optimization procedure assigns a sound power level value

to each source in such a way that the calculated levels at receiver points are lower than the limiting values.

3.2 Maximization of the noise emission of areas with planned new activities

Unlike the pure acoustical point of view the planning of new activities deals with additional requirements such as the financial and profitability aspects. Many national noise laws and regulations consider these when action plans are to be defined and therefore the optimization techniques implemented into noise prediction software should consider them as well so the sound radiating from different area sources should be optimized in such a way that:

- The limiting values at all receiver points are not exceeded.
- The intended use of the individual areas is not restricted as far as possible.

This optimization strategy is known as "Fixing of Noise Quota" and it is supported by use of a flexible usability function.

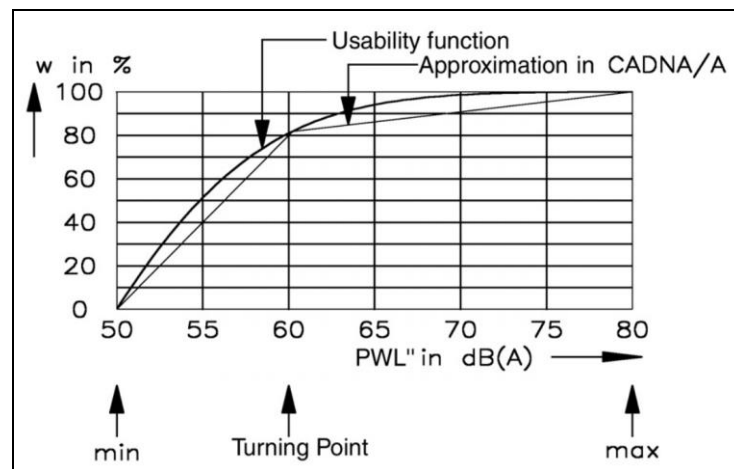


Figure 8 – Usability Function

Figure 8 shows the usability function which is assigned to each area source. The usability function assigns a usability value $w\%$ to any sound power level per unit area. The continuous shape of the usability function is approximated in the software⁶ by two straight lines and a **turning point**. To the right of the turning point, the decreasing slope of the function with increasing sound power level means that a further increase in emission cannot be exploited due to the intended use. On the other hand, to the left of the turning point, the usability decreases excessively when a particular emission required for the intended use is further reduced.

All the relevant values for the definition of the usability function are available within the optimizable source's edit dialog:

- The sound power level at the turning point is the emission value where the gradient of the usability function changes. A slight reduction of the sound power level below the turning point results in a stronger reduction in usability than the same reduction above the turning point.
- The value of usability K (%) at the turning point which represents the value below which a further reduction of the sound power level implies a strong reduction of the profitability of the activity.
- The minimum sound power level required by the activity which is determined based on the noise processes which are absolutely necessary to support the intended activity.
- The maximum exploitable sound power level by the activity which depends on the branch of industry or activity.

Figure 9 shows an application example of a new activity to be planned into a mixed situation of sources and where the application of an arbitrary sound power level of 75 dB makes the sound pressure level at critical receivers exceed the noise limits fixed by the regulation.

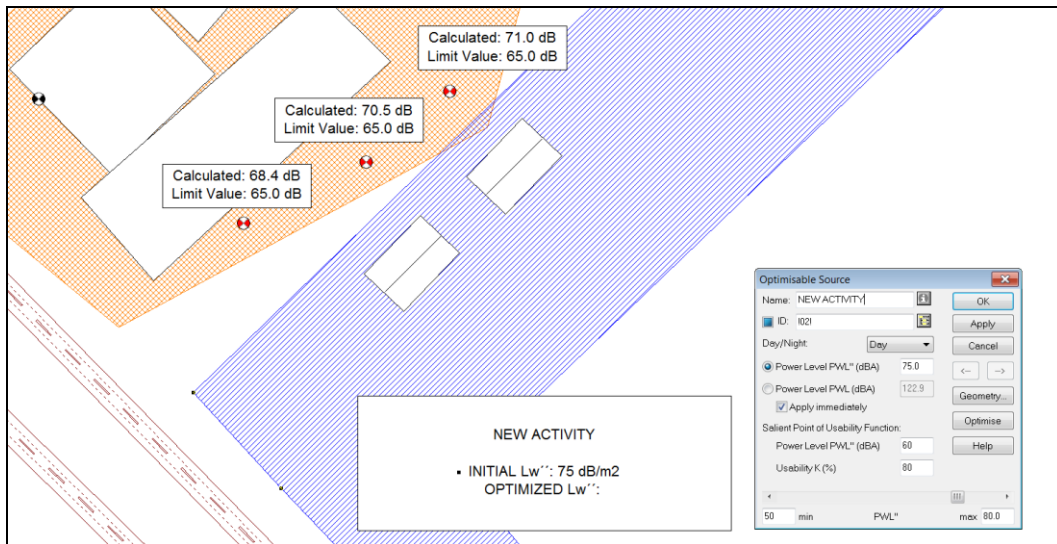


Figure 9 – New activity area defined by an optimizable source before the maximization. The edit dialog allows the definition of the usability function

After the definition of the usability function with the required parameters the automatic maximization of the sound power level can be achieved. Figure 10 shows that the sound power level per unit area dropped from $L_{w''} = 75$ dB to $L_{w''} = 68,9$ dB and the limits are now respected at all critical receiver points.

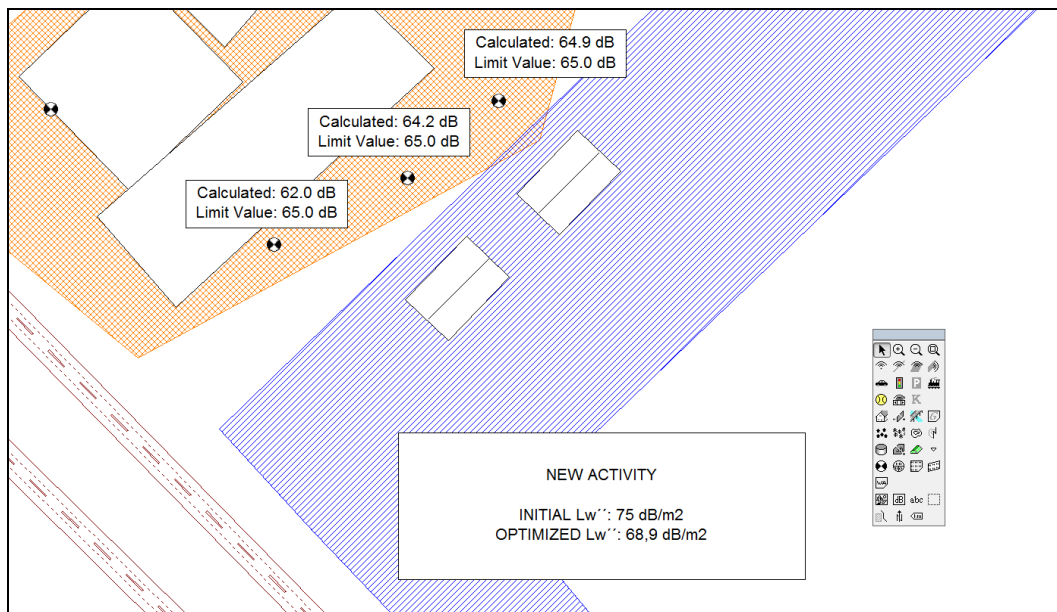


Figure 10 – Maximized sound power level for the new activity.

4. SUMMARY

The seamless implementation of input modes for the essential sets of data into commercial prediction software as well as the use of advanced techniques such as the projection at extended sources prove to improve the quality of the input data while reducing the deviations caused by the ray tracing calculation procedures. During the planning stage where the overall emissions of new industrial sources are unknown, optimization strategies by using prediction software are extremely helpful tools in situations where not only the acoustical, but other targets such as profitability, are pursued.

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