The pilot noise map of São Paulo: first findings and next steps

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ABSTRACT

São Paulo is one of the largest cities in the world, with more than 12 million inhabitants, however, environmental noise management is not taken into account on the urban planning. In 2012, a joint action between the Brazilian Association for Acoustic Quality - ProAcustica and the City Council, enabled the development of a Bill, approved in 2016. The document establishes the mandatory implementation of São Paulo's noise map. Currently, the law regulation is being developed, and a pilot noise map was executed by ProAcustica aiming to support the establishment of an agenda by the city council. A crucial aspect in this process is that there are no environmental noise calculation models or standards for Brazilian cities characteristics. A pilot area was determined, and different European models were tested and compared with filed sound measurements to verify which one is closer to Brazilian traffic conditions using specific input data. The whole procedure was based on several international standards and good practice guidelines. In this article the adopted assumptions and the applied methodology for the first version of the noise map are presented, as well as the identified issues that are to be studied in the near future

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1 INTRODUCTION

The Noise Map is a diagnostic tool for the sound problems of a city. In other words, the noise map assists in the identification of silent regions and regions with excessive noise or exceeding the limits allowed by the legislation. With the proper identification of the problem, it is possible to carry out interventions more efficiently.

In addition to making the diagnosis, the noise map is a tool that allows estimations of mitigating actions, such as pavement changes, one-way flow change, changes in permitted speed limits to impact of each measure in terms of the affected population. Traffic management is one of the main actions in terms of noise mitigation in cities and in this respect, noise mapping is a very important tool.

When a city has a noise map, all people are impacted because everyone can use the noise map as a tool to visualize the noise level before renting or buying a property, for example. On a larger scale, the public bodies are the main impactors, because through this tool, they can elaborate an adequate management of the noise, and silent areas, as well as create law of use and occupation of the ground and adequate acoustic zoning.

In São Paulo, since 2014 the elaboration of the Noise Map for the city has been much discussed. The discussions took place at the Municipal Conferences on Noise, Vibration and Sound Disturbance, organized by ProAcústica in the week of the International Noise Awareness Day (INAD), for 3 consecutive years[1,2,3]. In 2016 a great leap was made with the creation of Law 16.499, Urban Noise Map[4], which instituted the obligation to implement the noise map in the municipality of São Paulo within a period of 7 years.

For this reason, in 2017 ProAcústica created the Technical Group GT Mapa de Ruído, which was important to focus efforts on this issue. The GT Mapa de Ruíso is a part of the Environmental Acoustics Committee, in which more than 15 companies participate, and more than 20 experts, 3 of whom already have experience with the implementation of noise maps in Spain and France. In less than an year, the GT members were able to establish public partnerships and carry out several studies to adequately characterize the city of São Paulo.

In several countries, the sound mapping of cities is a well developed theme such as Chile[5], France[6], Spain[7] and Portugal[8]. In Brazil, there are only some cases, e.g.: Brasilia[9], Copacabana[10], Petrópolis[11], Aracaju[12], Belém[13] and Fortaleza[14]. Just Fortaleza's map was done by public administration initiative and result in some action plans. There is still a lot of resistance due to the difficulties of drawing up the map, which will be discussed next.

The main difficulty is due the methods for simulating the propagation of environmental noise are based on the reality of other countries. In other words, the entry data in the programs consider the typology of vehicles and pavements of other countries. Currently the best known procedures are CNOSSOS, NMPB 96, NMPB 08 and RLS 90, the latter being widely used in Brazil[10,12]. Next, each methodology will be detailed considering the road traffic noise.

The Common Noise Assessment Methods in Europe (CNOSSOS-EU)[15] is a methodology created in 2012 for the development of noise maps in Europe. In this method, the vehicles are divided into 4 categories, being light vehicles, medium vehicles, heavy vehicles and two-wheeled vehicles. The speed considered in the route noise emission calculation is the average speed. Consider the effects of acceleration and deceleration when there are traffic lights and has a library with 15 different types of pavements.

The RLS 90 is a German calculation methodology dating of 1990. It was created for the elaboration of noise maps considering the reality of vehicle flow specific to the country. In this methodology, the vehicles are divided into 2 classes, being light and heavy. The speed considered in the calculation is maximum permissible by the track and does not account for changes in acceleration. The floors are differentiated into 8 types.

As in the RLS 90, NMPB standards divide vehicles into two categories, light and heavy only. The speed used is also maximum, but in this case, the accelerations and decelerations due to the presence of intersections are considered. There are two NMPBs, one of them from 1996 and the other from 2008. The first one sought to cover the European context, and the last one fixed its input data on the French reality. Even with different approaches, the difference occurred only in the pavement typology, being reduced from 5 to 3 different types.

The Table 1 presents a brief comparison of the methodologies described in order to visualize the differences between them.

Table 1: Comparison of the requirements for each methodology

Method	Types of pavements	Velocity	Considering intersections	Types of vehicles
CNOSSOS	15	média	sim	4
RLS 90	8	máxima	não	2
NMPB 96	5	máxima	sim	2
NMPB 08	3	máxima	sim	2

2 METHODOLOGY

To conduct this study, ProAcústica structured the Working Group GT Mapa de Ruído, where the associates were able to carry out specific studies and present for discussion. In all the studies, the European Good Practice Guide for Strategic Noise Mapping[16] was used to evaluate each recommendation item in order to relate them to the Brazilian reality.

As already discussed, the main difficulty is define which of the methodologies best represents the conditions of vehicles and pavements in São Paulo, and can be extended to large Brazilian cities. For this reason, measurements were made at 1.5m height in some points and these measured sound pressure levels were later compared to simulated sound pressure levels in each situation. This study was carried out by three associated companies, in different regions, involving low, medium and high flow routes. Both studies pointed to the same result, which will be discussed in the next section.

Initially a major problem was the definition of the pavements to be used. In São Paulo, as well as in Brazil, there are not many pavement characteristics and so the visual inspection technique suggested by the European Good Practices Guide was used. With this, the pavements of São Paulo were divided in 4 categories, being concrete, smooth asphalt, even pavement stones and uneven pavement stones. After these four typologies were related to the existing types the CNOSSOS methodology and with the use of the reference[17] equivalence was established with the other calculation methods. The Table 2 shows this relationship.

Table 2: Types of pavements for each methodology

Type of pavement	CNOSSOS	RLS 90	NMPB 96	NMPB 08
Concrete	CNS_07	Concrete or Corrugated mastic asphalt	EC: Cement concrete	R1
Smooth asphalt	CNS_01	Smooth mastic asphalt, asphalt concrete or blinded mastic asphalt	Enrobé bitumé	R2
Even pavement stones	CNS_12	Pavement with a smooth surface	EC: Smooth texture Paving	R2
Uneven pavement stones	CNS_10	Other pavements	EC: Rough texture Paving	R3

Considering the difficulties of modeling for a city the size of São Paulo, other questions were verified based on the method already chosen. Studies were carried out to verify the need for medium or maximum speed, the use of traffic lights and the gradient of the roads. In order to obtain the average speed data, a Recommendation of the Good Practice Guide was used to walk in conjunction with the traffic and to note some speed collection points and then to make an average.

The Noise Map for the city of São Paulo began by applying the guidelines defined in a sample region, determined by the city's consul.

For the elaboration of the Noise Map was used the CadnaA software[18], and the CNOSSOS methodology. Vehicle flow data were obtained by counting or by means of public disclosures from the Traffic Engineering Company (CET) of São Paulo[19]. The maximum speed of the tracks was obtained through visual inspection on the Google Earth platform.

For the geometry of the roads and buildings, the OpenStreetMap platform[20] was used and for the topography, the GeoSampa platform[21]. It was considered one reflection in the calculation, being that the coefficient of absorption was of 0.2 for buildings with height superior to 6 m of height and 0,4 for the other buildings. The gradient of the pathways was also considered in the calculation. The meteorological and traffic distribution conditions followed the recommendation of the European Best Practices Guide.

All the cited configurations were assigned to the modeling. In parallel to this, the participating members of the GT Noise Map were asked to perform measurements in the sample region for map calibration. Thus 30 measurement points were determined, and each partner was responsible for some of these points. To standardize the measurement, a measurement guide was drawn up, containing all the necessary information as well as a spreadsheet for sharing the measured data. Together with the measurement of 30 minutes, with a microphone positioned at 1,50m in height, videos were collected for later counting of vehicles. The Figure 1 shows the sample region and the measurement points used for map validation.

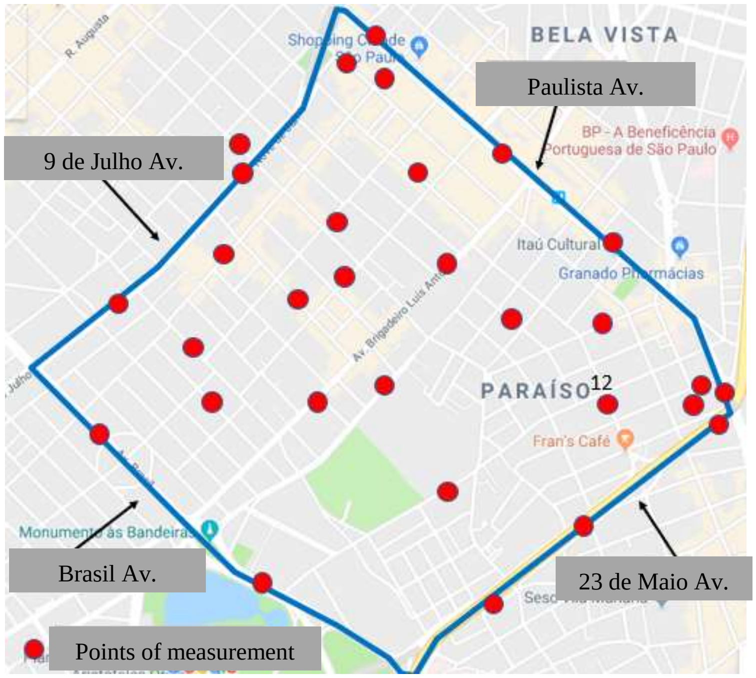

Fig. 1: Sample region delimitation and measurement points.

With the noise map in the sample region of the city of São Paulo, it was made compatible with the google earth platform, with Datakustik online platform and some case studies to exemplify some possible map applications by public agencies.

3 RESULTS AND DISCUSSION

The results were separated into two parts. The first named Modeling will describe the preliminary results about the way of modelling need to used in São Paulo. The second pat involves the results of the Noise Map and some examples of application.

3.1 Modeling

The first factor to be studied is the methodologies for the chosen one to be used for all other tests. The Figure 2 shows the comparison among methodologies for measurement in 10 points, in terms of sound pressure level. The dotted line represents what was measured and each continuum represents the value simulated at the same point using different methodologies. It is possible to observe that for 80% of the points, the CNOSSOS methodology was closer to the one measured. In other words, the CNOSSOS has the characterization of vehicles and pavements closer to the reality of the flow of vehicles of São Paulo. Only in 2 points did the most recent NMPB methodology demonstrate better results. The older RLS 90 and NMPB methodology are very distant from the characteristics of the city under study. This figure was used to illustrate the preponderance of CNOSSOS over the other methodologies, although the other studies have shown the same conclusion.

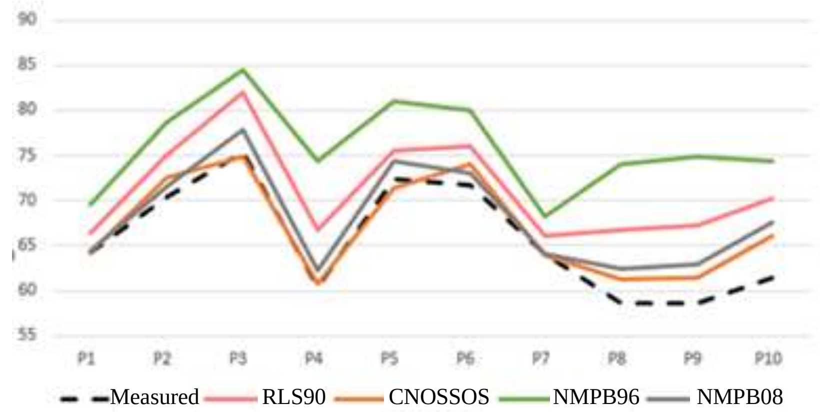

Fig. 2: Models comparison through the presentation of sound pressure levels at each point.

For the purposes of simplifying the calculation, comparative tests of the use and non-use of traffic lights for CNOSSOS were carried out. The results are presented in the Figure 3. In this case, it is possible to note that CNOSSOS considers the effect of acceleration and deceleration due to the presence of traffic lights. However, the best representation of the model occurs without the use of traffic lights. That is, using CNOSSOS, the best modeling occurs without the use of traffic lights. This was a conclusion that favors the time spent with the modeling, since it is one of the information that is not necessary besides reducing the computational cost when calculating the maps.

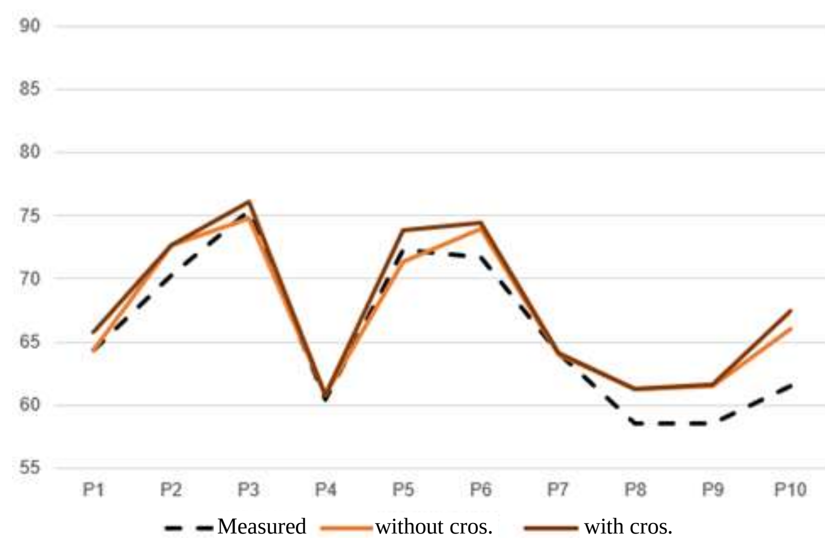

Fig. 3: Comparison of the use and non-use of crossing lights using CNOSSOS method.

As previously mentioned, CNOSSOS uses average velocity for the calculation, however this information may be more difficult to achieve and for that reason a comparison was made using average velocity and maximum velocity as input data in the modeling. The Figure 4 shows this comparison. In this case, it is observed that the use of the mean velocity, as expected, actually presents simulated results that are closer to those measured. On the other hand, it is observed that this difference is about 1dB which is little in terms of sound pressure level and still thinking about environmental noise situations. In this way it is concluded that the use of the average velocity is more adequate, but that the use of the maximum velocity, if necessary, does not a great relevance problem.

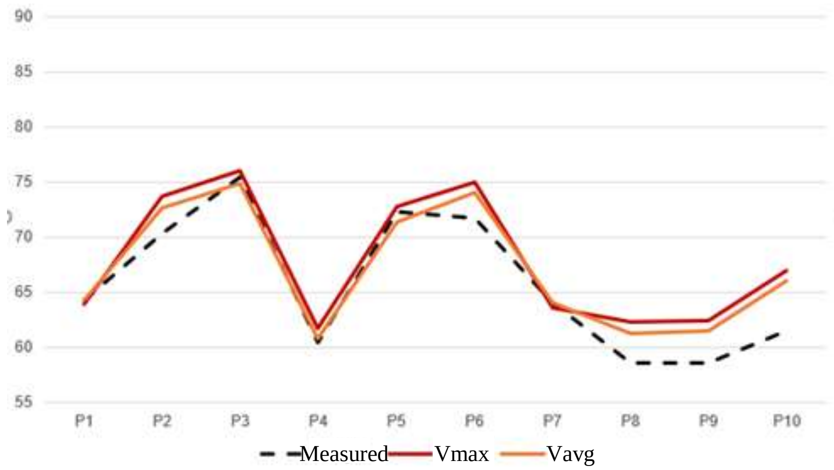

Fig. 4: Comparison of the maximum and average velocity using CNOSSOS method

Following the recommendations of the Good Practice Guide, other guidelines have been discussed but easily defined. The question of the characterization of the sources to be characterized and hours of operation for example, were defined to be used initially, for the first pilot project only urban and road traffic noise, from 07 a.m. to 10 p.m. the daytime period and from 10 p.m. to 07 a.m. the period the distribution of the flow of vehicles followed the one proposed by the Guide of Good Practices, where a percentage of vehicles for each period of the day is indicated.

Even though it was in methodology, the categorization of pavements was an important result of this stage, since in Brazil there is no variety of information about pavements.

Modeling in geometric terms is easily obtained through digital platforms and therefore we chose not to make simplifications in the geometry of buildings, as well as the terrain. For the terrain the GeoSampa platform was used and for the buildings and streets the OpenStreetMap was used. The soil absorption was defined as zero and followed the recommendation of the Good Practice Guide for large green areas or parks, where an absorption based on the use of the soil is defined. In the case of buildings, the absorption of 0.2 was adopted, for buildings above 6 meters in height and 0.4 for houses. In regions with very large clusters of houses, such as communities, for example, the build up area feature was adopted, where a region is drawn and the percentage of occupied soil is indicated.

The meteorology was also easily defined with the recommendation of the Good Practice Guide, being 50% favorable to propagation during the day and 100% favorable for the calculations at night.

The gradient of the streets was an important point to be studied. This aspect is related to the inclination and the direction of the ways. It has been verified by means of studies that the gradient of the track influences the simulated response, but in return this data is easily defined, since the calculation program itself, through the terrain, can determine the slope and the direction of the track is an information that already comes with the tracks collected in OpenStreetMap. However, for regions where there are no roads available on the online platform, it is necessary to stipulate the direction of each route with a gradient greater than 5% inclination.

The number of reflections was a point discussed, but not studied for the proposed reality. The number of reflections to be used was defined as 1, based on previous studies, already carried out by other countries such as the reference[22,23].

Another point of discussion referred to the software to be used for the simulations. It was found that any software that meets the ISO 17534-1[24] quality criteria can be used to perform the work.

In summary, the present work involved a series of studies that allowed to determine the guidelines to be adopted for the elaboration of the Sao Paulo noise map. These guidelines were implemented in a pilot project, the results of which will be presented on the next section.

3.2 Pilot Noise Map

As a result, the noise map was elaborated for the sample region for the day period and for the night period, as can be seen in the Figure 5.

Fig. 5: Day and Night noise map of the sample region.

It is possible to observe that the noisiest regions are those near the busiest roads such as 23 de Maio Avenue and Brigadeiro Luís Antônio Avenue. Through the map it is also possible to identify quieter regions. It is also observed that, as expected, the nocturnal sound landscape is less noisy than the daytime landscape. These results may lead to important discussions within the scope of public power, since the map shows a king of X-ray of the noise situation of the city. With this, it is possible to perform several analyzes in order to improve the current scenario.

Some examples of what can be done with this tool have also been developed, are available on the website and will be demonstrated in this work as follows. In the structured tests, the use of the noise map has always been thought of in a strategic way, for the application of action plans through the evaluation of its impacts. In this case it is worth remembering that the impact should not only consider the reduction in the sound pressure level, but also the cost-benefit of a mitigating action, the number of people affected, the use of the soil, etc. The Figure 6 shows the first example of a mitigating action involving the reduction of the speed of a track and its impact in terms of the sound pressure level incident on the façades of the buildings. By means of the simulation it is possible to observe that reducing the speed of a road, in this case, there was a reduction of 1dB in the NPS, since the first figure shows the default situation, the second one illustrates the situation with the applied mitigate measure and the third one presents a map of difference.

Default situation Change of the velocity Difference

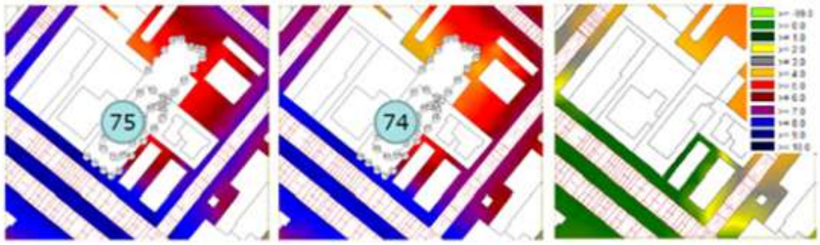

Fig. 6: Case study with change of the velocity of a pathway.

The Figure 7 illustrates another mitigating action that is to alter the track pavement. In this case, it is possible to notice that the sound pressure level incident on the facade reduced by 4 dB. That is, this mitigating action shows a greater efficiency than the previous one. A new attempt is presented in the Figure 8.

Default situation Change of the pavement 1 Difference

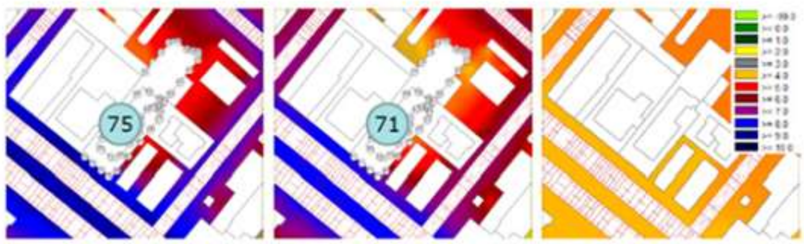

Fig. 7: Case study with alteration of one-way pavement 1.

Another test was performed with another type of pavement, the result of which is presented in the Figure 8. In this case, the noise reduction was even greater.

Default situation Change of the pavement 2 Difference

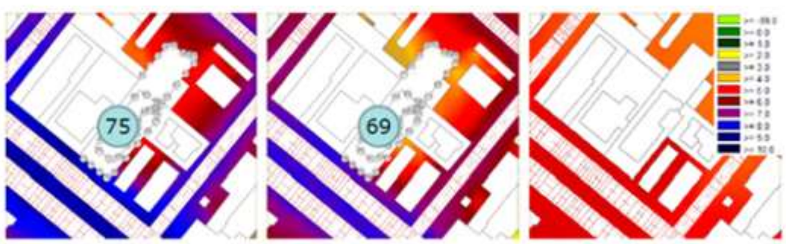

Fig. 8: Case study with alteration of one-way pavement 2.

Having these simulated maps shows that only the NPS is not enough, but rather the evaluation of the cost of each such measure. In addition, the study of how much needs to be reduced. The map showed that the reduction was greater when using floor 2, but it could be that this measure is the most costly and not necessary. By means of secondary studies, it is possible to observe the cost-benefit relation of each action. Another important observation is that noise maps can be presented in several ways. To compare actions in terms of sound pressure level, as in this example, it is not so interesting to see a map with sound pressure levels in the region, but rather the difference map, presented in the third column. Looking at the difference maps is easily noticeable which of the measures causes the greatest effect.

Another approach can be done by assessing the number of people impacted as illustrated in the Figure 9. By this evaluation it is observed that the measure that presented the greatest reduction of Sound Pressure Level (SPL) is not necessarily the best when the gaze is directed at people affected. In other words, when speed reduction was applied, the NPS in a building reduced 1dB, but reduced to less than half, people impacted by SPL higher than 70dB. In the case of the first floor change, the reduction in SPL was higher, but the same percentage of people continue to be impacted by SPL higher than 70dB. All these analyzes are an example of how a study can be done to refine a decision making.

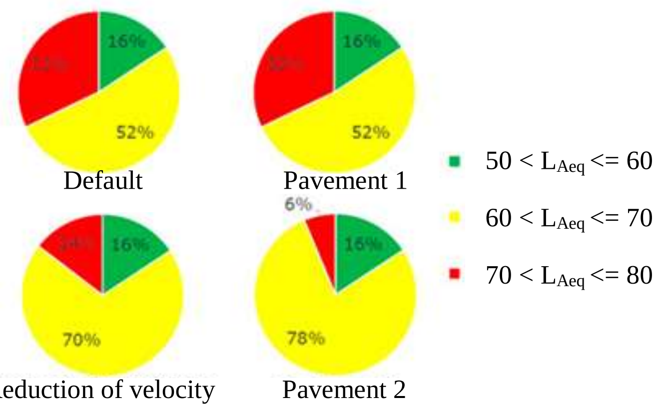

Fig. 9: Case study with evaluation of the number of people impacted.

Another aspect of analysis is done with regard to land use since an industrial zone may be noisier than a residential zone. Thus, this analysis allows to establish the urgency of applying measures, as the example shown in the set of the Figures 10, 11 and 12.

In the Figure 10, the sample region of the map was highlighted in the land use and occupation law map with zoning identification. Analyzing the map, it is observed that the region that requires the most attention is the one highlighted because it is a Residential Zone.

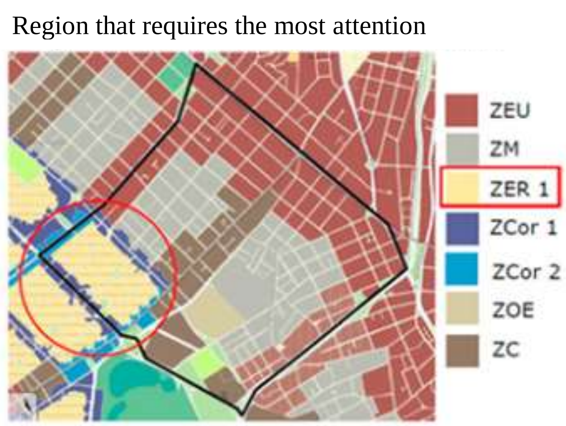

Fig. 10: Case study with evaluation of land use and occupation. First step: identification of the most sensitive regions.

The second step of the analysis is to observe the maximum levels allowed in this region. According to the Land Use and Occupancy Law, the maximum NPS allowed in this Zone for the daytime period is 50dB (Figure 11). After that, through the noise map (Figure 12) it is possible to observe if the urban traffic noise in this region is above that allowed by the legislation, with the objective of evaluating the need to perform some mitigating action or not.

Fig. 11: Case study with evaluation of land use and occupation. Second stage: evaluation of the maximum sound pressure level allowed according to zoning.

As shown in the Figure 12, the NPS produced by urban traffic in this region is already higher than allowed. In this case, the analysis points out that there is a need to perform some action in this region to solve the noise problem. The actions, in turn, undergo the analyzes exemplified earlier before their implementation.

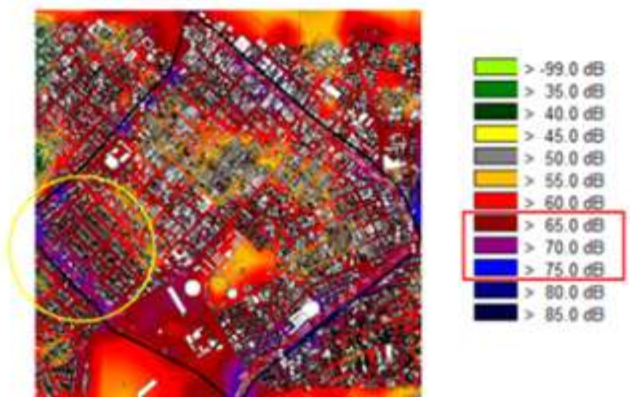

Fig. 12:Case study with evaluation of land use and occupation. Third step: verification of the need for action.

The map as well as the application examples are available online for anyone to have access to. The site with the noise map was launched at INAD and generated great repercussion[25].

4 CONCLUSIONS

In summary, with the joint work of the GT Mapa de Ruído, through studies and technical discussions it was possible to determine all the guidelines for the elaboration of the noise map of the city of São Paulo. With this, ProAcústica intends to join all these guidelines in a document with the objective of guiding the elaboration of noise maps in the Brazilian cities, aiming that more cities have this tool for strategic planning.

With the elaboration of the map it was possible to visualize a variety of applications of the noise map, such as prediction of mitigating measures, evaluation of the affected population, impact of noise in each building and identification of quiet and problematic areas with respect to the city legislation.

With the action of ProAcústica to launch the noise map in online platform at INAD, today public agencies can already use it as a tool to identify more problematic regions. It also seeks the support of the organs to elaborate the complete map of the city, dirty prediction is to finalize it in 2023 and for use of all its features.

Currently the map only contemplates the sources of urban traffic because it is the most present source in the day to day and for that reason is the most problematic. However, it is expected that in other versions of the map noise from railway and air traffic can be characterized. In addition, it is hoped that with this tool, it will be possible to raise awareness about the importance of making a noise map and how to use it in the management of large centers.

5 ACKNOWLEDGEMENTS

The gratitude goes to all the participating members of the GT Mapa de Rupido, especially those who have made available their own resources for conducting tests and studies, who brought their technical experience on the elaboration of city noise maps and to the companies that voluntarily carried out the measurements for map validation. Thanks to the Datakustk for lend the software CadnaA and for put the noise map on online platform.

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