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# Strategic noise map of a major road carried out with two environmental prediction software packages

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**Abstract** The main objective of this study is to analyze the differences found in the results of noise mapping using two of the most popular software techniques for the prediction of environmental noise. The location selected to conduct the comparative study is an area encompassed by the ring road that surrounds the city of Pamplona and on a grid, with a total of $6 \times 10^5$ points, approximately. In fact, and as the Environmental Noise Directive points out, it is a major road designated by a Member State (Spain). Configuration of the calculation parameters (discretization of the sources, ground absorption, reflection order, etc.) was as equivalent as possible as far as programs allow. In spite of that, a great number of differences appear in the findings. Although in 95.5% of the points the difference in the noise level calculated from the two programs was less than 3 dB, this general statistic result concealed some great differences. These are due to the various algorithms that programs implement to evaluate noise levels. Most differences pertain to highly screened receivers or remote ones. In the former, the algorithm of visibility is the main cause of such differences. In the latter, differences are mainly brought about by a different implementation of the propagation under homogeneous and favorable atmospheric conditions from both software systems.

**Keywords** Computational models · GIS · Noise maps · Traffic noise · Urban noise prediction

## Introduction

After the approval of the European Environmental Noise Directive (END) 2002/49/EC (Directive 2002/49/EC) for the evaluation and management of the environmental noise (transposed to Spanish Legislation by the Noise Law 37/2003 (Ley 37/2003)) in the prevention and reduction of the impact of acoustic pollution on the population, nowadays society is aware of the noise pollution effects and it has set out to do research and carry out inspections. Furthermore, establishing common assessment methods for environmental noise and setting limit values in terms of harmonized indicators for the determination of noise levels is required. The specific figures for any limit values must be determined by the Member States but taking into account, inter alia, the need to apply the principle of prevention so as to preserve quiet areas in agglomerations. According to the END, noise maps and action plans should be implemented progressively (Popp and Bing 2005). As a

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result, in the last few years, mathematical models and strategies for environmental noise prediction have been developed. The calculations needed to draw such a noise map using such methods are tremendously tedious, therefore making it necessary to program them on a computer. Some software applying various official models in noise mapping-both for agglomerations and for large infrastructures began to be commercialized approximately 10 years ago. It is impossible to implement theoretical methods explicitly in the calculation algorithms not only for their complexity but also for the increase in the calculation time. They simplify the algorithms attempting to obtain the best time–precision ratio. As a consequence of these simplifications, as well as their constant evolution, differences in results from programs appear.

Many countries have developed their own traffic noise prediction models (Arana 2001). Most of them were designed to meet the requirements of roadway engineers but they do not, however, meet the requirements of other users of traffic noise models (Steele 2001). For countries without their own method, the END recommends the use of the French method (NMPB-Routes 1997) to calculate both the source and propagation model for road traffic. This method is similar to ISO 9613-2 (ISO 9613 Part 2, 1996), but some of its features are more developed, such as the atmospheric propagation conditions. The NMPB considers both favorable and homogeneous conditions. Nevertheless, ISO 9613-2 only considers favorable ones. Another difference is the way of splitting up the line sources. On the one hand ISO 9613-2 describes the Raster Factor method and on the other NMPB also allows equiangular and variable splitting up methods.

Two of the most widely used software programs in the prediction of environmental noise—SoundPlan (SoundPLAN 2005) and Cadna/A (Cadna/A 2005)—have been analyzed in this work. We will refer to them as SP and CA respectively. Even though both programs implement the NMPB method, they are unable to configure all the parameters in the same way, thus giving rise to differences in the results. Examples of these variations are those caused by the source discretization method, which is implemented by angular step in SP and by the Raster Factor in CA.

The main objective of this study is to analyze the differences found in the results of noise mapping by resorting to the two above-mentioned software systems.

## Strategic noise map of the ring road in Pamplona (Spain)

### Case study

Pamplona is a medium-sized town with a population of 190,000 and capital of Navarre, a province located in the north of Spain. Previous research work relating to noise disturbance in the community (Arana and Garcia 1998) and noise mapping (Arana et al. 2003) has been carried out. The location selected to conduct the present comparative study is an area taking the ring road that surrounds the city of Pamplona. In fact—and as the END states—it is a major road designated by a Member State (Spain), which has an annual traffic flow of over three million vehicles. Figures 1 and 2 reflect the location of Pamplona in Spain and the calculation area respectively.

Traffic running on the ring road is the source of noise. Both the traffic flow and the average speed inserted at each and every line were provided by both the Transport Department of the Local Government of Navarre and by Navarre's Motorway Company basing themselves on recorded data from 2005. The Digital Terrain Model (DTM) was designed by using elevation points and level curves of the ground (iso-curves and elevation lines) elaborated by the Trabajos Catastrales S.A. company. This location is extremely interesting for a comparative study because it poses a great number of situations to evaluate. It combines not only urban and rural zones but also flat and sloping terrain with positive and negative gradients.

The European Working Group Commission Assessment of Exposure to Noise, WG-AEN, drew up a Position Paper with the aim to help Member States and their competent authorities to undertake noise mapping and provide the associated data as required by the END (WG-AEN 2006). It was hoped that the content of this Position Paper could be particularly helpful for the preliminary draft of strategic noise mapping,

**Fig. 1** Location of Pamplona, Spain (© 2008 Google Maps)

which was supposed to have been completed by 30 June 2007. It was not meant to be a manual for strategic noise mapping but a source of reference for advice on specific issues that were raised initially by Member States. The Position Paper agrees that several of these issues are quite complex and have been dealt with in detail. In fact, when a sole variable is under study, quantifying its influence on the calculation is not challenging. Nevertheless, many of the variables are somehow connected with the calculation.

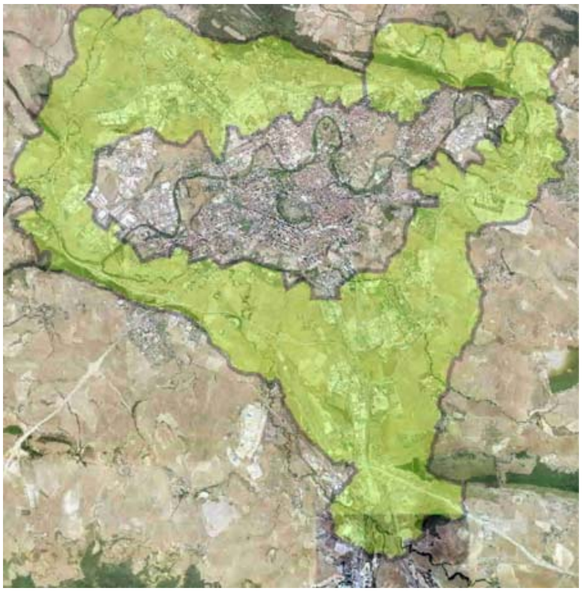


**Fig. 2** Calculation area, green for ring road (© 2008 Google Maps)

## Methodology

With the purpose of comparing the findings from both programs, a receiver points set was placed on a 10 × 10 m square grid, 4 m above the ground. The DTM was determined from the same elevation points and iso-curves. Naturally, all sources and buildings were identical for both software programs. The sole difference was how the bridge objects were dealt with. CA models bridges but in SP such objects do not exist and it is extremely complex to represent them in a similar way. The software procedures enabled us to come up with several configurations of the parameters. A similar configuration for both programs was used in this study (Table 1).

Even though line source maps offer more reliable knowledge as to point source maps (Yilmaz

**Table 1** Configuration of the parameters for both programs

| Parameter | SP | CA |
|---|---|---|
| Discretization of the sources | Angular step = 2 | Raster factor = 0.5 |
| Maximum search radius of sources | 2,000 m | 2,000 m |
| Lateral diffraction allowed | Yes | No |
| Tolerance (maximum error) | 0 | 0 |
| Grid interpolation | No (=1) | No |
| Calculate points inside buildings | No | No |
| Building absorption | 0.5 dB (=0.1) | 0.1 (=0.5 dB) |
| Ground absorption | 0.4 (mean value) | 0.4 (mean value) |
| Correction limit by diffraction | 25 dB | 25 dB |
| Reflection order | 1 | 1 |
| Reflection depth | 2 | Infinite (default) |
| Max. search radius of reflecting surfaces | Not available | 100 m |
| Min. dist. receiver–reflector and interpolation (for reflection) | Not available | 1 m; interpolation to 1 m |
| Max. dist. source–receiver and interpolation (for reflection) | Not available | 1,000 m; interpolation from 1,000 m |

and Hocanli 2006), a splitting up of the sources is needed in order to evaluate noise levels at receivers through a computational system. The splitting up of the line sources into equivalent point sources was configured by means of two different methods in SP and CA. The Raster Factor was established at 0.5, as it is the maximum value tolerated by ISO 9613-2 and which provides a very good time–accuracy ratio. Error in the calculation of an infinite line source is, in practice, equivalent if a Constant Angular Step of 2 is used (Arana and Aramendia 2006). While SP allows selecting lateral diffraction, CA does not calculate it whatsoever. A grid interpolation of 1 in SP is equivalent to no interpolation at all in CA. One of the most outstanding differences is found in the calculation of points within buildings. In SP it is possible to select the number of substitutive points but not the eliminated points. CA gives the option to either calculate them or not. Despite choosing not to calculate points inside buildings, both programs calculated some of them, but not exactly in the same way. The reflected surface search radius was only configurable in CA. Interpolation values were made use of. So as to select the reflecting surfaces depending on their sizes, SP applies two rules based on the angle of incidence, the wavelength and the distance between source, receiver, and reflecting surface. The configuration of reflection depth is only possible in SP, because

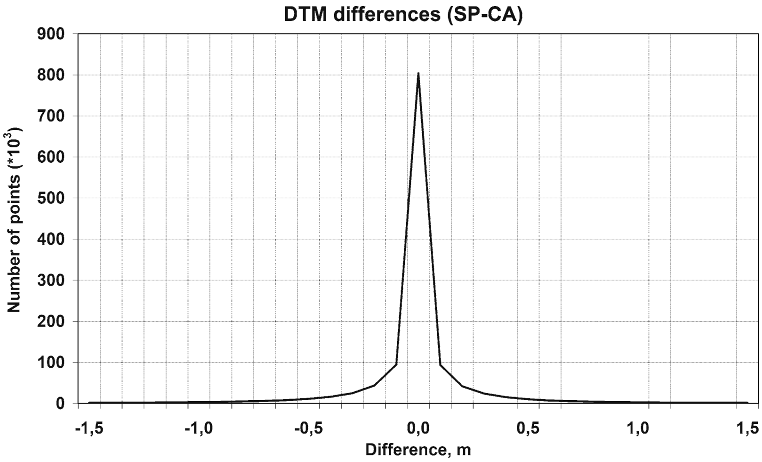
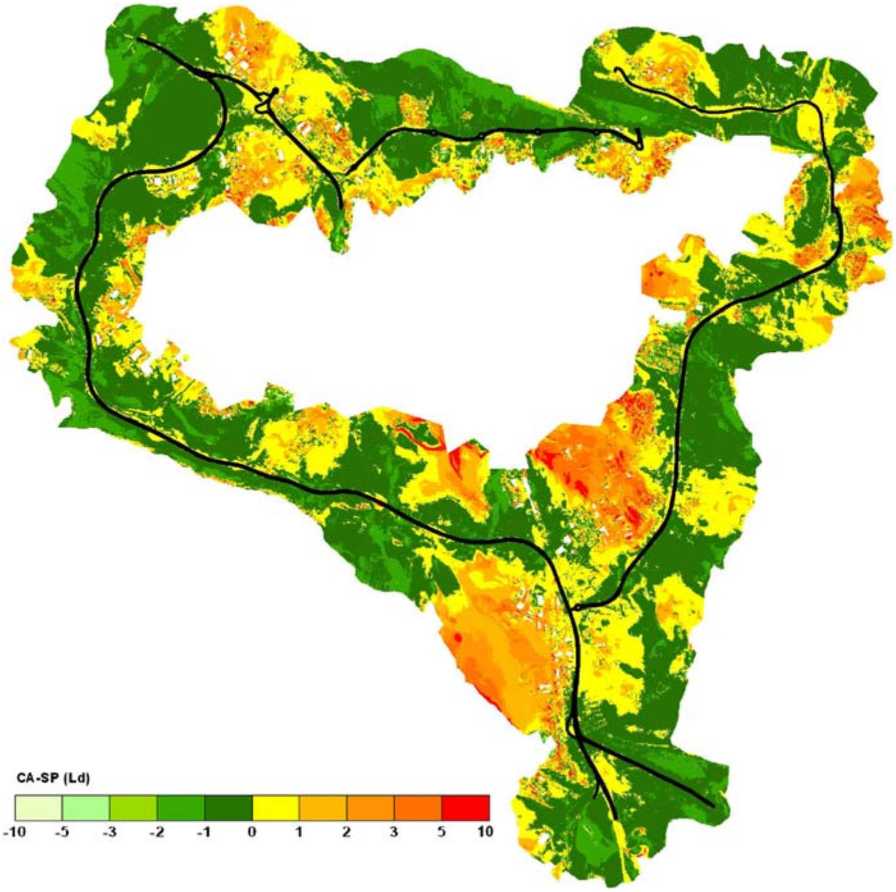


**Fig. 3** Histogram of differences in DTM (SP-CA)

**Fig. 4** $z$-coordinate differences (SP-CA) in the DGM

**Fig. 5** Map of differences (CA − SP)—*Ld* day period



through CA it is infinite by default. These are the reasons why the number of reflections is not the same in both programs.

## Results

### Differences on DGM

Wide variety methods have been developed to calculate the DTM by resorting to various algorithms. Concerning the two software systems analyzed in this work, CA presents three possible configurations whereas SP does not have any configurable parameter, and as a result its generated DTM is unique. This method—called triangulation—is based on the creation of triangular surfaces from existing contour lines and elevation points. Yet in CA it is also feasible to create a DTM by searching for contour lines with a specified radius. The first option so as to obtain the $z$-coordinates of the points is by calculating the average of the defined contour lines according to squared-distances. The second one is by reducing the distance from plane surfaces by means of defined contour lines. In addition to these two options, the relative height of the base of some objects may be taken as a reference point.

As the triangulation method generally provides the best results, this method has been used in our present research. It is based on Delaunay's triangulation since it is a computational structure which enables researches to obtain an excellent triangulation to depict the terrain. However, the various methods to implement the algorithm in geometric computational software to achieve a faster and less complex method of calculation generate some differences in the results.

To compare the DTM generated by CA and SP, calculating a grid of receivers will be required

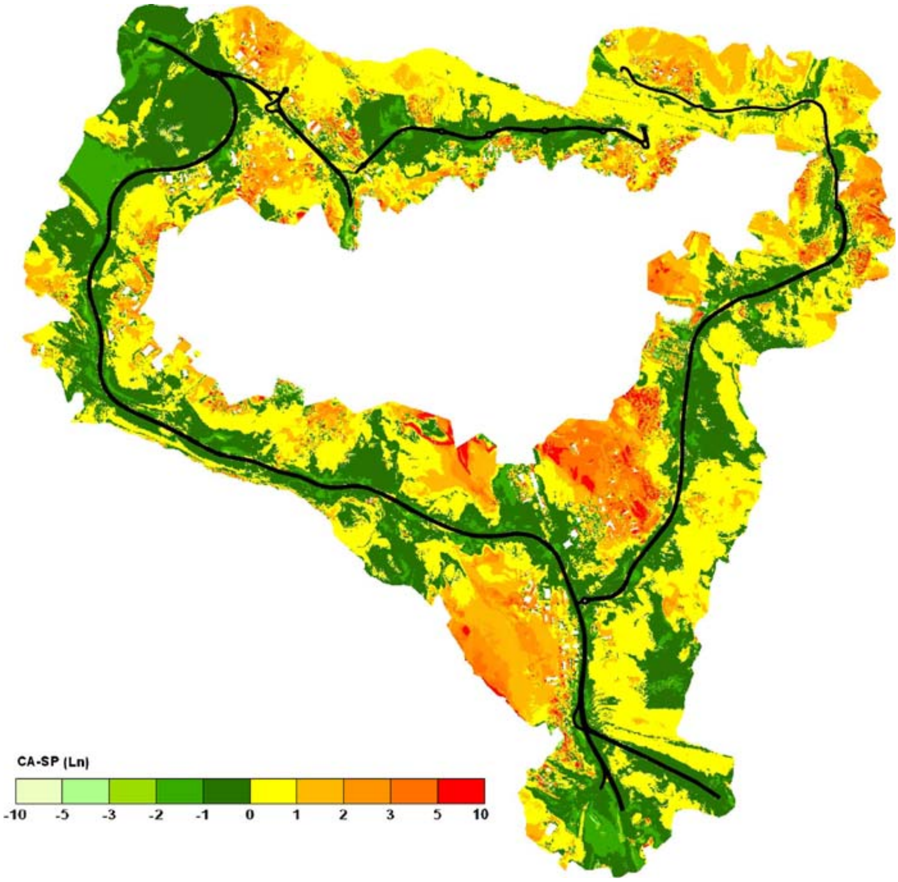


**Fig. 6** Map of differences (CA − SP)—*Ln* night period

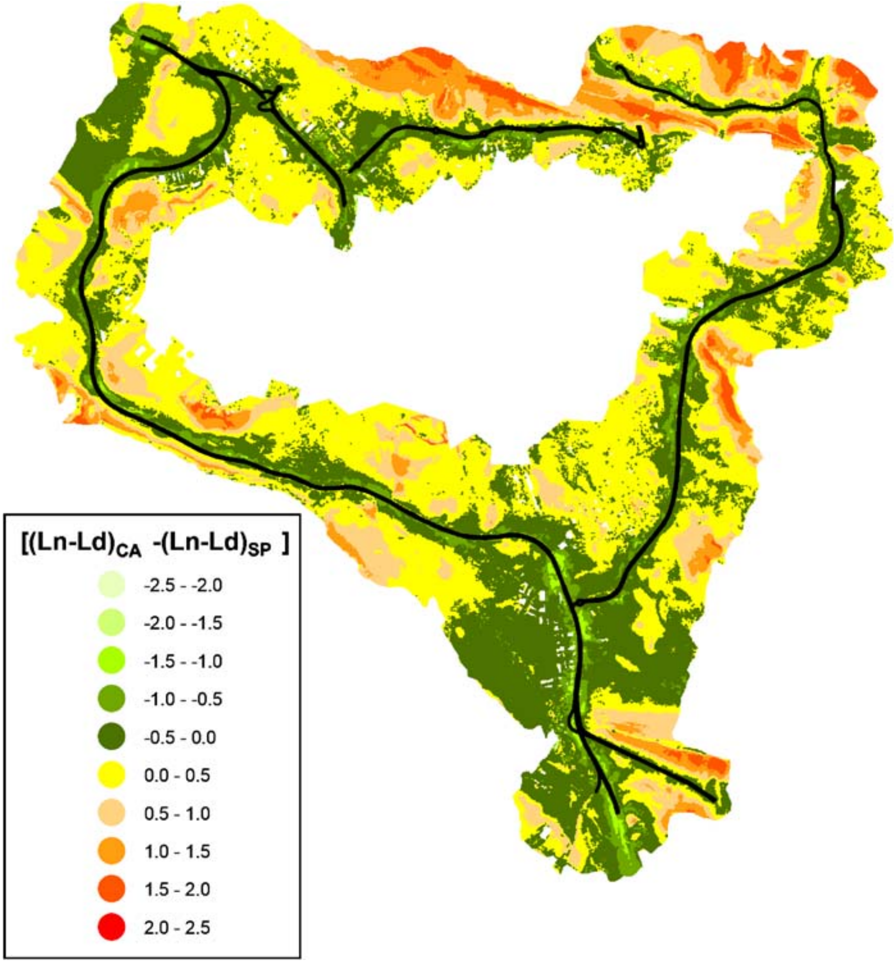
as it is not possible to export the triangulation of the DTM. The analysis is based on calculating the difference at each point of the grid. In this study, an area covering the city of Pamplona and its surroundings (including the ring road area) was used. The DTM was generated from 19,554 elevation points, 6,063 contour lines (iso-lines), and 11,448 curve lines (different height at each point). The *z*-coordinates of points ranged from 380 to 750 m. The grid was 10 × 10 m in size and the total number of points was, approximately, $1.26 \times 10^6$.

Figure 3 shows the histogram of differences (*z*-coordinate difference for all the $1.26 \times 10^6$ calculated points and compared one by one) grouped in ranges of 0.1 m, either positive or negative. Of the points, 93.3% differs less than 0.5 m, 5.8% differ between 0.5 and 2 m, 0.9% differs between 2 and 5 m, and 0.1% differs over 5 m. The two last ranges are not represented in the graphic. Figure 4 shows a colored map of differences outlining a small area that enables us to see the size of the grid and differences. The larger differences are concentrated near the boundary lines of the calculation area, especially in terrain with high gradients. With regards to this point, the most important conclusion drawn is that differences on predicted noise levels are not due (in the majority of cases) to differences obtained in the calculated DTM.

### Ld and Ln differences

For the strategic noise map of the ring road, the number of grid points calculated by each software—$6 \times 10^5$, approximately, in the calculation

**Fig. 7** Map of Ln–Ld differences [$(\text{Ln} - \text{Ld})_{\text{CA}} - (\text{Ln} - \text{Ld})_{\text{SP}}$]



area—varies. The main reason is that different methods are used to eliminate points inside buildings. Moreover, SP calculates some extra points in the boundary lines of the calculation area. To avoid unreal differences only the coincidental points from CA and SP have been utilized in the comparative study. Figures 5 and 6 show (again by a colored map) the differences on Ld and Ln figures from both programs.

Figure 5 shows an evident predominance of zones with a higher level in SP. These negative differences are almost in all cases less than 2 dB and are located in open air zones and/or areas with positive ground gradients viewed from the line sources. Even though there are fewer zones with positive differences—higher level predicted from CA—such differences are larger. These areas are found in urban areas and/or areas with

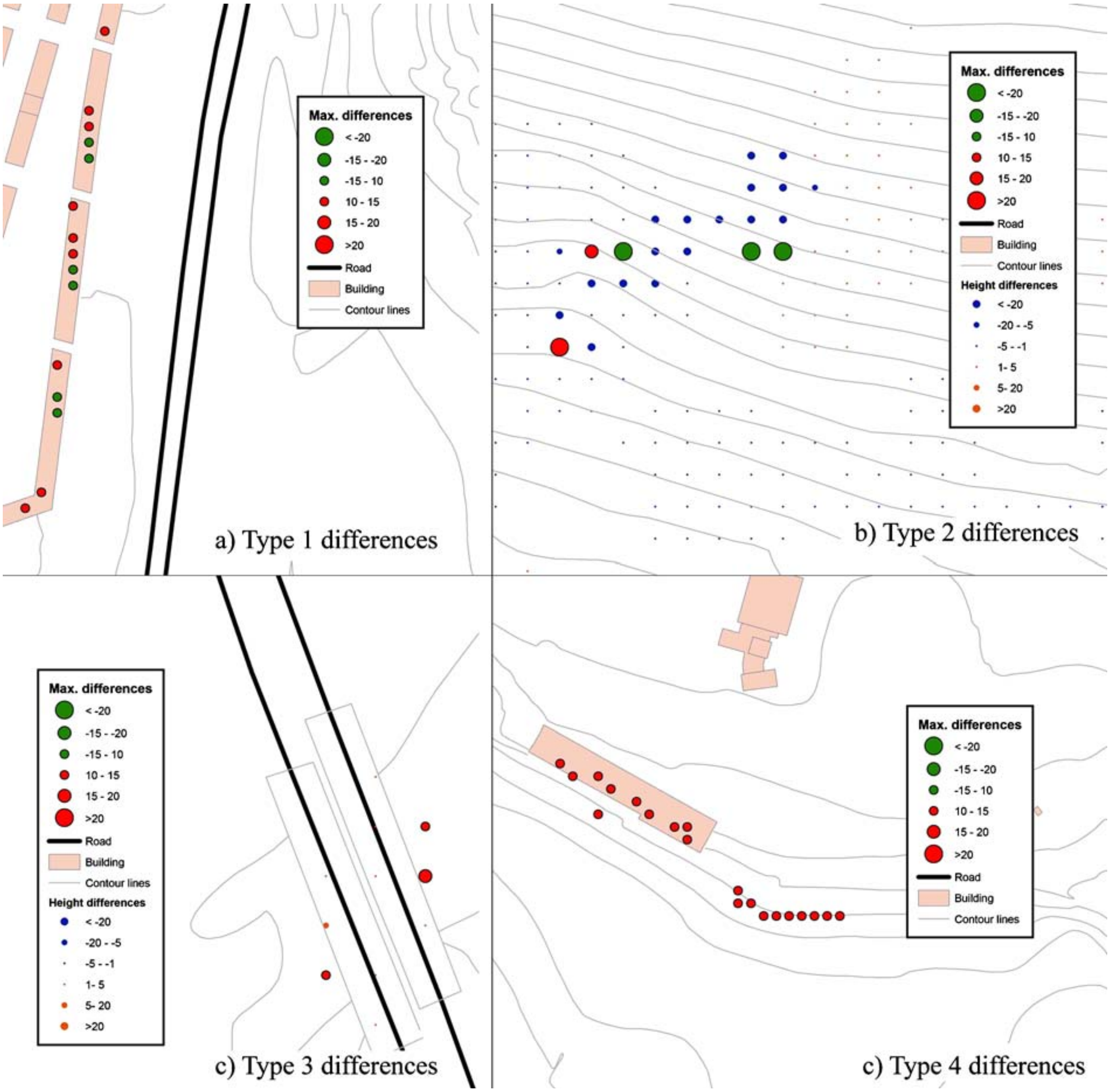


**Fig. 8** Main reasons to explain the noise levels differences

**Fig. 9** Normalised percentage histogram for levels intervals—*Ld* day period

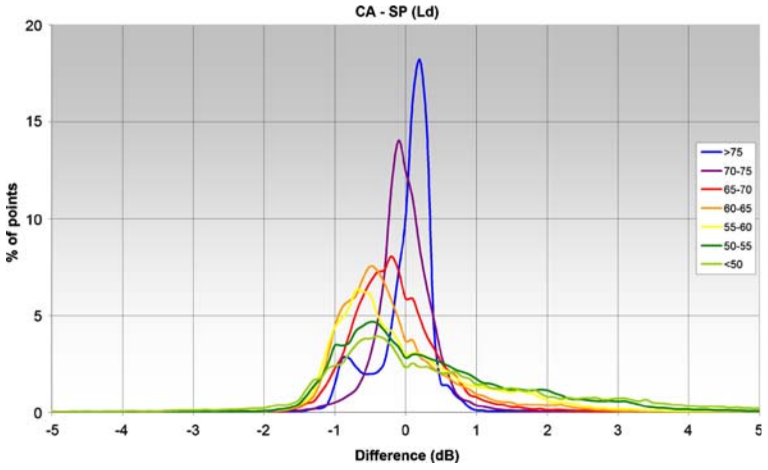


**Fig. 10** Normalised percentage histogram for levels intervals—*Ln* night period

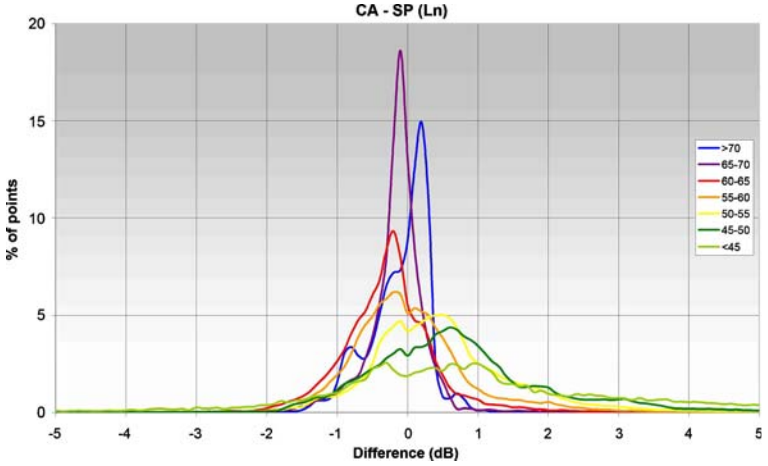
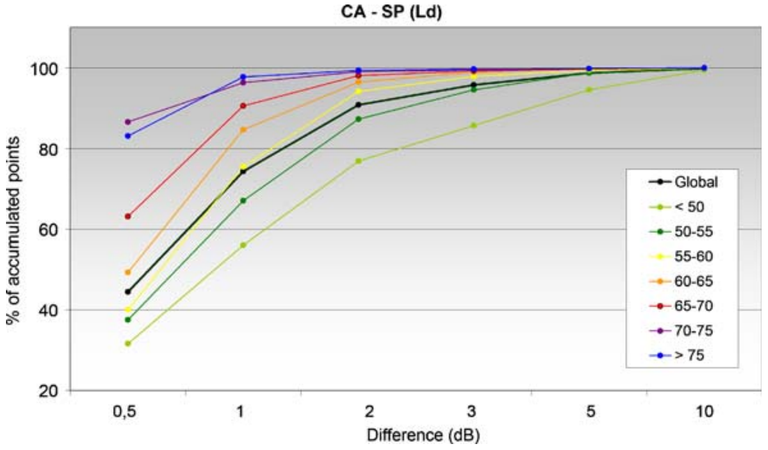


**Fig. 11** Accumulated percentage histogram of differences—*Ld* day period



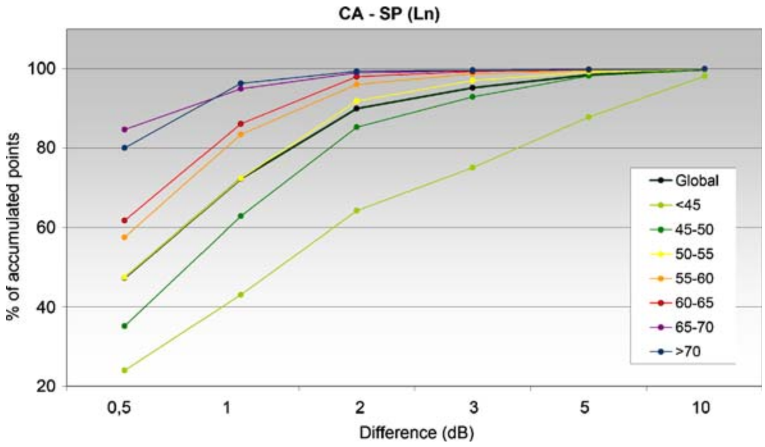


**Fig. 12** Accumulated percentage histogram of differences—*Ln* night period

negative gradients. In short, areas where receivers are screened more.

As shown in Fig. 6, there is a substantial change for the night. We must bear in mind that all the source variables—traffic flow, speeds, etc.—are identical for both software programs but the algorithms they make use of—discretization of the sources, reflection, etc.—are not exactly identical. Therefore, the ideal way to identify the cause of these differences is to display the Ln–Ld differences, that is to say, the difference among the differences from both programs (see Fig. 7). The implementation of the propagation under homogeneous and favorable atmospheric conditions varies according to the software programs resorted to.

A positive value in the map of Fig. 7 means that the difference between favorable and homogeneous conditions for propagation is higher in CA. and a negative one is higher in SP. Clearly, CA favors propagation under favorable atmospheric conditions.

The number of points with differences over 10 dB—positive or negative—represents a very low percentage of the total points (926 of 500,000) and the causes can be classified under four different types: (1) points within or on the building's boundaries calculated with both programs, (2) points with a great *z*-coordinate difference from the DGM, (3) points located behind bridges (only CA covers these situations), and (4) points located far away from sources and/or on great sloping terrain (see Fig. 8).

From a statistical point of view, there is yet another way to display the results with the aim of finding causes for the differences. By grouping the noise levels in ranges of 5 dB (from less than 50 dB to over 75 dB for Ld and from less than 45 dB to over 75 dB for Ln), Figs. 9 and 10 are obtained.

Three findings are achieved from these graphs. Firstly, the higher the noise level is (receiver points near the line sources) the lower the differences are. Only 3% of the receiver points with noise levels up to 70 dB differ over 1 dB. Secondly, the lower the noise level is (receiver points either far away from the line sources or screened) the greater the differences are. Almost 27.4% of the receiver points with noise levels down to 70 dB differ over 1 dB. Finally, although the day and night period graphics are quite similar, a displacement of the lower ranges to positive differences is perceptible. These entire findings suggest that the accuracy of predictions is exceptional for receiver points with high levels when the source discretization algorithm is solely used—and assuming there is a reliable source model—but predictions deviate for receiver points with low levels when many algorithms have a bearing, namely order and depth reflection, diffraction, etc. Figures 11 (Ld) and 12 (Ln) show identical results although through accumulated distribution.

## Conclusions

Two of the most widely used programs for the prediction of environmental noise have been used to determine the strategic noise map of the ring road that surrounds the city of Pamplona. All the initial data, both to generate the DGM (points, iso-curves, etc.) and to define the sources of noise (roads, traffic flow, speeds, etc.) were exactly the same. The French method, NMPB, was used to evaluate noise levels on the grid, with a total of $6 \times 10^5$ points, approximately. Configuration of the calculation parameters was the most equivalent model that programs allowed. In spite of that, many differences appeared in the findings. Differences were due to the various algorithms that programs implement to evaluate noise levels.

Although in 95.5% of the points the difference in the noise level calculated from the two programs was less than 3 dB, this general statistic result concealed some great differences. Most differences were related to points which were highly screened or located far away from the sources. In the former, the algorithm of visibility was the main cause of such differences. In the latter, differences were mainly brought about by a different implementation of the propagation under homogeneous and favorable atmospheric conditions from both software procedures.

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