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Social Acoustic Survey and Noise Mitigation Solutions on a Portuguese Urban Highway

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Abstract As result of the European Directive 2002/49/CE approval on the 25th June 2002, the Portuguese government through the Portuguese Road Authority (EP – Empresa Pública Estradas de Portugal) and the support of the University of Porto, decided to analyse the situation on one of the most noise annoyed areas of Portugal concerning road traffic (L_{Aeq} up to 77 dB), and to evaluate the need for noise mitigation solutions. This paper refers to the analysis of those particular circumstances regarding a high-speed regional ring, crossing the urban expansion zone of Porto (named IC23-VCI) that exceeds the yearly limit of 6 million vehicle movements settled by the European Directive. In fact, there are actually, over 50 million movements a year on that road (AMDT ≅ 140000 vehicles) with a circulating speed of about 100 km/h (light vehicles) and 80 km/h (heavy vehicles). Such a noise-challenging road has tremendous implications on the welfare of local inhabitants. To assess the subjective noise annoyance caused by this road, a social acoustic survey was carried out (5000 inquiries mailed) that indicates a high percentage of very annoyed and extremely annoyed persons (44% of the returned answers). Concerning noise mitigation solutions, the analysis of the situation: measurements, noise maps [actual conditions and future developments], local constraints [safety, available space, drainage system and interference with other infra-structures (electricity, gas, telephone and cable TV facilities)] in addition to the Portuguese Noise Code limits, demanded the need for lowering the noise levels at the closest receivers. The typical noise mitigation solutions considered were: drainage pavement (already in place), noise barriers, retaining walls covered with absorbing materials and facade sound insulation.

1. INTRODUCTION

The opportunity for this study becomes more important since EP (Estradas de Portugal, “Roads of Portugal”) received a growing number of complains during the past years. Spite the initial situation was not of much concern, the increasing number of licenses for housing construction given by the local authorities, has created a significant social and economical problem. Nowadays, the closest residents to this road complain about health problems (sleep disturbance, stress, lack of concentration, etc.), for the obligation of window sound insulation and about the reduction on the house market prices. Facing this situation, EP decided to schedule a profound intervention to reduce the actual noise levels to the maximum limits imposed by the Portuguese Noise Code, which means, $L_{Aeq,\ daytime}$ = 65 dB and $L_{Aeq,\ nighttime}$ = 55 dB [1]. At the same time, it was considered important to analyse the residents' response to the present situation. To determine the level of annoyance in the vicinity of the VCI ("Via de Cintura Interna", Internal Ring Road) a social acoustic survey was undertaken in the study area (500 m wide centred on the VCI) whose results will be referred in this paper.

2. SITE DESCRIPTION

The present paper refers to the analysis of a particular situation concerning a high-speed regional ring, crossing the urban expansion zone of Porto.

This road is located in the north of Portugal on the second most important city of the country (about 270000 inhabitants in the town and about 1260000 in the main metropolitan area). Porto is the nucleus of Portugal Northern region, and so, crossed by the most important highways and roads. Porto has a particularly dense urban area, as it can be seen in Figure 1, where is not difficult to find housing occupancy facing the major roads, as well as schools and hospitals.

The studied zone corresponds to an area of about 500 m wide band centred on the regional ring axis. This width was defined by EP, the Portuguese Road Authority.

Actually, this road has an annual mean daily traffic (AMDT) of 140000 vehicles, including 5% of heavy vehicles. It is expected on the horizon year (2024) an AMDT of 160000 vehicles with 5.5% of heavy vehicles. The average circulating speed is now around 100 km/h for light vehicles and 80 km/h for the heavy vehicles.

The finishing surface of the pavement was in dense asphalt but during the second semester of 2004 it was replaced by a drainage layer which reduced the corresponding noise emission level.

Figure 1: Site location.

3. NOISE STUDY

Situation Analysis

The first step of this study consisted in the characterization of the prior situation that led to this analysis. A 3D digital ground model of the area was given, with poor quality that was

then updated, restructured and organized in order to be used on the chosen software: SoundPlan 6.2.
There was also the need to identify all the buildings in the study area as well as the actual traffic flow and composition. With that purpose an accurate traffic study from 2004 to 2024 (the considered horizon year) was elaborated for every section of this road (between all intersections: 4 sections). The conclusion of this traffic study revealed an annual mean daily traffic, in 2004, between 120000 on the least demanded section and 140000 on the most demanded. This traffic volume will increase, until 2024, to 140000 and 160000, on the correspondent sections, considering the new traffic allocation that will take place in 2009.
The traffic distribution (light and heavy vehicles) and density, along with speed (100 km/h for light vehicles and 80 km/h for heavy vehicles) and road surface characteristics (drainage layer with absorbent properties) determine the noise levels next to VCI.
The results obtained from SoundPlan6.2 (considering the French noise prediction model as determined on the European Directive [2] and described on "Guide du Bruit" [3] and NMPB-Routes-96 [4]) where then compared with the on-site measurements realized on chosen spots for calibration purposes. All the measurements were conducted with respect for the procedures indicated in NP 1730-1/1996 [5] similar to ISO 1996-1 [8].The comparison revealed no important deviation from the calculated noise levels (differences lower than 2.0 dB(A)).

Present Situation (2004)

The surrounding area of VCI is characterized by a diverse occupancy. It is possible to find housing areas as well as industrial ones, schools, hospital and leisure facilities. As an important regional circulation ring, VCI has a primary role on traffic distribution to the major highways where the most part of the traffic from Porto Metropolitan Area is concentrated, creating some conflict situations, specially during morning, lunch and evening rush-hours.
In the study area, from Francos' to Outeiro's intersections (a section of VCI with 5 km extension, between km 2+000 to km 7+000), has the most diverse situations in terms of buildings position. As it can be seen on the example presented on Figure 2, there are some aged buildings facing the road and not suited for such high noise levels ($L_{Aeq,\ daytime} \geq 70$ dB). On the other side of VCI, there is an industrial area, with no legal limitations on noise pollution.
Then, it is possible to identify recent dwellings, 13 floors height (Figure 3), also not prepared to face the actual noise pollution level ($L_{Aeq,\ daytime} \geq 70$ dB). The reduced façade insulation is easily noticed once several owners had to reinforce them, situation that can be identified by sight. On the opposite direction it is possible to find Prelada hospital (Figure 4) and Maria Lamas school (Figure 5). Due to the actual noise level, school administration decided to build a concrete wall, 2.5 m height.
Following the Hospital place it is possible to detect innumerous dwellings, from controlled cost housing to high quality buildings in the direct surrounding area of VCI, also with daytime noise levels over 70 dB(A). These diverse types of buildings continue to appear all along the roadside until the end of the studied section as it can be seen on Figure 6 and Figure 7.


Figure 2: km 2+500.

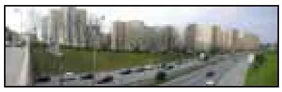
Figure 3: km 3+000.


Figure 4: km 3+700.


Figure 5: km 3+500.

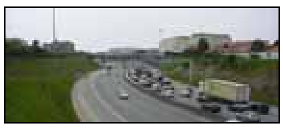
Figure 6: km 6+000.

Daytime noise levels exceed 70 dB(A), in most part of VCI,

specially on frontline dwellings and 60 dB(A) during the nighttime period.
Regarding this situation it was recommend the adoption of mitigation measures on both sides of VCI.

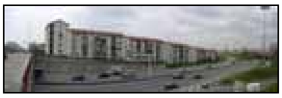

Figure 7: km 6+800.

The noise levels mentioned on the previous analysis of the present situation were obtained from SoundPlan6.2. The Noise Maps chromatic presentation used followed the instructions mentioned on NP 1730/1996-2 [6] similar to ISO 1996-2 [9](Figure 8 and Figure 9).

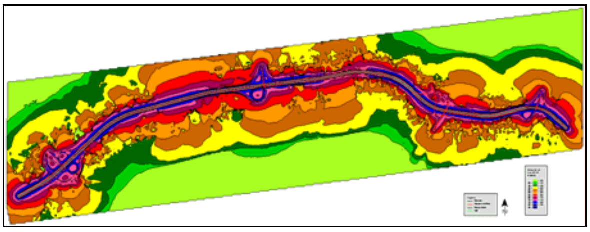

Figure 8: Noise Map 2004 (present situation) – daytime period.

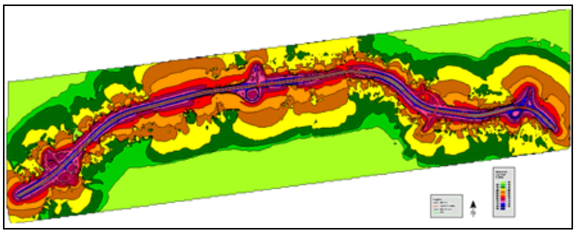

Figure 9: Noise Map 2004 (present situation) – nighttime period.

As this color images show the actual conditions on the surroundings of this highway are of great concern. Almost all the frontline buildings are under high noise levels exceeding actual legal limitations, even if it is considered the most unfavorable acoustical zoning: Mixed Zone (according with [1]).

Horizon Year (2024)

On the horizon year (2024), the ending of the regional road network will involve a reassignment of traffic volume and composition as mentioned on “Situation Analysis”, corresponding to a daily increase of about 20000 vehicles. Taking into consideration the new traffic distribution, the same circulation conditions (traffic flow and speed) and road surface (drainage top layer), new Noise Maps were calculated for the future circumstances. Those noise maps shown on Figure 10 and Figure 11 demonstrate the persistence of the initial problems; all the dwellings facing VCI remain under elevated noise levels exceeding legal limitations.

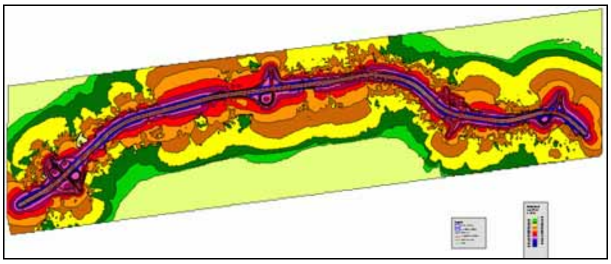

Figure 10: Noise Map 2024 (future situation) – daytime period.

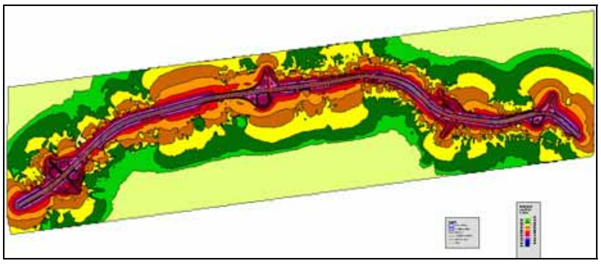

Figure 11: Noise Map 2024 (future situation)– nighttime period.

Assessment Methodology

The results obtained from on-site measurements and software analysis confirmed the expected non accomplishment of the legal limits. In most of the receivers on the vicinity of VCI noise equivalent levels over 65 dB(A) were found in daytime period and over 55 dB(A) in nighttime. These limits established on the Portuguese Noise Code [1] refer to the threshold

of “Mixed Zone” acoustical classification, in which is possible to find the coexistence of housing occupancy with other uses. The other possible acoustical classification is “Sensible Zone” where are included hospitals, schools, housing (exclusively), religious buildings and some public facilities regarding a quiet environment. In this last situation the limits decrease in 10 dB(A), which means: $L_{Aeq,\ daytime} \leq 55$ dB and $L_{Aeq,\ nighttime} \leq 45$ dB.
All the measurements were conducted with respect for the procedures indicated in NP 1730-1/1996[5]. As the acoustical zoning of this area was not yet officially defined the occupancy of the buildings had to be identified and it was concluded that the majority of those buildings were compatible with a “Mixed Zone” classification, with the exception of three areas. The notorious exceptions were public facilities: Maria Lamas School, Paranhos School and Prelada Hospital, whose classification, according to the Portuguese Noise Code, was “Sensible Zone”.
To assess the existence of a “Noise Impact”, a criterion was defined based on the limits settled on the Portuguese Noise Code, and described on the following Table 1.

Table 1: Impact Assessment Criteria

Noise Impact	**L_{Aeq} [dB]**			
	Sensible Zone		**Mixed Zone**	
	Daytime	**Nighttime**	**Daytime**	**Nighttime**
No Impact	< 55	< 45	< 65	< 55
Low Impact	[55 , 60[	[45 , 50[	[65 , 70[	[55 , 60[
Moderate Impact	[60 , 65[	[50 , 55[	[70 , 75[	[60 , 65[
High Impact	≥ 65	≥ 55	≥ 75	≥ 65

Mitigation Measures

This study involved two phases: The first concerning the design of mitigation measures without any constraints except the accomplishment of noise limits and a second stage where some limitations were imposed. In the first stage, the goal was to determine the expected height of noise barriers in order to fulfill the Portuguese Noise Code limits, both in daytime and nighttime periods. It was a difficult task once the actual and predicted noise levels are considerably high (in some situations over 70 dB(A)) which, in several situations, lead to a needed insertion loss over 15 dB(A), specially during nighttime period.
For this reason, the need of conjugated mitigation measures was considered, namely: noise barriers, façade sound insulation, covering of all retaining walls with absorbent materials and the enforcement for the 90 km/h speed limit.

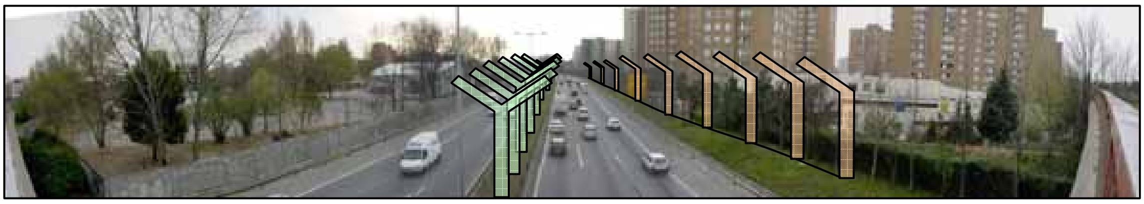

Figure 12: Example of expected noise mitigation measures (first phase).

The primary designed action was to include 28 noise barriers, from 2.0 m to 6.0 m height on vertical barriers and 6.0 m height plus 3.0 m to 6.0 m of tilted screen on fragmented barriers (Figure 12), arranged with mixed materials being the lower part (until 2.0 m height) in concrete covered with porous wooden fiber panels and the top layer (over 2.0 m) in acrylic panels, to minimize the tunneling effect and avoid lack of lightening implications.

In one situation, due the position of the buildings, the planned intervention consisted in half a tunneling, on the right lane, with a metallic structure, acrylic and metallic absorbent panels on the top and covering of the retaining walls with porous wooden fiber panels (*Figure* 13).
This first proposal consisted in 9500 m of noise barriers (noise barriers area of about 58700 m^2), on both sides of VCI, and roughly represents the total length of the studied sector. The estimated total cost, including urban and landscaping integration, is about 10 million euros.

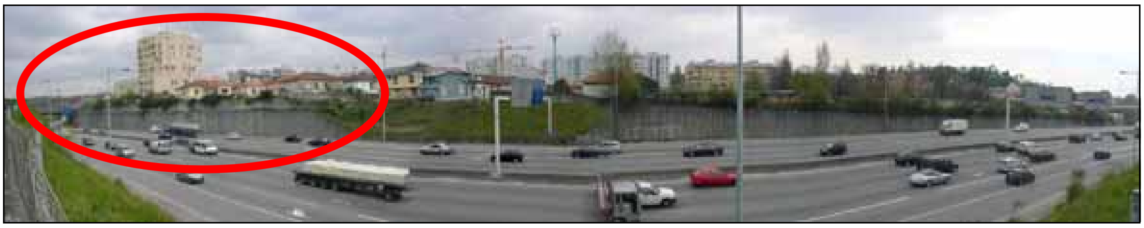

Figure 13: Proposed location for half - tunneling situation.

Figure 14: Example of projected noise mitigation measures (second phase).

On the second phase the following limitations were imposed:
- removal of all noise barriers located on the central separator due to road safety reasons;
- tilted screen length constraint on fragmented noise barrier to a maximum of 3.0 m;
- reduction of noise barriers height due to special, local and urban integration constraints;
- introduction of façade sound insulation;
- interaction with existent infra-structures.

The revised designed action was to include 22 noise barriers, from 2.0 m to 6.0 m height on vertical barriers and 6.0 m height plus 3.0 m of tilted screen on fragmented barriers. This second analysis pointed to 8200 m of noise barriers, disseminated along both sides of VCI (noise barriers area about 40300 m^2). The anticipated total cost, including urban and landscaping integration, is about 8.5 million euros.

4. SOCIAL ACOUSTIC SURVEY

Social Survey Characteristics

A social acoustic survey was carried out during July 2004, in all the buildings of the study area, even if it is possible to consider that the most part of these dwellings are not facing VCI and so not directly influenced by the corresponding traffic noise. The social acoustic survey carried out on this area fulfilled the requirements indicated on ISO/TS 15666:2003 [7].
The site object of this analysis covers 3225 buildings, 65% corresponding to housing (2000 buildings), 30% to auxiliary constructions and the remaining 5% to hospitals, school, sport and industrial facilities. For the purpose of this survey only the 2000 buildings were inquired,

which represents approximately 5000 dwellings.
The primary noise source is road traffic noise from VCI, as the previous part of this paper demonstrates; additionally there are some minor sources such as local road traffic, aircrafts, light train, industries (bakeries and others) or outdoor activities. All disturbing noise sources were considered, but only road traffic noise from VCI was modeled and measured, both in daytime and nighttime periods.

Social Survey Data

The mailing survey consisted in 5000 questionnaires invoiced and in 800 replies with reference to 2000 persons, approximately.
Several questions were formulated, including the two questions presented in first place on the questionnaire about noise rating scale: one question with a verbal rating scale and one with a numerical rating scale, as indicated on ISO/TS 15666:2003 [7].

a) Question with verbal rating scale:
"*Thinking about the period in which you have lived in this area, when you are at home, how much does noise from traffic circulation on VCI bother, disturb or annoy you: not at all, slightly, moderately, very, or extremely*?"

b) Question with numerical rating scale:
"*Thinking about the period in which you have lived in this area, what number from 0 to 10 best shows how much you are bothered, disturbed or annoyed by traffic noise on VCI? (If you are not at all annoyed choose 0; if you are extremely annoyed choose 10; if you are somewhere in between, choose a number between 0 and 10).*"

Besides these two questions it was considered appropriate to include in the same questionnaire some pertinent questions about:

- socio-economic conditions, such as: address, number of cohabitants, housing and vehicle ownership, education level and monthly salary;
- past investments done in sound insulation of the dwelling;
- related healthcare costs;
- willingness-to-pay concerning fuel price per litre and housing market price on a less noisy area;
- other noise sources.

The returned questionnaires were not totally fulfilled by all respondents. Some families refused to reveal their monthly income, others the kind of housing or vehicle ownership and some others the number of cohabitants. Concerning this last parameter, 1 person was attributed whenever the information missed. In relation to the sound insulation investments, some family recognized they had done it in the past but, unfortunately, did not have the total cost or did not remember the investment year. The respondents were also asked if they would allow on-site measurements and 80% of the families authorized them, showing a highly cooperative behavior.

Social survey Analysis

The basic social characterization of the sample is displayed on Figure 15 and Figure 16.
The first graph represents the type of dwellings' distribution, regarding the number of bedrooms. The large majority of the families live on owned properties (81%) against 19% of rented houses, with two or three-bedrooms (71%). Approximately 60% of the respondents have a University degree but these data may show a bias because the higher the education level of the population the higher their willingness and technical skills to answer this type of

questionnaires.

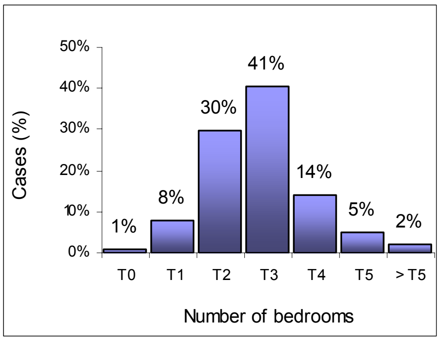

Figure 15: Characterization of the sample by dwelling type (number of bedrooms).

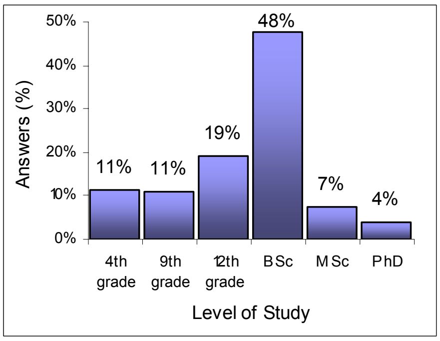

Figure 16: Characterization of the sample by educational level of the respondents.

The results of this social survey indicated that 44% of the families consider themselves as very or extremely annoyed (Figure 17). Given the opportunity to numerically grade the surrounding noise, 11% of the families rated their annoyance with the maximum value (10) and 35% of the families with the three highest values (8, 9 and 10) (Figure 18). These outcomes are a reasonable image of the reality in VCI's vicinity regarding environmental noise. The actual noise levels together with reduced construction quality in most buildings, justify the amount of negative answers. Figure 19 displays the numeric sound level each respondent thinks to grade their neighboring environment. As expected, their lack of technical knowledge on this subject, gave about 60% of unrealistic answers, divided on both sides of the scale.

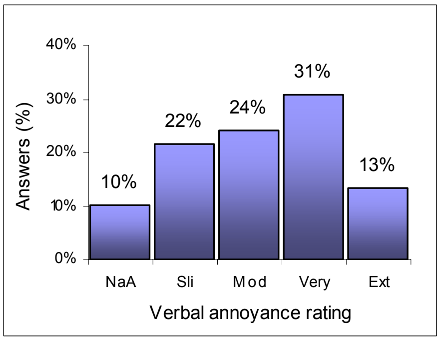

Figure 17: Verbal annoyance rating (from Not at All to Extremely).

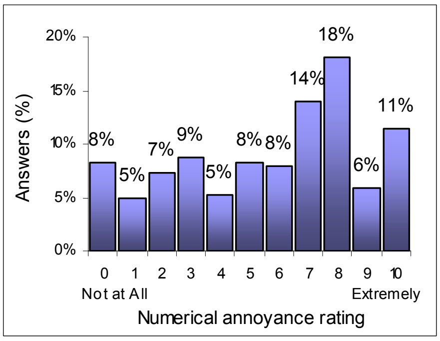

Figure 18: Numerical annoyance rating (from 0 to 10).

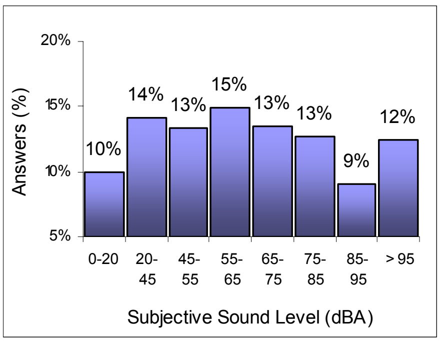

Figure 19: Percentage of answers concerning the sound level thought to be heard by respondents at their home.

On the topic of willingness-to-pay regarding fuel and housing prices the answers demonstrated no acceptance for any price change (over 40% in both cases, as shown on Figure 20 and Figure 21). But these results may show a bias because the population that does not own any vehicle or house tends to accept higher price changes for those properties. In the present situation, a case sensitivity analysis was done and shown families with lower monthly income more reluctant to any price changes.
Concerning fuel price some of the families mentioned they did not accept any price changes once those changes would affect them on public transportation prices, but 25% of these same families accept the highest price change suggested (Figure 22), what attest the bias previously mentioned.
Regarding housing price, 52% of the highest income families revealed their acceptance for higher housing prices in less noisy zones, in opposite position only 8% of the lower income families accepted the same price variation. As it is noticeable on the four figures below the most frequent answer for both fuel and housing price changes is "no change", regardless the income class of the respondent families.

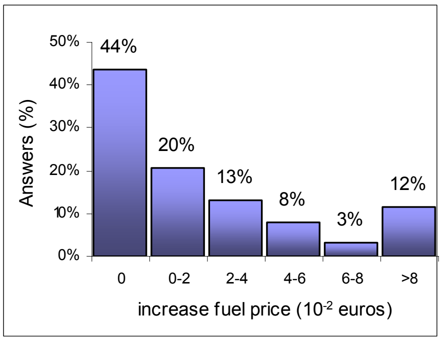

Figure 20: Increase in fuel price per litre the respondents are willing-to-pay for a reasonable noise reduction at their homes.

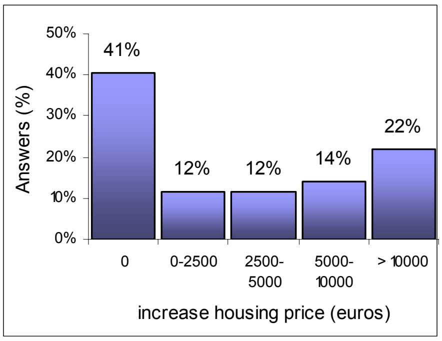

Figure 21: Increase in housing price the respondents are willing-to-pay to live in a less noise area.

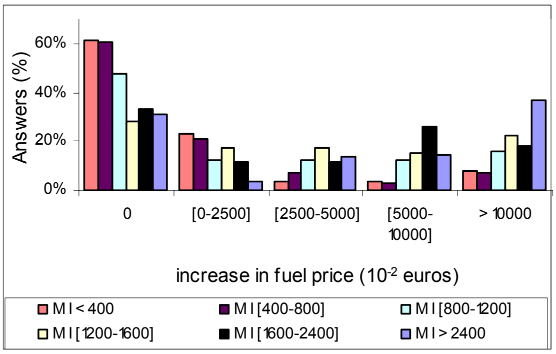

Figure 22: Willingness-to-pay for an increase in fuel price per litre controlling for monthly income.

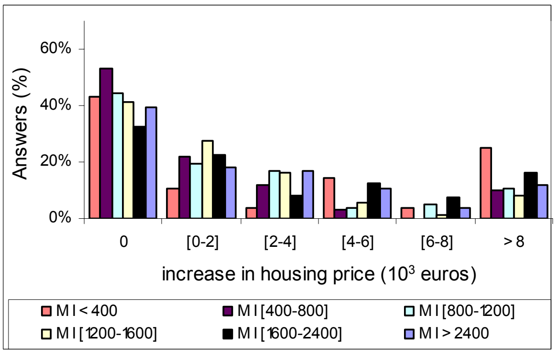

Figure 23: Willingness-to-pay for an increase in housing price controlling for monthly income.

5. SUMMARY

The annoyance related to road traffic noise in VCI, Porto high-speed regional ring, is obvious. A significant traffic flow (over 6 million movements a year) and high noise levels together with low construction quality of the aged dwellings, built to accommodate families with low economical resources, led to a land use conflict situation.

At the present time, noise levels in the vicinity of VCI exceed 70 dB(A) in daytime period and 60 dB(A) during nighttime period on frontline buildings, whose occupancy is quite diverse from housing to schools, hospital, leisure places and industrial. Such a noise-challenging road has enormous implications on the welfare of local inhabitants.

The resultant annoyance was assessed through a mailing survey and the received answers demonstrated a high dissatisfaction with the present situation. When asked about a verbal rating of their annoyance, 44% of the population considered to be under very or extremely annoying conditions, and when the question referred to a numerical rating 49% of the respondents believe to be under a noisy environment classified as 7, 8, 9 and 10 (on a 0 to 10 scale).

Identified the magnitude of this problem, the Portuguese Road Authority decided to analyse different noise mitigation measures, taking into account not only the needed insertion loss but also the social, urban, landscaping and economic implications. All the typical noise mitigation processes were explored: noise walls, façade sound insulation, and absorbent materials. The final recommended solution gathered all this noise mitigation solutions and ended on 22 noise walls (31000 m^2), 10000 m^2 of absorbing materials over retaining walls and 4000 m^2 of façade sound insulation. The anticipated total cost, including urban and landscaping mitigation measures will come up to 8.5 million euros, or about 1.7 million euros per kilometre.

REFERENCES

[1] *Portuguese Noise Code* (Decreto-Lei n.º 292/2000 from November 14)

[2] *European Directive* 2002/49/CE, European Parliament and the European Union Coucil, June 25, 2002)

[3] *Guide du Bruit des transports terrestres, fascicule prévision des niveaux sonores*, CETUR 1980

[4] NMPB-Routes-96 – Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, article 6, SETRA-CERTU-LCPC-CSTB

[5] NP 1730/1996–1 – *Acústica. Descrição e medição do ruído ambiente. Parte 1: Grandezas Fundamentais e procedimento*

[6] NP 1730/1996–2 – *Acústica. Descrição e medição do ruído ambiente. Parte 2: Recolha de dados relevantes para o uso do solo*

[7] ISO TS 15666 - 2003 *Acoustics - Assessment of noise annoyance by means of social and socio-acoustic surveys*

[8] ISO 1996-1, *Acoustics — Description and measurement of environmental noise — Part 1: Basic quantities and procedures*

[9] ISO 1996-2, *Acoustics — Description and measurement of environmental noise — Part 2: Acquisition of data pertinent to land use*