Noise Mapping of the Flyover Highway in Genoa: comparison of different methods

Abstract: In urban noise mapping the accuracy of the simulation tools is often challenged by the complexity of the modeled scenario, particularly when its extent coincide with the whole city. In this paper, a meaningful case study is reported concerning the flyover highway “Aldo Moro” in Genoa. The particular morphology of the city and the location of the highway make it a significant test for analyzing the effectiveness of current modeling tools in simulating complex urban areas. Noise mapping has been implemented in accordance with the standard NMPB-Routes-2008. Results have been then analyzed complying with the END. Next diverse computational methods have been compared, considering ISO 9613-2, NMPB-Routes-1996, and Harmonoise, and even different frequency partitions (octave band or one-third octave band) for the last two standards. The computational time for the different calculation methods has been analyzed. In order to get a reciprocal validation, the simulated noise maps have been finally compared with maps coming from on field measurements. In this way a case study helpful for public administrations and stakeholders facing similar issues is provided, defining the state of the art and the forthcoming perspectives.

Keywords: noise mapping; traffic noise; computational methods; flyover highway

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1 Introduction

Since the last decades of the past century, the noise turned out to be one of the main environmental problems in Europe, with deep social effects that are to be dealt with not at level of the single individual but on a community scale [1–3]. The assessment of the exposition to environmental noise and of the related effects shall be made through an acoustic planning at territorial level in order to provide effective actions of noise control.

In the resolution of June 10th 1997, the European Parliament pointed out the need to lay down in a Directive measures and initiatives in order to reduce the environmental noise [4]. The Resolution supports in this way the Green Paper on Future Noise Policy [1], in which the noise in the environment has been defined as one of the main environmental problems in Europe. On 18th July 2002, the Official Journal of the European Communities published the European Directive 2002/49/EC (hereafter referred to simply as the END, acronym for Environmental Noise Directive) [5] relating to the assessment and management of environmental noise. By means of the END, the European Community faces the issue of noise pollution in urban areas, introducing common noise indicators, shared measurement techniques and evaluation methods for acoustical planning. Not all environmental sources are considered, but only roads, railways, air traffic and sites of industrial activity. The END is specially aimed at protecting from the environmental noise built-up areas, public parks or other quiet areas in an agglomeration, as well as quiet areas in open country, near schools, hospitals and other noise sensitive buildings. According to the END, the assessment and the control of the noise shall be done by progressively implementing these actions:

a) Determination of exposure to environmental noise, through noise mapping, by methods of assessment common to the Member States;

b) Ensuring that information on environmental noise and its effects is made available to the public;

c) Adoption of action plans by the Member States, based upon noise-mapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good.
After introducing noise indicators \( L_{den} \) for the annoyance and \( L_{night} \) for the sleep disturbance, the END considers computational methods in order to assess the values of \( L_{den} \) and \( L_{night} \) due to the various source typologies. In the lack of a common computational method, it is possible to use one of the interim computational methods recommended by the END in Annex II, relating to the noise source typology (e.g.: NMBP-Routes-1996, REKENEN 96, ECAC.CEAC Doc 29, ISO 9613-2).

While a precise definition of dose-effect relations, able to assess the harmful effects due to a long exposure to environmental noise, is postponed to future revisions of Annex III, the European Directive introduces two tools of acoustical planning in order to assess and manage the environmental noise: they are respectively the “strategic noise map” and the “action plan”.

The “strategic noise map” (SNM) is defined as “a map designed for the global assessment of noise exposure in a given area due to different noise sources or for overall predictions for such an area” and requires EU Member States to produce strategic noise maps in the major cities, for agglomerations with more than 250000 inhabitants, and for the main noise sources (major roads, major railways and major airports). Strategic noise map provides a representation of the noise levels perceived within this area, using as noise indicators \( L_{den} \) and \( L_{night} \).

After the issuing of the Directive 2002/49/EC, technical working groups (WG) of the European Commission have been set up in order to provide guidelines about how:

- to assess the effect of noise on populations in terms of annoyance and sleep disturbance, using suitable dose-effect relations;
- to make a strategic noise map;
- to design noise abatement plans and to execute these plans;
- to properly inform the public.

The guidelines have been written out in Position Papers for each topic. The contributions of these works will be implemented in a new revision of the European Directive. Member States had to bring into force the laws, regulations and administrative provisions necessary to comply with the END no later than 18th July 2004 (Article 14 of Directive 2002/49/EC).

Italy has acknowledged the END only in 2005 with the Decree D.P.C.M. no. 194 of 19th August 2005 “Attuazione della direttiva 2002/49/EC relative alla determinazione e alla gestione del rumore ambientale” [6]. From then on, Italy has started its path to the noise strategic mapping, promoting its implementation through the Municipalities and the Authorities in charge for the different infrastructures. Consequently, the Municipality of Genoa, a long time committed in facing noise pollution issues, promoted the noise strategic mapping of the town, focusing in particular on the major urban roads, as the END requires.

In the present paper, the Strategic Noise Mapping of a flyover highway that crosses a densely populated urban area in the center of Genoa is presented and analyzed. This important arterial road, named after Aldo Moro, is 5 kilometers long and connects different neighborhoods of the downtown. The path skirts the historical town and passes along the old port and a densely populated area, so that the road is a relevant source of noise annoyance and sleep disturbance for a large number of citizens. The particular position of the highway and the fact to be a flyover infrastructure makes difficult to design improvement actions. The exposed population reacts to this with complaints and protests, so that the Municipality decided to face this issue with a specific analysis of the noise impact in terms of Strategic Noise Mapping, whose results are reported in the present paper. The purpose is to provide a case study helpful for public administrations and stakeholders facing similar issues, defining the state of the art and the forthcoming perspectives.

2 Noise Mapping and Strategic Noise Map

Strategic Noise Maps shall contain unwanted or harmful outdoor sounds, also known as environmental noise, created by different human activities, including noise emitted by road, rail, air traffic and industrial activities. To investigate the environmental noise, some noise indicators should be introduced to show a physical scale and a relationship with the effect on the population, including annoyance and sleep disturbance.

The European Directive 2002/49/EC has defined separately noise mapping and strategic noise map in this way:

- “Noise mapping” shall mean the presentation of data on an existing or predicted noise situation in terms of a noise indicator, indicating breaches of any relevant limit value in force, the number of people affected in a certain area, or the number of dwellings exposed to certain values of a noise indicator in a certain area (European Directive 2002/49/EC, Article 3, letter q);
- “Strategic noise map” shall mean designed for the global assessment of noise exposure in a given area due to a different noise sources or for over-
all predictions for such an area (European Directive 2002/49/EC, Article 3, letter r). Furthermore: strategic noise mapping should be imposed in certain areas of interest as it can capture the data needed to provide a representation of the noise levels perceived within that area (European Directive 2002/49/EC, Point 10).

In a nutshell, a Strategic Noise Map is a map designed for the global assessment of noise exposure in an urban area due to various noise sources. Also, it could be a tool for an overall noise impact prediction on which action plans and specific improvement actions can be based. At operational level, practice guidelines for Noise Mapping and Strategic Noise Map have been drawn up with regards to the different noise sources and, in particular, the road noise.

“Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure” was gathered in a document called Position Paper. Three different versions of this document can be found:

- 1st Version published on 5th October 2003 [7]
- 2nd Version – Final Draft published on 13th January 2006 [8]
- 2nd Version published on 13th August 2007 [9]

At Italian level, these Practice Guidelines have been gathered in Italian Standard UNI/TS 11387 [10] of October 2010, adding some specific aspects at national level.

The 2nd Version [9] will be here considered and discussed since it drastically revised, modified and enhanced the 1st Version of the Position Paper, taking into account the feedback from consultation process and recent developments, including the results of two research projects, NANR93 [11] and NANR208 [12], sponsored by the United Kingdom (UK) Government. In particular the report NANR208 “Part 4: Quantified Accuracy of GPG Toolkits – RMR Interim” [13] is the most relevant with regards to this 2nd Version of the Position Paper. As in the present research, noise mapping has been implemented only in relation to road traffic noise, topics of the Position Paper concerning other noise source typologies will not be taken into account and discussed.

It is important to underline that the Position Paper is not a manual for strategic noise mapping but it provides advice on specific issues that were surfaced initially by the EU Member States and more recently were highlighted through consultation on 1st Version. With this paper WG-AEN has attempted to find an appropriate balance between the need for a consistent approach across Europe and the flexibility required by individual Member States to develop noise-mapping programs that meet their own national needs.

A number of different subjects are analyzed in the different Chapters of the Position Paper. During the development of the noise mapping of the flyover highway our attention has been focused especially on Chapter 2, which deals with the issues that can occur during the preparation of strategic noise map, debating them and providing recommendations, and on Chapter 4, which provides toolkits that deal with these issues. In this sense, in order to exemplify the methodology of the Strategic Noise Map, the flyover highway in Genoa represents a considerable case study, through which the above mentioned elements are put in action and analyzed, and portrays a reference experience useful for all people involved in carrying out the SNM or needing to implement its monitoring.

3 The Noise Mapping of the flyover highway in Genoa

The flyover highway Aldo Moro in Genoa passes through the urban districts of Genoa Foce, Genoa Centro, Genoa Dinegro and Genoa Sampierdarena, until the toll gate of Genoa Ovest on the A7 highway. A satellite view of the flyover highway and the surrounding area is shown in Figure 1 and a height contour map is presented in Figure 2. In Figure 2 it is also shown the use of the building in the case study area.

More than 25 million of vehicles annually pass through the flyover with a traffic trend almost constant throughout the year. Since the number of vehicle passages exceeds the number of 6 million is required by the Euro-
pean Directive 2002/49/EC to create a strategic noise map for this area.

The route is about 5 km long and is formed by 2 carriageways, one for each direction without emergency lanes, divided by a gap and a central double guard rail. Each carriageway has 2 lines. The width of each line is averagely 3.5 m and the total width is about 16 m. The road altitude is variable with an average height of 14 m. The vehicles that commonly pass through the flyover are cars and motorcycles since the road is interdicted to mopeds, bicycles, heavy vehicles (more than 2.5 t) like trucks and buses for public transportation. The area on the south side of the flyover Aldo Moro is quite different from the area on the north side, both at morphological and urban level, since also the land use is different on the two sides, as well as from west to east.

At morphological level, the terrain is quite variable with significant slope and retaining walls in the area close to “Foce” district and with a more open field for “Dinegro” and “Sampierdarena” districts. At urban level, the south side is less densely populated as the land use is characterized by industrial sites (shipyards, dry docks, marinas, ferryboats stations, etc.) while the north side is mainly characterized by historical dwellings and few recent buildings (Figure 2). Both sides are characterized by a net of roads under the flyover, many of which are quite narrow, as it is typical of the urban fabric in Genoa. Another main road is placed parallel and somewhere under the flyover, from “Foce” to “Dinegro”.

The data traffic from year 2005 have been used to get the annual average number of vehicles per hour in each considered section. Results are shown in Table 1 for the direction West to East, divided in the 3 periods per day: day (6.00 a.m. – 8.00 p.m.), evening (8.00 p.m. – 10.0 p.m.) and night (10.0 p.m. – 6.0 p.m.). The annual average number of vehicles per hour in each considered section for the direction East to West is shown in Table 2, divided in the 3 periods per day: day (6.00 a.m. – 8.00 p.m.), evening (8.00 p.m. – 10.00 p.m.) and night (10.00 p.m. – 6.00 p.m.).

As a consequence of the traffic flows, road characteristics and intersection with the entrance (one from east to west, named Quadrio) and with the exits (one from east to west, named Casacce, and two from west to east, named Caricamento and Portoria) the speed changes in the differ-

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**Table 1:** Annual average number of vehicles per hour for Direction West to East.

| Section 1 Entrance | Day | Evening | Night |
|--------------------|-----|---------|-------|
| Caricamento        |     |         |       |
| Left Line          | 1034| 687     | 299   |
| Right Line         | 1101| 404     | 132   |

| Section 2 Caricamento | Day | Evening | Night |
|-----------------------|-----|---------|-------|
| Left Line             | 844 | 364     | 113   |
| Right Line            | 1112| 693     | 271   |

| Section 3 Caricamento | Day | Evening | Night |
|-----------------------|-----|---------|-------|
| Left Line             | 623 | 255     | 78    |
| Right Line            | 698 | 471     | 180   |

**Table 2:** Annual average number of vehicles per hour for Direction East to West.

| Section 1 Foce | Day | Evening | Night |
|----------------|-----|---------|-------|
| Casacce        |     |         |       |
| Left Line      | 907 | 284     | 153   |
| Right Line     | 1093| 604     | 345   |

| Section 2 Casacce | Day | Evening | Night |
|-------------------|-----|---------|-------|
| Left Line         | 935 | 598     | 354   |
| Right Line        | 956 | 253     | 119   |
ent road sections. In general the speed is higher when the
traffic is smooth-flowing, and for the studied period (data
traffic from year 2005) the annual average values 85 km/h.
To create the model the used speed is the value of speed
limit, equal to 60 km/h.

To predict the traffic noise propagation in the chosen
area, a numerical model of the acoustic field has been
implemented by using the commercial software MITHRA-
SIG version 3.3.0 [14], a calculation and simulation soft-
ware based on ray and beam tracing algorithms integrated
with a geographic information system (GIS, in French Sys-
tème d’Information Géographique-SIG, hence the name
of the software) able to calculate noise levels in accor-
dance to EU Directive 2002/49/CE. The advantage of hav-
ing a noise simulation software integrated with a GIS is
the possibility of merging together various datasets, usu-
ally available in a number of different file formats, thus
obtaining additional useful information from the simu-
lations carried out [15]. The computation method NMPB-
Routes-2008 [16], which is the latest revision of the NMPB-
Routes-1996 [17] method recommended by the END and by
the Italian Decree D.P.C.M. 194/2005 for road traffic noise
was used for road noise modelling. Simulations have been
carried out using a PC equipped with a Windows 7 Profes-
sional 64 bit operating system, an Intel Core i7 3770 CPU
(with 8 available threads) and 16 GB of RAM.

The area to be mapped was defined only through the
traffic noise originated by the flyover highway, and no
other road source was taken into account. Because of the
sharp reduction of the noise level due to the dense layout
of buildings close to the highway, instead of following the
guidelines in Position Paper, i.e. the level line 50 dB(A), the
interest area was extended at 700 meters from the highway
centerline on both sides, so setting the mapping distance
for sound propagation.

The map was created considering the ground mor-
phology and its absorbing characteristics and the road
traffic sources belonging to the flyover highway. In or-
der to recreate the real situation of field for noise propa-
gation, the buildings and other infrastructures were in-
serted into the model. The receivers point grid has been
set as a 10×10 m square grid, 4 m above the ground.

In the real situation there are many other roads and
single events linked to the road traffic noise which can an-
noy the people, as the honk and the braking. These kinds
of noise were not taken into account in the model, because
the single events are spread on the long period and there-
fore they do not give a significant contribution to the noise
indicators considered for the noise mapping.

The resulting maps, representing the noise propaga-
tion at 4 meters above the ground and the flyover, using
the NMPB-Routes-2008 method in 1/1 octave band for both
the noise indicators $L_{den}$ and $L_{night}$ are reported in Fig-
ure 3. Map colors have been defined in accordance with the
ISO 1996-2:1987 [18] standard, since the newer ISO 1996-
2:2007 does not define the colors for the different noise lev-
els [19]. For both day period and night period the mapping
shows a different behavior on the two sides of the high-
way, due to the different urban pattern. The dense build-
ings network and the sloped hills on the north side pro-
duce a sharp reduction of noise levels with the distance,
that the model correctly reproduces. On the sea side the
open area and the raised position of the highway cause the
simulator to predict a far away propagation of noise, as it
actually happens. Similar noise propagation patterns are
simulated during the two reference periods, with an over-
all reduction of noise levels due to the lower night traffic
flow. It must be underlined these maps refer to 4 m from the
ground. That is effective for flat ground and low buildings.
But when the terrain is sloped and buildings are tall, not
all useful information can be caught with this representa-
tion, since while at 4 m height the receivers are screened by
the buildings in front, the highest floors are in direct view
of the source, and there noise levels are definitely louder
than what shown in the map.

In order to have a comparison and a benchmark (in
terms of computational time) with other methods suitable
for evaluating road traffic noise, simulations have been
carried out using also NMPB-Routes-1996, NMPB-Routes-
2008 (1/3 octave band), Harmonoise [20–23] (both in 1/1
and 1/3 octave band) and ISO 9613-2 [24]. These meth-
ods are very different for what concerns the sound prop-
agation: basically, ISO 9613-2 is based on simple empiri-
cal correlations, while algorithms used in NMPB-Routes-
1996 and NMPB-Routes-2008 are able to handle more sit-
uations, several of them being approximations of more
complex physical formulations or heuristic corrections; in
Harmonoise, on the other hand, each physical phenom-
ena is modelled using a physical model and this results
in more complex mathematical expressions. These models
were evaluated (except NMPB-Routes-1996) in the frame-
work of phase A of the CNOSSOS-EU process using six
qualitative criteria, i.e. precision, accuracy, computational
speed, flexibility, simplicity and number of parameters [25].
Results of the evaluation, made with a limited number of
rather simple ideal test cases, showed that, for the purpose
of strategic noise mapping, all the methods can be run
from the same set of input parameters; the Harmonoise
method appears to be the most flexible due to its capability
of modelling different ground impedances and meteoro-
logical conditions, but less accurate in predicting attenua-
tions with respect of a reference receiver close to the source.
and also less precise (intended as the degree of spread in the result obtained if the method is applied by different experts) and transparent (traceability of unexpected results) if compared to the other two methods. Kephalopoulos et al. [25] state anyway that no general conclusions can be drawn and that extended validations have to be performed in phase B of the CNOSSOS-EU process. As it could be expected, for what regards simplicity the degree of complexity arises starting from ISO 9613-2 to NMPB-Routes-2008 and finally Harmonoise, while the computational speed is similar for the first two methods but drastically rises for Harmonoise: this latter aspect will be deeply discussed in Section 4 of the present paper.

Regarding the road emission simulation method, MITHRA-SIG converts roads into linear sources and assigns a source height in accordance with the chosen method; for the simulations described in this study, the NMPB-Routes-2008 emission method has been chosen for all the simulations, setting so the height of the source at 0.05 m above the road surface [26, 27]. In addition, since the MITHRA-SIG software is available with different licenses, that allow or do not allow multiple CPUs computations, all simulations have been run two times, with both single-CPU and multiple-CPUs configurations, in order to test the difference in computational time for the different methods considered.

Maps from Fig. 4 to 8 represent the \( L_{den} \) calculations carried out for the purpose of comparing the different calculation models. The same colors in all maps were used in compliance with ISO 1996-2:1987 standard. In general, maps show relevant discrepancies, so confirming the criticalities that presently occur in traffic noise modeling. These discrepancies concern not only diverse methods, since the same standard seems to produce slightly different results depending on the frequency partition adopted (octave band or one-third octave band). All these aspects have been discussed in detail in the following section.

4 Discussion of the results

The picture of the noise impact of the flyover highway, based on the noise maps showed above, represents a critical situation. A noticeable number of citizens resulted to be exposed to high sound pressure levels, considering both the whole day (\( L_{den} \) indicator), both the night period (\( L_{night} \) indicator).

The total estimated amount of people living in the area settled up as the domain of the acoustical simulation is 62300 units, estimated considering the population indicated in the statistical report of the Municipality of Genoa for the situation at 31st December 2012.

As requested by the END, in Table 3 is shown the total amount of people living in dwellings exposed to each of the different \( L_{den} \) bands as well as the total affected surface, expressed in km\(^2\). In Table 4 the same quantities are reported regarding \( L_{night} \). In each table the results for diverse methods are reported. For NMPB-Routes-2008 and Harmonoise methods, even the comparison between different frequency partitions (octave band or one-third octave band) is shown.

Concerning the range of \( L_{den} \) values higher than 55 dB(A), for all the computational methods except NMPB-Routes-2008, the most of the population is exposed to levels from 55 to 59 dB(A), followed by people exposed to
Figure 4: $L_{den}$ simulation using NMPB-Routes-2008 (1/3 octave band).

Figure 5: $L_{den}$ simulation using NMPB-Routes-1996.

Figure 6: $L_{den}$ simulation using Harmonoise (1/1 octave band).

Figure 7: $L_{den}$ simulation using Harmonoise (1/3 octave band).

$L_{den}$ ranging from 60 to 64 dB(A) and from 65 to 69 dB(A). For the simulations made with the NMPB-Routes-2008 method, the results show that the most of the population is exposed to levels between 60 and 64 dB(A). Analyzing the map in Figure 8 and the values reported in Table 3, it could be noted that, with a little increase of surface affected by $L_{den}$ levels from 55 to 59 dB(A), the population exposed according to the ISO 9613-2 method is about four times higher than the value calculated with the other methods. This fact can be explained by considering that the model, for each building, takes into account a mean occupation calculated in function of the total surface and the number of floors of the building itself, and the total amount of people was estimated using the statistical report of the Municipality of Genoa without a real reference to the actual distribution in each building. In this way, the software allocates to certain mixed-use buildings (both commercial/public and residential) with a very large volume a number of occupants that is not representative of the real situation: incidentally, for ISO 9613-2 some of these buildings fall exactly in the 55÷59 dB(A) $L_{den}$ range, thus causing the observed overestimation of the exposed people. In this way a small increase in the area extension can be linked to a large increase in the exposed population, not necessary corresponding to a real rise. This point must be accurately considered in noise mapping of large areas, when a precise definition of the characteristics of buildings cannot be implemented, and deserves a post processing analysis and correction.

As shown in Table 4, the number of exposed citizens decreases as $L_{night}$ increases for all used methods, with few
receivers in the bands over 60 dB(A). A number of high values is not surprising, since the road passes through a dense urban area. Some dwellings are few meters away from the highway and the traffic along is actually continuous, as the vehicle flow indicates.

Two elements are to be underlined. The first is the relevant role played by the morphology of the territory. The highway lies between the coast and the hills, on which buildings are built. The first row of buildings only partially shields the ones behind, since only the lower floors are obstructed. It must be considered that tall buildings are typical of the Genoa downtown, having 5 floors or more. The result is that a number of citizens are in sight of the road, thus receiving a direct contribution from the source. A second point concerns the area south of the flyover highway, occupied by the port and poor of dwellings. On that side there are mainly working activities and the noise emissions primarily affect the working conditions rather than the life comfort. The presence of an industrial area on the south side of the road tends to limit the meaning of such an analysis, which should be restricted to the urban zones of the city. In other words, the evaluation of the exposed area according to the EU Directive overweights the real noise impact on the territory.

Regarding the comparison among noise mapping methods, it is well known that this is a critical issue, since there is not a uniform approach: the END recommends several standards, but the Member States are free to use their own calculation methods or alternative ones [28]. In literature studies are present regarding comparisons between software [29–31], methodologies and procedures [32, 33] and prediction methods [31, 34], also in the form of reviews [35, 36]. Probst [34] underlines that there are very large differences in terms of calculated levels and computational time between the various methods, but refers only to test cases with very simple geometries and built up scenarios.

Aiming to deepen this topic, simulations have been run using the various computational methods implemented by the software MITHRA-SIG (namely ISO 9613-2, NMPB-Routes-1996, NMPB-Routes-2008 and Harmonoise) in a real and complex scenario like the one described in this paper. In order to facilitate the analysis, the road source emission method NMPB-Routes-2008 was adopted for all the simulations carried out, as previously described. For the sake of brevity, in the paper are only reported the comparisons concerning $L_{den}$ indicator. Similar maps have been drawn for $L_{night}$ indicator too, with similar results.

Maps from Figure 9 to Figure 13 show the difference between the $L_{den}$ values obtained with the NMPB-Routes-2008 (1/1 octave band) method and the other methods considered, while Table 5 and Table 6 show a statistical analysis of the levels distribution at the receiver points (86725 receivers) for $L_{den}$ and $L_{night}$ indicators respectively. For NMPB-Routes-2008 and Harmonoise methods even the comparison between different frequency partitions (octave band or one-third octave band) has been implemented.

It could be noted that the legends of these figures are different from one to another: the reason is that every comparison has its own range of maximum and minimum difference values, and the software creates an automatic optimum subdivision of these intervals in order to better show differences among methods and avoid the omission of certain values. Authors decided to follow this approach for the purpose of highlighting the actual difference between two specific methods. As it can be noted, the differences between NMPB-Routes-2008 method in octave band and the same method with one-third octave band are negligible, while the comparison with NMPB-Routes-1996 shows that the predictions of this latter method tend to overestimate the ones obtained by means of the 2008 revision. The comparison with the Harmonoise model shows differences generally ranging between $-2$ dB(A) and 6 dB(A), while the biggest differences occur, as it might have been expected, when the comparison is made with ISO 9613-2 model. ISO 9613-2 method is also the one that shows the highest variance and deviation values, the lowest mean and median values and the only one of all considered methods that shows two peaks in the levels distribution. All of this happens for both $L_{den}$ and $L_{night}$ indicators.

Interesting information has been obtained regarding computational time versus simulation method: as it can be seen in Figure 14, for all the simulation methods with the exception of Harmonoise, the time needed to run the sim-
Table 3: Total amount of people exposed and total surface affected ($L_{den}$).

| $L_{den}$ Noise Level | NMPB-Routes-2008 oct | NMPB-Routes-2008 1/3 oct | NMPB-Routes-1996 | ISO 9613-2 | Harmonoise oct | Harmonoise 1/3 oct |
|-----------------------|-----------------------|---------------------------|-------------------|------------|---------------|-------------------|
| People (km$^2$)       | People (km$^2$)       | People (km$^2$)           | People (km$^2$)   | People (km$^2$) | People (km$^2$) | People (km$^2$)   |
| 55 - 59 dB(A)         | 738                   | 849                       | 849.57            | 740.41     | 741.26         | 726               |
| 60 - 64 dB(A)         | 840                   | 842                       | 629               | 545        | 549           | 549               |
| 65 - 69 dB(A)         | 409                   | 409                       | 482               | 317        | 320           | 320               |
| 70 - 74 dB(A)         | 257                   | 257                       | 254               | 237        | 64            | 64                |
| > 75 dB(A)            | 13                    | 13                        | 9                 | 2          | 2             | 2                 |
| People (km$^2$)       | People (km$^2$)       | People (km$^2$)           | People (km$^2$)   | People (km$^2$) | People (km$^2$) | People (km$^2$)   |
| 55 - 59 dB(A)         | 738                   | 736                       | 736               | 700        | 671           | 671               |
| 60 - 64 dB(A)         | 840                   | 840                       | 449               | 322        | 321           | 321               |
| 65 - 69 dB(A)         | 466                   | 466                       | 449               | 469        | 322           | 322               |
| 70 - 74 dB(A)         | 76                    | 76                        | 67                | 73         | 198           | 198               |
| > 75 dB(A)            | 0                     | 0                         | 0                 | 0          | 0             | 0                 |

Table 4: Total amount of people exposed and total surface affected ($L_{night}$).

| $L_{night}$ Noise Level | NMPB-Routes-2008 oct | NMPB-Routes-2008 1/3 oct | NMPB-Routes-1996 | ISO 9613-2 | Harmonoise oct | Harmonoise 1/3 oct |
|-------------------------|-----------------------|---------------------------|-------------------|------------|---------------|-------------------|
| People (km$^2$)         | People (km$^2$)       | People (km$^2$)           | People (km$^2$)   | People (km$^2$) | People (km$^2$) | People (km$^2$)   |
| 50 - 54 dB(A)           | 830                   | 830                       | 683               | 700        | 671           | 671               |
| 55 - 59 dB(A)           | 466                   | 466                       | 449               | 322        | 321           | 321               |
| 60 - 64 dB(A)           | 76                    | 76                        | 67                | 73         | 198           | 198               |
| 65 - 69 dB(A)           | 4                     | 4                         | 4                 | 4          | 4             | 4                 |
| > 70 dB(A)              | 0                     | 0                         | 0                 | 0          | 0             | 0                 |

Figure 9: $L_{den}$ comparison NMPB-Routes-2008 (1/1 octave) vs. NMPB-Routes-2008 (1/3 octave).

Figure 10: $L_{den}$ comparison NMPB-Routes-2008 (1/1 octave) vs. NMPB-Routes-1996.

ulation grows with the complexity of the chosen method with a quite slow trend, both considering single CPU or multiple CPU computations. When considering the Harmonoise method, the computational time suddenly becomes a number of times higher than the adopted reference method (NMPB-Routes-2008 in 1/3 octave band), for both the single and multiple CPU configurations. In general, calculation time considerably increases if running a one-third octave band simulation enabling either multiple or single CPU computations. The computing goes further almost two or three times for Harmonoise, while for NMPB-Routes-2008 the further duration strongly depends on CPU category. As to be expected, the usefulness of multiple CPUs becomes more and more relevant as the complexity of the model rises.

Other simulations have been carried out using different road source emission methods, and although they will not be illustrated in this paper for reasons of brevity, it is nevertheless interesting to report here the extreme values obtained (single CPU calculations): using ISO 9613-2 calculation method coupled with NMPB-Routes-1996 road emission method results in a simulation time of 01h:21m:43s, whereas a 1/3 octave band Harmonoise simulation with its own road emission sources gives a computational time of...
### Table 5: Simulation statistics at receiver points (\(L_{den}\))

|                      | Num. of receivers | Minimum | Maximum | Mean | Variance | Deviation | Median | Percenter 75 | Percenter 50 | Percenter 95 | Percenter 99 |
|----------------------|------------------|---------|---------|------|----------|-----------|--------|--------------|--------------|--------------|--------------|
| ISO-9613-2           | 86725            | 0.00    | 90.99   | 42.44| 131.95   | 11.59     | 41.23  | 49.06        | 56.66        | 62.27        | 76.16        |
| NMPB-Routes-1996     | 86725            | 0.00    | 80.90   | 42.17| 134.42   | 11.99     | 41.74  | 49.45        | 56.85        | 62.34        | 76.18        |
| NMPB-Routes-2008 (1/1 octave band) | 86725            | 0.00    | 80.87   | 42.79| 116.91   | 10.91     | 41.49  | 47.90        | 56.99        | 62.89        | 76.51        |
| NMPB-Routes-2008 (1/3 octave band) | 86725            | 6.45    | 81.27   | 42.79| 123.72   | 11.40     | 41.42  | 47.29        | 56.11        | 62.20        | 76.41        |
| Harmonoise (1/1 octave band) | 86725            | 0.00    | 81.19   | 41.62| 115.10   | 11.10     | 35.55  | 47.29        | 56.11        | 62.20        | 76.41        |
| Harmonoise (1/3 octave band) | 86725            | 0.00    | 81.19   | 41.62| 123.72   | 11.40     | 35.55  | 47.29        | 56.11        | 62.20        | 76.41        |
Table 6: Simulation statistics at receiver points ($L_{night}$).

| Method          | Num. of receivers | Minimum | Maximum | Mean | Variance | Deviation | Median | Percentile 75 | Percentile 95 |
|-----------------|-------------------|---------|---------|------|----------|-----------|--------|---------------|---------------|
| ISO-9613-2      | 86725             | 0.00    | 72.61   | 35.51| 113.77   | 10.67     | 35.50  | 40.55         | 54.08         |
| NMPB-Routes-1996| 86725             | 0.00    | 72.56   | 33.38| 123.13   | 11.10     | 32.96  | 40.51         | 54.01         |
| NMPB-Routes-2008 (1/1 octave band) | 86725 | 0.00 | 72.54 | 33.09 | 122.99  | 11.09     | 32.67  | 40.53         | 54.00         |
| NMPB-Routes-2008 (1/3 octave band) | 86725 | 0.00 | 72.32 | 33.17 | 112.34  | 10.60     | 31.32  | 38.90         | 47.75         |
| Harmonoise (1/1 octave band)       | 86725             | 0.00    | 72.90   | 33.15| 172.34   | 10.80     | 31.28  | 38.92         | 53.90         |
| Harmonoise (1/3 octave band)       | 86725             | 0.00    | 72.90   | 33.15| 172.34   | 10.80     | 31.28  | 38.92         | 53.90         |
105h:03m:15s. This confirms that Harmonoise is certainly a superior method if compared to the other ones, but it could be difficult to carry out the calculation of large scale noise maps using this method [25] unless having access to very powerful computing workstations or clusters [37]. The large difference among calculation times can then lead to the consideration that, when very large urban areas are to be modeled, simpler methods can be effective for a first rough assessment, since the computing does not take such a long time as for Harmonoise.

An interesting comparison can be made with the noise mapping by measured data implemented by the Municipality of Genoa for the same urban area (Figure 15 and Figure 16) [38]. Each map reports noise indicator values expressed by means of a chromatic scale on the basis of a square mesh. Figure 15 refers to 24-hours period; the noise annoyance indicator is $L_{den}$. In Figure 16 the noise characterization for the same area during the night period is shown through the indicator $L_{night}$. These maps are the result of a measurement campaign performed by the Municipality with a multilevel approach, in which long-term, mid-term and short-term measurements have been combined to get a full description of the sound climate in the investigated area. Square domains of one hundred meter side have been analyzed and finally classified by a chromatic scale.

Because of the diverse spatial approach and of the different focus, the comparison between simulated and measured results is not immediate. The measured noise map is generally affected by the superimposition of the several sources operating in the actual condition, often with a stochastic behaviour, while the strategic mapping is able to focus on the main sources, defining each single contribution to the overall noise levels. Even if at a first look sim-
simulated and measured maps seem to differ, a deeper analysis reveals several common points. $L_{den}$ are higher than $L_{night}$ but the pattern is similar in the two analyses, indicators values largely exceed the noise limits, strong variations in noise levels occur inside the urban area even at small distance. In the same time, a combined analysis of the two noise maps coming from simulations and measurements it is recommended for getting a real comprehension of the urban noise pattern and for defining action plans actually able to reduce noise impact of the infrastructures on the population.

Finally, it must be noted that the graphic output is a key issue, because information about noise pollution must be easily comprehensible to the exposed population and to its representatives. For this reason, coloured maps shall facilitate a general sharing of Noise Mapping results: the choice of the representation criteria and, particularly, of the graphic form is therefore very important. Since there are standards governing the graphic output, it is strongly recommended to follow them strictly: a low attention to these aspects and a bad quality in output can vanish a deep work in noise modelling. In particular, different graphic outputs make difficult to compare and merge results.

## 5 Conclusions

With the European Directive 2002/49/EC a new strategy to noise planning has been introduced, requiring new tools for modeling and predicting. In particular, the Strategic Noise Mapping has become the main tool for acoustical planning and control of environmental noise in large urban conglomerates, or those with a population greater than 250000 (100000 inhabitants since 2012).

Different calculation methods have been developed, aiming to an accurate and effective modeling of noise propagation, and especially, of traffic noise propagation, which in urban areas represents the most diffuse source of annoyance. The precision of the models is often challenged by the complexity of the simulated scenario, particularly when its extent coincide with the whole city. The flyover highway Aldo Moro in Genoa represents in this sense a very interesting case. The particular morphology of the city of Genoa and the location of the highway make it a meaningful test for analyzing the efficacy of current modeling tools in simulating complex urban areas, not neglecting that this road is the major source of annoyance for people living in the whole downtown.

In order to apply the requirements of the END in such urban context, characterized by a flyover noise source, long distances source-receivers, complex morphology of the ground, compact layout of the buildings, the commercial software MITHRA-SIG has been used. Starting from the analysis of the traffic, noise mapping has been implemented in accordance with the standard NMPB-Routes-2008, as required for road noise by the current regulations. Results have been then analyzed complying with the END.

Outcomes indicate a quite critical condition for the urban area closer to the highway, according to both noise indicators, while the overall situation seems to be not so bad according to the simulations. Considering $L_{den}$ values higher than 55 dB(A), most of the population is exposed to levels from 55 to 59 dB(A), with about 1.5% of total inhabitants exposed. Similarly, for the noise indicator $L_{night}$, where only the 2.4% of the population is exposed to values higher than 50 dB(A) with less than 7% of exposed area, while almost 56000 inhabitants are exposed to $L_{night}$ value lower than 35 dB(A). This positive picture conflicts with the experience of the population and with the complaints addressed to the Public Administrations in charge of noise pollution.
There is some correct information coming from the implemented model and a few mismatches. Only the facades of the first row of dwellings are exposed to high noise levels, since the dense layout of buildings creates a barrier effect. The buildings closer to the flyover highway somehow screen the ones behind, since the narrow and curved streets of the historical town that surround large part of the flyover highway prevent sound propagation. This point is well portrayed by the maps, whereas a weakness can be identified in the choice to analyze the noise levels at 4 m from the ground, coming from the END approach. Indeed, where the ground has a sharp morphology with steep ascending and descending sides, the last floors of the buildings behind can be directly exposed to noise coming from the road source, in particular when this is a flyover infrastructure. Therefore there is a noticeable relevance of the vertical distribution of noise levels that is not completely reported in the maps. The assessment of the number of people exposed to the different noise ranges is then affected by this element, which would need an improved focus. Also the opposite situation on the two sides of the flyover highway has been properly described by the simulator. The south side of the road faces the port area, containing recreational facilities, shipyards and workshop, as well as quays and maritime terminals based at a lower level in comparison to the flyover highway. The sharp asymmetry of the maps reflects this actual situation, with a near-free propagation and high noise levels also far from the source, which emits from above in a large area towards the shore.

Diverse computational methods have been compared, considering ISO 9613-2, NMPB-Routes-1996, NMPB-Routes-2008 and Harmonoise, and even different frequency partitions (octave band or one-third octave band) for the last two standards. Results point out negligible differences between octaves and one-third octaves, while noise maps can markedly vary when passing from a method to another one. The biggest differences occur when the NMPB-Routes-2008 reference method is compared with the ISO 9613-2 standard, while the comparison with NMPB-Routes-1996 shows this latter method tends to overestimate the noise levels. In respect of the Harmonoise model differences generally range between −2 dB(A) and 6 dB(A).

The computational time for the different calculation methods has been then analyzed. In general, for both single and multiple CPU computations, the time needed to run simulations grows up with the complexity of the method with a quite slow trend. Computing time considerably rises if running a one-third octave band simulation enabling either multiple or single CPU computations. When considering the Harmonoise method, the computational time increases several times in comparison with the adopted reference method (NMPB-Routes-2008), depending on the CPU configuration. Simulations carried on confirm that Harmonoise is certainly an accurate method, but it could be difficult to run large scale simulations unless using very powerful computing workstations or clusters.

Finally, simulated noise maps have been compared with maps coming from on field measurements in order to a reciprocal validation. The diverse approach to noise mapping reflects on the output, which is influenced by the adopted graphic form. Nevertheless, some key elements resulted from this comparison, as well as the need to match the two methodologies for getting a real comprehension of the urban noise pattern and for setting effective action plans.

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