COMPUTATIONAL MAPPING OF THE SOUND PRESSURE LEVELS: TOOL FOR NOISE ASSESSMENT IN INDUSTRIAL ENVIRONMENT

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Abstract. *The objective of this work is to develop a methodology for noise propagation analysis, using computational mapping concerned to the distribution of the sound pressure levels existent in industrial environments, in order to recognize graphically areas with major or minor contribution to the external noise pollution. Some metal-mechanic industries were chosen for this work, all of them located in the northeast region of the Rio Grande do Sul State in Brazil, where measurements of the sound pressure levels were realized in different points of two rings around the industries, known as recevivers. These measurements were placed in a commercial program in order to discover through manual assessment the main sound sources. Adopting this methodology makes possible to predict patterns of intensity and noise distribution near to a industrial environment, in order to develop control measures for noise reduction and satisfying the current noise legislation.*

Keywords*: Noise, Noise Pollution, Industrial Acoustic.*

1. INTRODUCTION

The sound is forms of energy emitted by a vibrant body that when spreading through a half reaches the ear and cause the sensation of the audition. The limits of frequency in human ear are 20 Hz to 20000 Hz. The noise problem consists of three interrelated elements: the source, the receiver and the transmission path.

According to Attenborough (2007), the propagation of the sound in external areas involves dispersion, absorption of the air, interaction with the soil, barriers, vegetation, refraction associated with the wind and temperature gradients.

Several programs are industrially used for evaluation of the noise propagation, an special program is Sound PLAN essential, whose objective is evaluate the noise emitted in industrial's sources, analyzing the influences on receiver changing the propagation conditions. The data uses some norms that are selected by the user and the results are presented in tables and in graphics, (Sound PLAN LLC, 2006).

Lan and Chiu (2008) use the technique of genetic algorithms (GA) together with the method of square minima in numerical optimization to identify the sources. The results of mathematical model present appropriate agreement with obtained by the program Sound PLAN essential. The results reveal that the location of the resonant sources can be conveniently recovered.

In the research developed by Hodgson (2003), the correspondence of empiric models is evaluated for the continuous noise levels prevision and reverberation times in home machines in typical industries.

Noisy machines are the main cause of noise exposure to the workers in industrial rooms, where the characteristics acoustics are appraised usually by the sound pressure level (SPL).

The direction evaluation of those resonant sources can help in solutions for the reduction of the noise. Chatillon (2007).

The noise produced by most of the sources in a city, such as vehicles and factories, can be periodic or not. The noise levels quantification is necessary in the resonant pollution control. The measurements of the noise levels make possible the accomplishment of impact conditions analyses produced by the noise, allowing control.

The Brazilian Association of Technical standards (ABNT) published several norms ABNT NBR, for sampling and analysis of the resonant pollution, to define guidelines for the control of noise in industrial sources.

The combination of techniques to control the noise depends on the extension of the reduction of requested noise, interest frequencies, and the nature of the equipments and the economical aspects of available techniques.

The employed techniques for the noise control focus the control of the source, the control of the transmission path or the use of the protection equipment.

The Brazilian norm ABNT NBR 10151 (2004) regulates maximum noise levels in industrial areas to 70 dBA during the day and 60 dBA in night.

In this article, the main objective of the work is to evaluate computationally the propagation of industrial noise.

2. PROPAGATION MODELING OF THE INDUSTRIAL NOISE

The noise can be emitted of several sources with data and private descriptions. Usually, the industrial noise needs experimental data. Numerically, the source type determines the geometry type to be used. A punctual source needs a coordinate; a lineal source is defined at least with two coordinates, while a plane source requests at least three coordinates.

The Sound PLAN essential is software of simulation of resonant propagation and dispersion of pollutant. It allows to modeling internal and external atmospheres, such as factories, highways, railroads and airports. Still allows the optimization of acoustic barriers, to generate maps of acoustic impact, dispersion of pollutant and comparative maps that can be used to evaluate the individual impact of each pollutant source in a certain area.

As noise maps are created from discrete receivers, it is important to describe the noise level calculation process for single receivers. As noise sources are independent, they can be calculated separately. Results of all source contributions can be expressed as the sum of imission levels with Eq. (1)

$$L_{i\ soma} = 10\log\left(\sum 10^{\frac{L_i}{10}}\right) \quad (1)$$

with

$L_{i,\text{sum}}$ resultant of immision levels at the receiver, [dB],

L_i immision level of a source i at the receiver, [dB].

The single source contribution at the receiver can be derived from its sound power and the propagation by Eq (2),

$$L_i = L_w - C_1 - C_2 - \ldots - C_n \quad (2)$$

with,

L_w sound power, [dB],

$C_1 \ldots C_n$ coefficients relative to propagation (spreading, air absorption, screening, ground effect, reflection).

There are three principal standards for calculations of frequency dependent industrial noise. The ÖAL 28 is similar with the Nordic General Prediction Method for Industrial Plants. The ISO 9613 Part 2 is identical with the German VDI 2714 / VDI 2720. Finally, the Hong Kong Construction regulation is identical to the ISO 9613, but ignores the air absorption and the ground attenuation.

The Nordic and the CONCAWE methods assume all calculations are based on octave bands. However, the ISO method does not supply different formulas for different frequencies and can be used for any frequency.

The ISO 9613 is a general purpose Standard for outdoor noise propagation. Its main differential is to supply a reliable standard easy to use where the formulas can produce smooth curves.

The sound pressure at the receiver L_{eq} is the sum of all contributing frequencies. The sound pressure for a single frequency is calculated by Eq. (3).

$$L_s = (L_w + D_I + K_0) - (D_s + \Sigma D) \quad (3)$$

with,

L_s sound pressure for a single frequency, [dB],

L_w sound power, [dB],

D_I directivity of the source,

D_s spreading,

ΣD contributing factors (air absorption, ground absorption, volume absorption, screening, meteorological effects),

K_0 spherical model, defined by the spatial angle Ω, through $K_0 = 10\log(4\pi/\Omega)$ dB.

3. EXTERNAL NOISE PROPAGATION OF THE PLANT 1

The objective of this section is the evaluation of the industrial noise propagation in the external environment in a sector metal mechanics typical plant, in order to consider alternatives for the noise control.

3.1. Experimental procedure

Two audiosimeters had been simultaneously used in each receiver: one to measure the sound pressure level in the A balance curve (continuous noise), and other to measure the sound pressure level in the C balance curve (impact noise).

In the experimental measure carried through with the measurement instrument, when programmed to measure the sound levels pressure in A scale, it identifies the continuous noise, whereas, when programmed to measure sound pressure levels in the C scale, it indentifies the impact noise.

The experimental evaluated places were the external areas of the plant located at industrial zone of the Caxias do Sul city. To the industrial zones, o maximum noise level emission is 70 dB at daylight, measured in the A or C curves, and 60 dB at nocturnal period, measured in the A or C curves.

The locals of measure are understood by two rings of receiving points. The first is decided in the perimeter that it skirtes the external walls of the plant, to a distance of 1 meter and height of 1,2 meter of the ground. The same it occurs for the measure second ring, located in the perimeters that it skirtes the external walls of the evaluated plants. The amount of the measurement points change in accordance to the perimeters dimensions of the each plant, keeping only the distances between measurements of the 10 meters, in the maximum.

In relation to the noise levels measurement is distinguished adoption of the follow considerations:

a) use of sound level meter of type II;
b) air velocity lower than 5,0 m/s and temperature of the air between -10 e +30 ºC;
c) deep noise lower at least 10 dB in relation to the experimental measures levels;
d) measurements of the sound level pressure considering L_{eq};
e) acquisition programming of data in the measurement instrument of SLP to each 5 seconds in a total period of the 3 minutes in each point of evaluation, getting the resultant L_{eq} of 36 instantaneous measurements.

3.2. Computacional methodology

The experimental measurement in the limits that is skirted the external walls of the plants in external environment can be incorporating other sources of the sound emission, from neighboring plants, streets, etc. When more distant the mensure perimeter it will be of the source, more chances of capture the influence of the external sources.

Comparing the results of the experimental measurements in the limits of the plant perimeter with the gotten ones from the computational simulation, allow the attainment of an error, associated with the participation of the external sources to the plant.

The values of the experimental measurements of twos receptor rings can be inserted in CAD 2D or 3D programs, with the existing relief conditions e consideration the neighboring constructions of interest, and soon exported to the SoundPLAN essential program environment, where add relatives data to the emission condition and propagation, ground, natural barriers, etc.

As the sonorous sources are multiple inside of the plant, come close the same as point sources at external walls, in all the perimeter of the construction.

Assumed in the work that the number of point sources of the simulation is same of the number of receiving points, located in the first ring. Each receiver is associated with the emission point source located in the same quota of height, in the frontal position to the receiver and the 1 meter of distance of the same.

As the sound pressure level of the sources are Unknown, initially regulates one determined value for a source, the same that is calibrated by sound pressure levels of the respective receiver. As first approach, for each point source can be attributed the same experimental value of the sound pressure level of the respective frontal receiver. This calibration is reviewed successively with the adjacent sources participation, until the values of the simulation in the first ring receivers successively approach to the experimental values, inside of a tolerable edge of up 1,0 dBA ou dBC.

Observed that the measurements in the second ring are carried through in this work for attainment of the contribution of sources in the sound pressure levels, for the difference of the experimental value or error in relation to the computational result.

3.3. External noise propagation of the Plant 1

The work activities are executed in the daylights and nocturnal, distributed in work turns that cover 24 hours of daily production. The work environments are distributed in a main construction, destined to the production and an adjacent construction destined to the administration and services.

The production sectors are located in a ground pavilion, constructed in masonry, with right foot of 13 meters. It possess floor in polishing concrete, painted and roof with covering and metallic structure. The disposal of the sectors is opened form, without fixed walls.

The administrative sectors are located in ground construction to the side of the main construction, with right foot of approximately 4 meters, constructed of masonry with coated floor and roof.

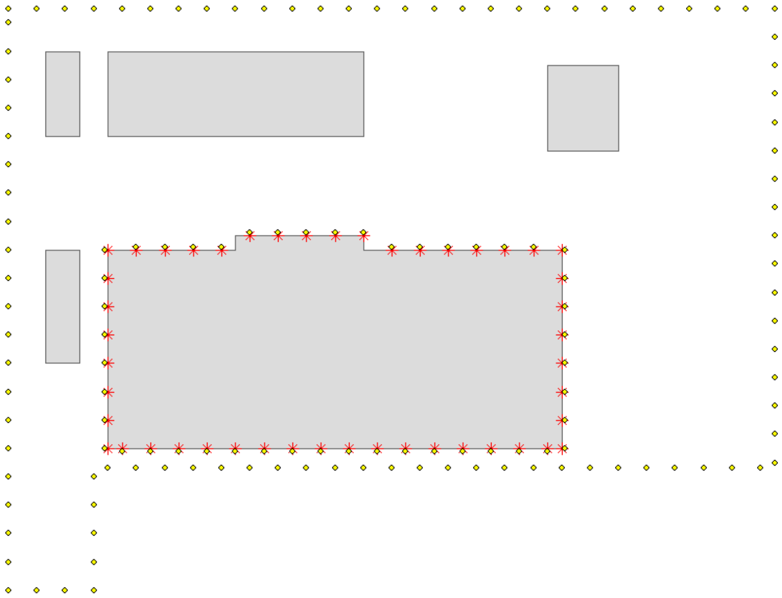

Figure 1. Internal and external rings of receiving points in the plant 1

3.3.1. Experimental measurement of the Plant 1

From experimental measurements of the sound level pressures for the external environment, is intended to determinate if the noise produced for the plant would be inside of the emission limits. On the bases of the gotten results could be adopted, or not, measured them of containment and control of noise.

The SLP values had been collected in 143 receiving points, distributed in two experimental measurements rings. As it shows Figure 1, the first receiving ring possesses 47 points. Whereas the second receiving ring possesses 96 points.

The Table 1 show the measurements of continuous and impact noise in the daylight and nocturnal, measured in the receiving points of external and internal rings.

Table 1. Experimental noise measurements in the Factory 1.

Internal ring	SPL day shift		SPL night shift		External ring	SPL day shift		SPL night shift	
	dBA	dBC	dBA	dBC		dBA	dBC	dBA	dBC
1	63,4	63,8	63,2	66,5	48	48,1	68,5	61,2	61,2
2	60,1	61,5	58,2	60,2	49	54,5	70,1	59,3	62,8
3	62,0	60,3	63,1	60,8	50	55,2	66,5	58,5	64
4	65,7	58,6	60,1	61,3	51	50,6	68,4	60,1	63,5
5	65,0	62,3	65,8	62,8	52	52,7	71,8	58,5	61,8
6	64,8	62,1	72,9	61,5	53	56,1	69,0	60,1	60,4
…	…	…	…	…	…	…	…	…	…
38	86,8	86,3	88,5	83,9	85	52,9	57,2	54,1	61,3
39	87,1	85,9	90,4	85,2	86	52,5	57,9	50,9	60,5
46	70,0	68,5	75,3	75,1	93	53,0	62,8	56,3	65,1
…	…	…	…	…	…	…	…	…	…
47	70,1	68,0	71,1	73,0	94	54,9	63,4	57,8	64,4
					95	55,3	65,6	58,1	65,3
					96	56,2	58,7	60,3	61
…	…	…	…	…	…	…	…	…	…
					142	56,2	58,2	55,0	58
					143	56,8	60,1	56,4	59,3

Day limit dBA=dBC=70, night limit dBA=dBC=60

3.3.2. Computacional avaliation of the noise propagation in the plant

The square where the plant is located is classified as Industrial Zone. This means that the noise emission limits are limited the 70dBA, or dBC, for the daylight and 60 dBA, or dBC, for the nocturnal.

On the Table 2 are indicated in two groups, the values of the SPL of gotten receivers of experimental and computational forms.

Table 2. SPL of the internal ring in the Factory.

	Case 1 - experimental measurements					Case 1 – computational results			
Internal	Continue		Impact		Internal	Continue		Impact	
ring	Day	Night	Day	Night	ring	Day	Night	Day	Night
1	63,4	63,8	63,2	66,5	1	63,6	64,5	64,8	66,8
2	60,1	61,5	58,2	60,2	2	60,2	61,7	58,8	60,5
3	62,0	60,3	63,1	60,8	3	62,1	59,9	63,2	61,0
4	65,7	58,6	60,1	61,3	4	65,7	58,6	60,4	61,3
…	…	…	…	…	…	…	…	…	…
44	81,1	75,0	84,1	82,9	44	81,1	75,0	84,0	82,9
45	78,3	75,0	81,7	78,7	45	78,3	75,0	81,7	78,8
46	70,0	68,5	75,3	75,1	46	70,6	68,5	75,5	75,1
47	70,1	68,0	71,1	73,0	47	70,0	68,0	71,3	73,0

Table 3 presents the errors gotten in the internal ring for comparison of the computational values in relation to the experimental values for the first receivers ring, where the more near to zero, better is the calibration of the adopted model.

Table 3. Calibration of the SPL of internal ring in the plant.

	Case 1 – error of SPL in the internal ring			
	Continuous		Impact	
Internal ring	Daylight	Nocturnal	Daylight	Nocturnal
1	0,2	0,7	1,6	0,3
2	0,1	0,2	0,6	0,3
3	0,1	-0,4	0,1	0,2
4	0,0	0,0	0,3	0,0
…	…	…	…	…
44	0,0	0,0	-0,1	0,0
45	0,0	0,0	0,0	0,1
46	0,6	0,0	0,2	0,0
47	-0,1	0,0	0,2	0,0

A time calibrated, the values of the first receivers ring simulation, obtain the results of SPL of the simulation of second receivers ring, Table 4.

Table 4. SPL values of the external ring in the Plant 1.

	Case 1 – experimental measurements					Case 1 – computational results			
External	Continue		Impact		External	Continue		Impact	
ring	Day	Night	Day	Night	ring		Day	Night	Day
48	65,3	64,1	67,1	68,1	48	62	60	63,5	64,7
49	60,5	53,2	58,5	58,8	49	52,9	52,3	54,6	55,1
50	60,0	52,9	59,0	58,3	50	53,1	51,5	54,6	53,9
51	56,2	54,2	58,9	57,2	51	53,9	49,7	54,3	52,3
…	…	…	…	…	…	…	…	…	…
140	59,8	56,3	63,7	61,1	140	55	53,1	59,1	56,6
141	65,7	59,2	64,8	62,5	141	56,2	54,4	60,2	57,9
142	71,0	62,1	66,4	64,3	142	58	56,2	61,8	59,8
143	66,9	64,3	68,7	67,6	143	61,2	59,7	64,3	63,5

Table 5 indicates the existent mistake of the experimental measurements in relation to the computational values for the second field, values that represents the influence of the external sources.

Table 5. Influence of other sources in the external field of the Plant 1.

Case 1 - error of SPL External ring				
	Continuos (dBA)		Impact (dBC)	
External ring	Day	Night	Day	Night
48	3,3	4,1	3,6	3,4
49	7,6	0,9	3,9	3,7
50	6,9	1,4	4,4	4,4
51	2,3	4,5	5	4,9
…	…	…	…	…
140	4,8	3,2	8,7	4,5
141	9,5	4,8	8,6	4,6
142	13	5,9	8,4	4,5
143	5,7	4,6	7,5	4,1

Table 6 provides the average of the existent mistake of the experimental measurements in relation to the computational values for the second field, corresponding to the influence of external sources, around 5 dB.

Table 6. Average of the influence of other sources in the external field of Plant 1.

Average error of the SPL no External ring			
Continue (dBA)		Impact (dBC)	
Day	Night	Day	Night
5,37	4,87	5,69	5,10

Table 7 presents the amount of points of SPL of the external field of Plant 1 with superior values to the emission limits. A smaller amount is observed of no conformities in the computational results, indicative that the source of Plant 1 participates in smaller degree in noise pollution if compared with the external sources.

Table 7. SPL of the external field above the emission limits in Plant 1.

	Experimental measurements					Computational results			
	Continue		External ring		Continue	External ring		Continue	
External ring	Day		Day	Noturno	Day	Day		Day	
Number of points	3	17	1	23	Number of points	0	4	0	2
%	3,1	17,9	1	24,2	%	0	4,2	0	2,1

The graphic analysis favors the visual identification of the noise propagation field and appraised the impact in the edges sources. Figure 2 presents two outline lines that delimit the area of analyzed influence of Plant 1, the interior denominated of calculation and exterior denominated of mitigation, both necessary ones for demand of the program SoundPLAN essential.

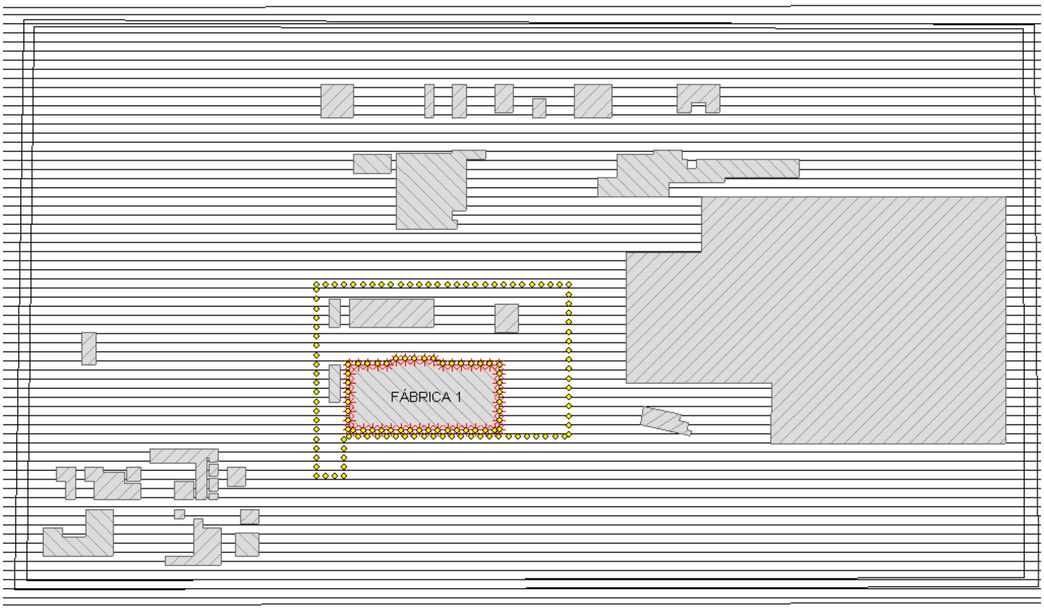

Figure 2. Area of it influences appraised of Factory 1.

In Figure 3 and Table 7 is observed that SPL of continuous noise computational measured in the shift of the day didn't exceed the limit of 70 dBA in Plant 1 external field.

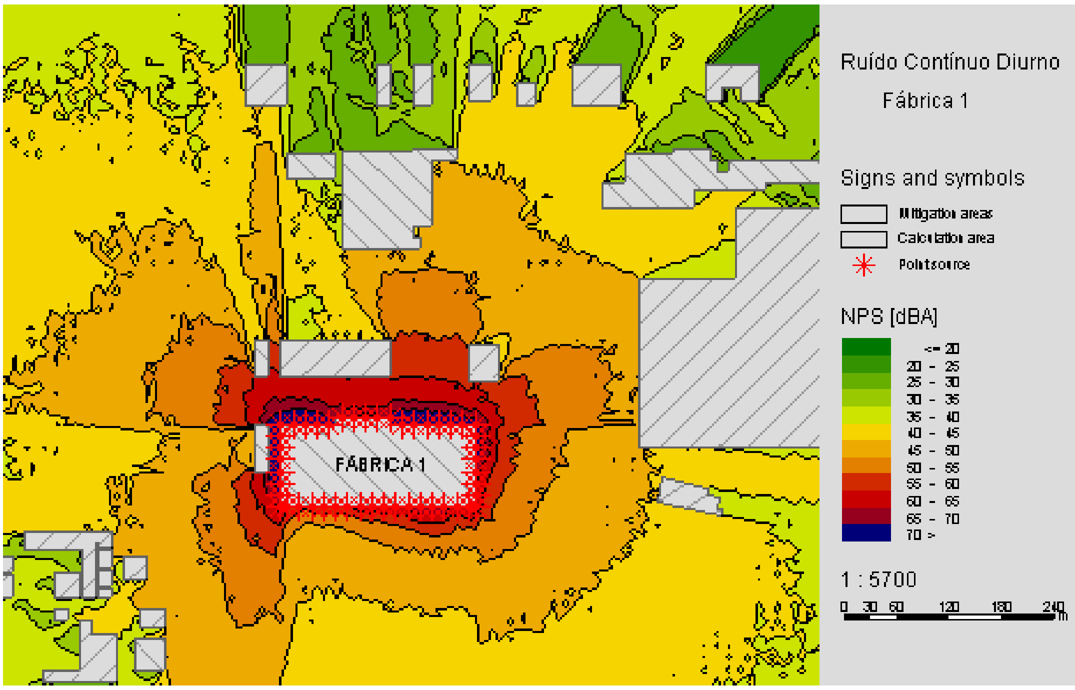

Figure 3. Propagation of the noise continues of the day of Plant 1.

In Table 7 it is observed that 4 points of the night continuous noise exceeded the emission limits. It stands out in figure 4 in blue color that the propagation field with emission levels above 60 dBA is more intense in areas where the press sections, cut and welding are installed.

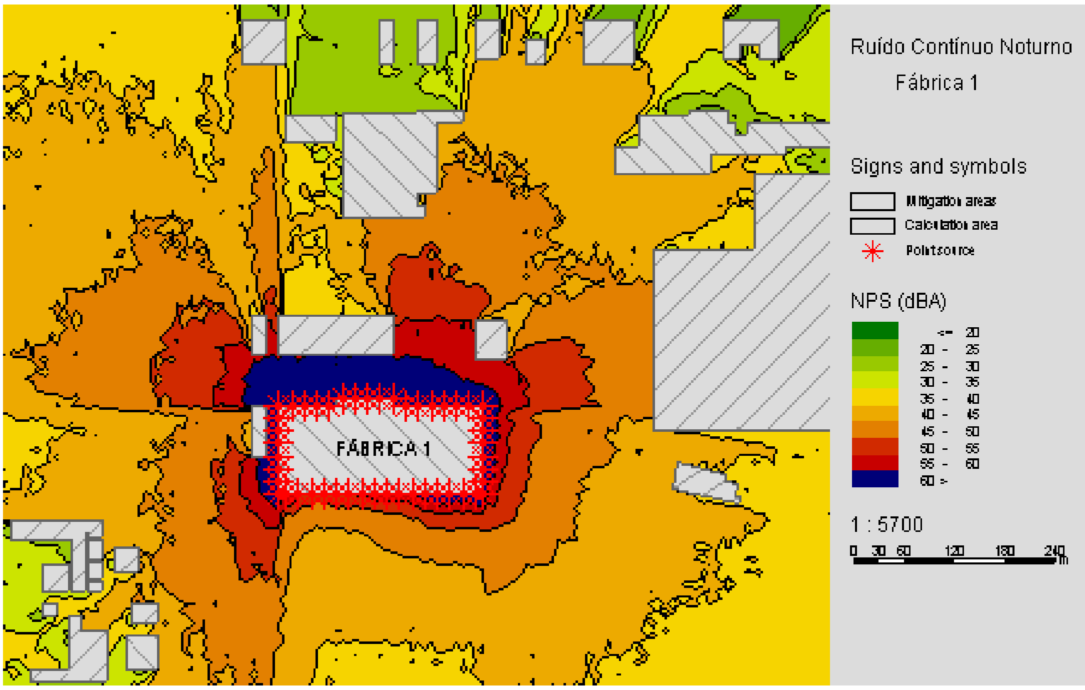

Figure 4. Propagation of the noise continues nocturnal of Plant 1.

It is observed in figure 5 that the levels of the impact noise generated in the day shift, stayed inside of the limits of emission of 70 dBC.

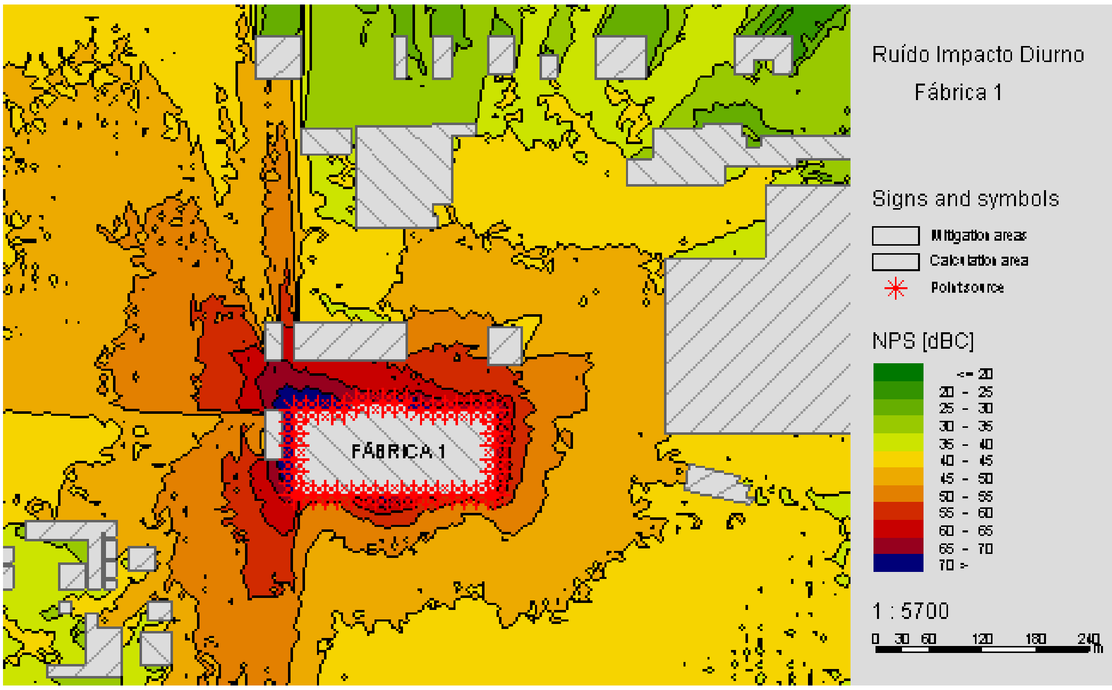

Figure 5. Propagation of the noise of impact of the day of Plant 1.

In Table 7 it observes that 2 points of the night impact noise exceeded the emission limits. It stands out in Figure 6 again in blue color that the propagation field with emission levels above 60 dBC is more intense in areas where the press sections, cut and welding are installed.

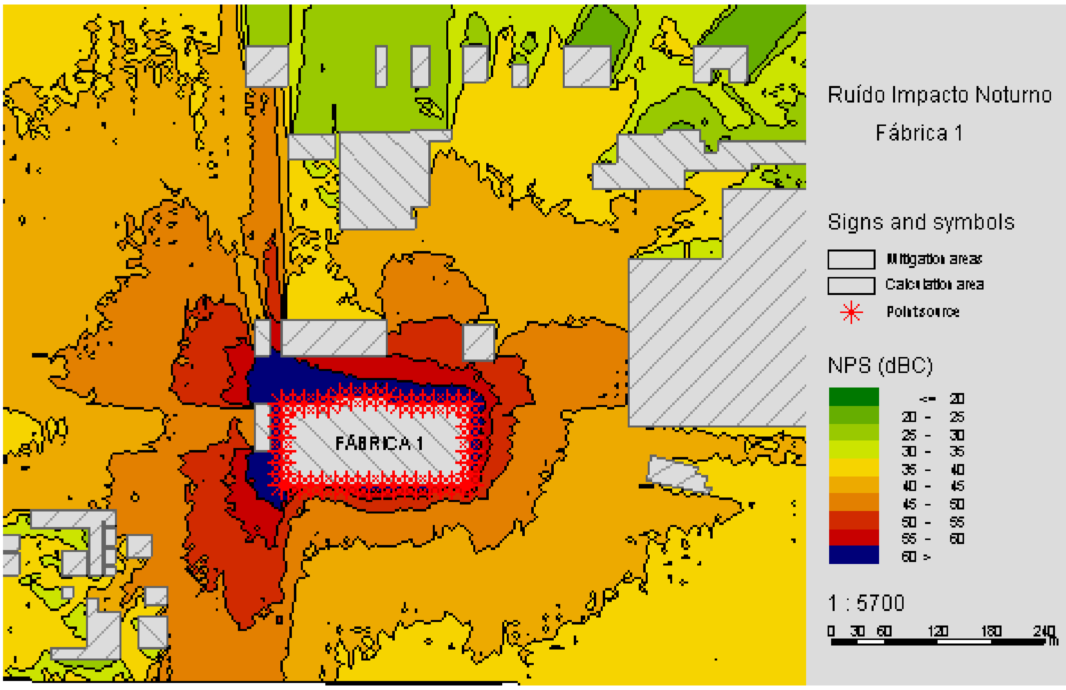

Figure 6. Propagation of the noise of night impact of Plant 1.

The results of the computational simulation allow establishing a criterion priority of actions, where the areas with larger SPL should receive larger attention and measures for it controls.

4. CONCLUSIONS

The use of the program SoundPlan essential, fed levels of sound pressure measured in the field enabled the generation of the computational propagation field of noise generated by Plants 1, 2 and 3, free of influence from external sources nearby.The comparison between the results of experimental measurements at the limits of the factories boundary with those obtained by computer simulation, allows to obtain an error, with the participation of external sources to the factory, for which it is essential to develop a methodology for computing evaluation of the propagation of sound.

5. ACKNOWLEDGEMENTS

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