LIFE DYNAMAP PROJECT: the case study of ROME

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Abstract
The DYNAMAP project (Dynamic Acoustic Mapping - Development of low cost sensors networks for real time noise mapping) is a LIFE project aiming at developing a dynamic noise mapping system able to detect and represent in real time the acoustic impact due to road infrastructures. Scope of the project is the European Directive 2002/49/EC relating to the assessment and management of environmental noise (END).
The main project idea is focused on the research of a technical solution able to ease and reduce the cost of noise mapping, through an automatic monitoring system, based on customized low-cost sensors and a software tool implemented on a general purpose GIS platform, performing the update of noise maps in real time (dynamic noise maps). The feasibility of this approach will be proved implementing the system in two pilot areas with different territorial and environmental characteristics: an agglomeration and a major road. The first pilot area will be located in Milan, in a significant portion of the town, while the second one will be situated along the motorway A90 surrounding the city of Rome. The two pilot areas show peculiar needs and characteristics, such as the presence of multiple noise sources, roads junctions, traffic and weather conditions, that require a different system's implementation approach. In this paper the main issues related to the design of the system configuration in the pilot area of Rome are described.

Keywords: low cost sensors, dynamic acoustic maps, noise mapping, road noise sources, road junctions, weather conditions, real time**.**

1. Introduction

The DYNAMAP project (Dynamic Acoustic Mapping - Development of low cost sensors networks for real time noise mapping) is a LIFE project aiming at developing a dynamic noise mapping system able to detect and represent in real time the acoustic impact due to road infrastructures. Scope of the project is the European Directive 2002/49/EC relating to the assessment and management of environmental noise (END) [1] [2], enforcing Member States to provide and update noise maps every five years in order to report about changes in environmental conditions (mainly traffic, mobility and urban development) that may have occurred over the reference period. However, the update of noise maps using a standard approach requires the collection and processing of many new data related to such changes [3]. This procedure is time consuming and costly and has a significant impact on the financial statements of the authorities responsible for providing noise maps. Thus, cheaper solutions are required in order to reduce the cost of noise mapping activities, as it was highlighted and solicited at high priority level by the working group Road Noise of the Conference of European Directors of Roads (CEDR) in [4] and [5].
To meet such requirements and the growing demand of information about noise pollution, the Dynamap project foresees the development of an automatic noise mapping system delivering short-term (real-time dynamic noise maps), as well as long-term noise assessments (annual evaluations). Despite real time noise maps are not explicitly required by the END, their automatic generation is estimated to lower the cost of noise mapping by 50% with added significant benefits for noise managers and receivers, such as the possibility of providing updated information to the public through appropriate web tools or the opportunity to abate noise with alternative measures based on traffic control and management.
While this approach seems quite promising in suburban areas, where noise sources are well identified, in complex urban scenarios further considerations are needed to make the idea feasible. In the past the possibility of implementing dynamic noise maps was partially tested using standard sound level meters and expensive acoustic calculation software. More in details, in 2003 Madrid Environmental Administration, together with Brüel&Kjær, decided to develop a new concept of data post-processing, based on dynamic noise maps or SADMAM (Sistema Actualización Dinámica Mapa Acústico Madrid) [6]. Mobile monitoring devices equipped with GIS systems were used to measure sound pressure levels at strategic places and

noise maps were achieved using the Noise Calculation Software Lima. Nevertheless, the project showed some critical aspects, such as the need for mobile monitoring devices to sample sound pressure levels and the use of very complicated and time consuming algorithms to update the noise maps, that made this approach quite expensive and unable to automatically update noise maps in real time. Likewise, in 2003 also the city of Paris published daily noise maps on the internet using commercial sound level meters and software.

In the next years, further attempts of linking sound level meters to acoustic simulation models were made by the main software houses with the development of customized modules running on their own acoustic application environment. Unfortunately, also in this case, a software license for each mapping area was necessary, making the application extremely costly and unsuitable to monitor large territorial contexts. For this reason such application, although extremely appealing from a technical perspective, suffered a setback.

Another approach was proposed by the Multimedia System Department of Gdansk University of Technology in 2009 [7], with the development of a system consisting of many autonomous universal monitoring stations, a server to process and store data, a supercomputer to calculate the noise map and a web server to report the noise map on the web. In this case the attention was focused on the time needed to recalculate the noise levels and update the maps.

A step forward towards dynamic noise maps was made in 2011 with the project SENSEable PISA [8][9]. In this project large volumes of environmental data were gathered to extrapolate information on public health, urban mobility, air pollution, etc., using appropriate mathematical tools (data mining). To accomplish this task low cost sensors and data transmission devices were developed. The availability of such devices made rethinking the real possibility of developing a dynamic noise mapping system.

In 2013 another concrete progress was made in the ReSoNo project, where dynamic noise maps were achieved using sensor arrays made of microphones, cameras, GPS receivers and sophisticated algorithms to extrapolate from the overall noise level the contribution of the competing sources [10].

Finally, in 2014 the LIFE Dynamap project was co-funded by the European Commission to develop a simpler and promising approach, based on low cost customized devices and a general purpose GIS platform for data processing and system management, as described in more details in the following paragraphs.

2. The Dynamap project idea

The main project idea is focused on the research of a technical solution able to ease and reduce the cost of noise mapping, through an automatic monitoring system, based on customized low-cost sensors and a software tool implemented on a general purpose GIS platform, performing the update of noise maps in real time (dynamic noise maps).

The update of noise maps is accomplished by scaling pre-calculated basic noise maps, prepared for different sources, traffic and weather conditions. Basic noise maps are selected and scaled using the information retrieved from low-cost sensors continuously measuring the sound pressure levels of the primary noise sources present in the mapping area. A complete basic noise map covering the entire mapping area is calculated and saved for each source. Scaled basic noise maps of each primary source are then energetically summed-up to provide the overall noise map of the area. In this way, the need for several and expensive software license is extremely reduced and limited only to the preparation of the basic noise maps.

In order to reduce the costs of the entire mapping process, the DYNAMAP project involves the development of customized low cost devices to collate and transmit data, and the implementation of a simple GIS based software application for maps scaling with reduced calculation load. Such a standalone dynamic mapping software, together with low cost noise monitoring stations, makes the DYNAMAP system a very efficient and versatile noise mapping tool, virtually able to interface any existing or future noise modeling software, including the new European model CNOSSOS, which is expected to be operative for the 2022 round of END. The DYNAMAP system provides also for some unique characteristics that are not available in commercial products, like algorithms for eliminating spurious events (recognizing and masking unwanted events: i.e. occasional noise, etc.), traffic model data features, and future adaptability to other environmental parameters. In figure 1 a schematic representation of the DYNAMAP system is shown.

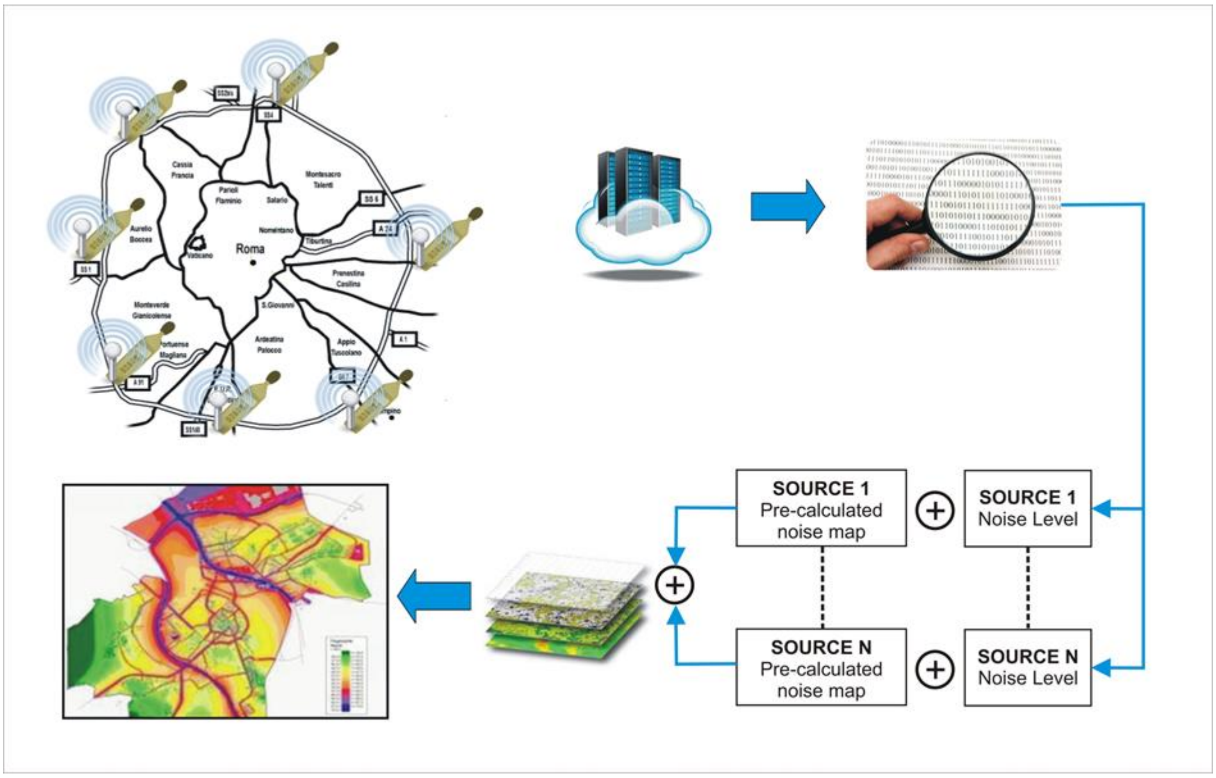


Figure 1. Schematic representation of the DYNAMAP system.

The project has been broken down into four main steps:

- Development of low-cost sensors and tools for managing, processing and reporting real-time noise maps on a GIS platform.
- Design and implementation of demonstrative systems in two pilot areas with different territorial and environmental characteristics: an agglomeration (Milan) and a major road (Motorway A90 – Rome).
- Systems monitoring for at least one year to check criticalities and analyze problems and faults that might occur over the test period.
- Provision of a guideline for the design and implementation of real-time noise mapping.

The project is currently approaching the implementation step, after two years of technological development and design of the system configuration.

The design of the system configuration entailed the study of procedures to optimize the number and type of sensors needed to update the noise maps. This study also involved the identification of the basic noise maps to be prepared as a function of the parameters influencing noise emission and propagation. These specifications are closely linked to ambient features, thus different studies were carried out to configure the system in the two pilot areas.

In this paper the study undertaken to define the system configuration in the pilot area of Rome is described.

3. The case study of Rome

The pilot area of Rome is located along the ring road (A90 Motorway) surrounding the city. The ring road is a six lanes motorway, 68 km long, skirting many suburban areas where noise levels were found to impact critically on the residents. Critical areas are characterized by the presence of single or multiple noise sources, such as railways, crossing and parallel roads.

Two main critical issues were found to affect the pilot area of Rome in the preparation and update of the basic noise maps: the contribution of multiple noise sources to the overall sound pressure level and the influence of meteorological conditions.

The first issue is particularly relevant, since usually major roads cross suburban complex scenarios, where several connections to other transport infrastructures are present. In such contexts the noise level at receivers is given by the contributions from all noise sources. This is quite a tricky situation, as based on END requirements noise maps should be source selective and avoid the influence of the other noise sources. This aspect will be investigated and discussed in chapter 4.

The second issue is substantial only in suburban areas, where usually receivers are located at a greater distance from the road (≥ 80 m) [11].In this case, noise levels are affected by weather conditions, whereby different basic noise maps should be prepared to take into account their influence on acoustic waves propagation. This requires the monitoring of meteorological conditions and the conversion of this information in classes of acoustic propagation (favorable, unfavorable or homogeneous). This aspect will be investigated and discussed in chapter 5.

4. AVOIDING THE CONTRIBUTION OF COMPETING NOISE SOURCES

The Motorway A90, as many other major roads, cross suburban complex scenarios, that include connections to a variety of transport infrastructures. In these contexts the noise level at receivers is given by the contributions from all noise sources. This is quite a tricky situation, as based on END requirements noise maps should be source selective and avoid the influence of the competing noise sources. Therefore, the acoustic characterization of the Motorway A90, as well as its noise impact assessment, should prevent such contributions and simply provide a measure of the sound power due to the main road axis and its several junctions. In order to improve the noise model calibration and meet the requirements of the END, an innovative approach to extrapolate the noise contributions of the A90 motorway stretches has been developed. The description of the technique used and the results achieved are the objects of this chapter.

4.1 State of the art

The classical approach to noise source identification is based on the near-field acoustic holography (NAH), developed to locate sound sources in free-field environment. This technique is implemented using microphone arrays [12], that unfortunately must be physically as large as the source region of interest, making the method unsuitable to pass-by applications. For these reasons, another method, named beamforming, has recently replaced holography to investigate sound sources in complex scenarios. Also in this case arrays of microphones are used,. Even if this method is capable of identifying and tracking large moving sources during uncontrolled vehicle pass-by testing, at frequencies below 1000 Hz the source regions may appear quite large and source identification uncertain [13]. As an alternative to the above mentioned approaches, in the last years other methods known as Sparse Component Analysis (SCA) [14] have been developed. They may be seen as an extension of multiple-sensor single-source localization methods to multiple source localization. In this case, if the geometry of the microphone array is known, the noise sources can be easily localized, as described by Swartling in [15]. Unfortunately, most of the SCA methods are off-line [16].

In this work, the sound characterization of single sources (i.e.road junctions) has been carried out using an experimental technique, especially developed for the project, aimed at reducing the duration and cost of the measurement campaign, as well as the number of sites to be monitored.

4.2 Theory

In the pilot area of Rome the A90 motorway runs through different scenarios and it is connected to many other roads. For this reason, different type of sites, representative of the main suburban scenarios, have been identified and 17 critical areas have been selected to host the Dynamap sensors. Eleven out of seventeen critical areas include the presence of road junctions, whose impact was not taken into account in the first and second cycle of the END by the road owner. This contribution is not negligible and must be included in the characterization of the motorway noise impact.

Table 1 shows the ranking lists of the seventeen critical areas, with their location (see also figure 2) and intersections (if any). In order to refine the acoustic characterization of the A90 motorway and to include the road junctions contribution, a fit to purpose monitoring has been arranged.

Table1. Identification of the selected areas including the presence of junctions.

RANKING LIST	**Location on themap** (figure 2)
A - Single road critical areas	1
	2
	3
	4
	5
	6
	7
	8
	9
	10
	11
	12
B - Critical areas with additional crossing or parallel roads	13
C - Critical areas with railways crossing or running parallel the A90 motorway	14
	15
D - Complex critical areas with multiple connections	16
	17

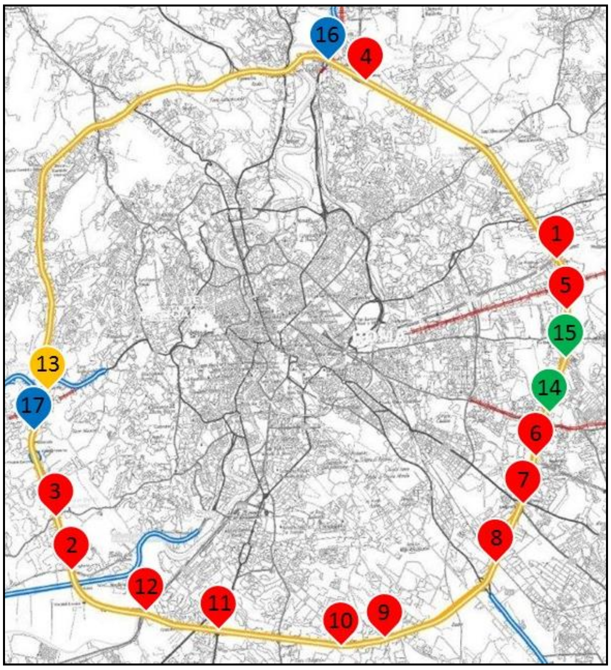


Figure 2. Rome pilot area. Critical areas location identified with different colors: red (ranking list A); yellow (ranking list B); green (ranking list C) and blue (ranking list D).

The measurement campaign was accomplished using an innovative approach based on Kirkhhoff's junction rule. This rule states that at any node (junction), the sum of electric currents flowing into the node is equal to the sum of currents flowing out the same node. This simple rule, developed for electric networks, can be also applied to traffic flows and allows to arrange a measurement scheme that reduces the number of sites to be monitored, as shown in figure 3.

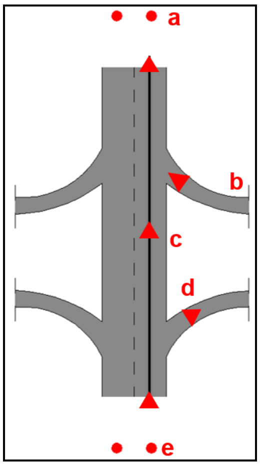


Figure 3. Position of sound level meters and traffic counters needed in a simple intersection scheme.

In this scheme, three monitoring points are necessary for each carriageway: two sound level meters placed on the main road axis (for instance, points **a** and **e** for the external carriageway) and one traffic counter (point **b** or **d**). From the latter, the acoustic power level is calculated from traffic data to avoid the noise level contribution generated by the main axis and the connected roads. The sound power on the remaining arcs (for example those related to the measurement points b and c) are then assessed using the equations (2) and (4):

$$a = c + b \quad (1)$$

$$c = e - d \quad (2)$$

$$e = c + d \quad (3)$$

$$b = a - e + d \quad (4)$$

In order to reduce the estimate error due to local ambient conditions (slope, pavement type and traffic conditions [accelerated, decelerated]), the calculated power levels are corrected with calibration factors achieved by short-term parallel noise level measurements on the same junctions.

4.3 Test measurement set-up and results

To check the feasibility and veracity of the proposed scheme, this procedure was first applied to two test sites and then extended to the other junctions. The sound level meters were installed on portals, hosting Variable Message Panels (VMP), to get easy access to the electric power grid (figure 4) and prevent theft. Traffic counters were, instead, blocked with shaped brackets to road signs, placed close to the junctions (figure 4).

Figure 4. A variable Message Panel (left) and a traffic counter on a road sign (right).

Figures 5 and 6 show the measurement set-up applied to the two selected test sites (number 11 and 12) . In green are highlighted the measurement points where sound level meters were installed (the Px code indicates the name of the portal where the devices have been placed), while in red are shown the positions of the traffic counters. The test sites included a total number of 16 road junctions, six sound level meters and six traffic counters (radars).

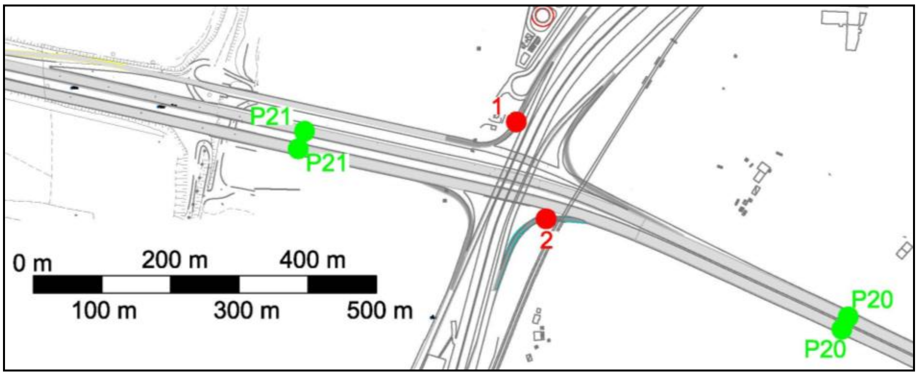


Figure 5. Test site number 12: A90 motorway in light gray and junctions in dark gray.

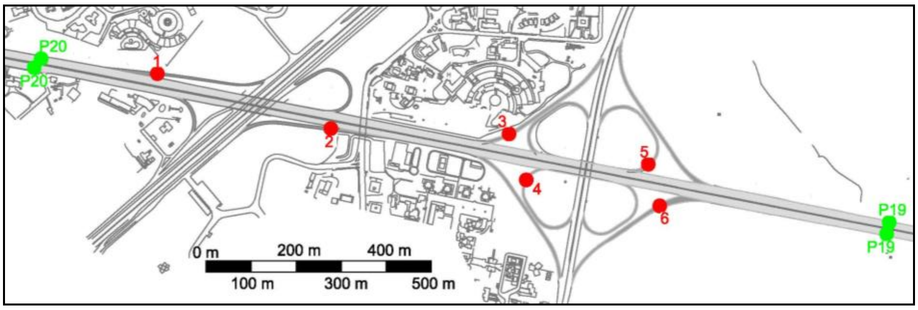


Figure 6.Test site number 11: A90 motorway in light gray and junctions in dark gray.

Figure 7 and 8 report the sound power levels measured in the two test sites. A difference varying from 1 to 2 dB was detected between the carriageways. This difference is very tight and doesn't justify in principle the cost of using two separated monitoring devices, as shown in figure 9, where the hourly trends related to the internal and external carriageways in a working and a weekend day are traced. Therefore, a general hypothesis of equally distributed traffic on the two carriageways can be made without leading to significant errors. This means that only one sound level meter can be placed on the main road axis without major consequences in terms of noise model calibration and its impact on receivers.

Figure 7. Results obtained from the sound level meters installed at the test site n° 12.

Figure 8. Results obtained from the sound level meters installed at the test site n. 11.

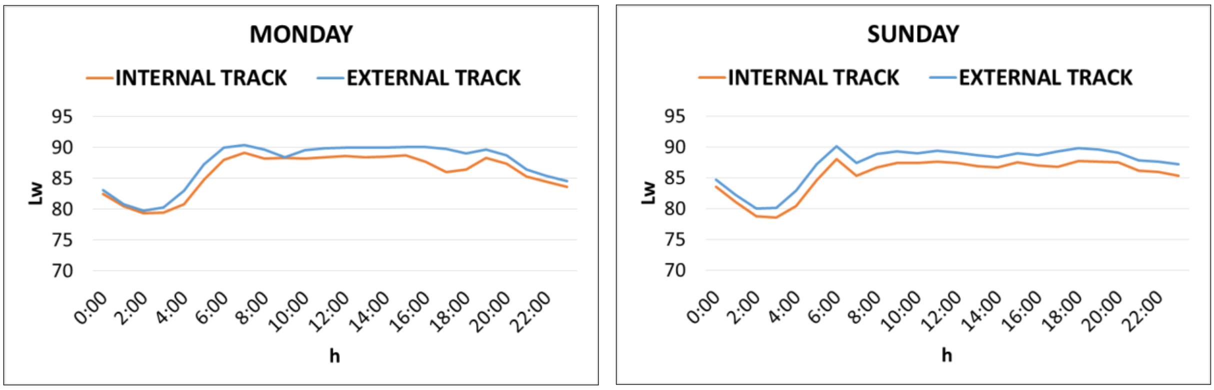


Figure 9. Hourly sound power level in the two carriageways related to a working and a weekend day.

In order to find a relationship between the sound power levels generated by the junctions and the motorway main axis, hourly traffic measurements were converted into sound power levels and compared to the measured values on the carriageways axis. This comparison shows that the hourly noise trends on the junctions and on the main motorway axis are almost the same (figure 10).

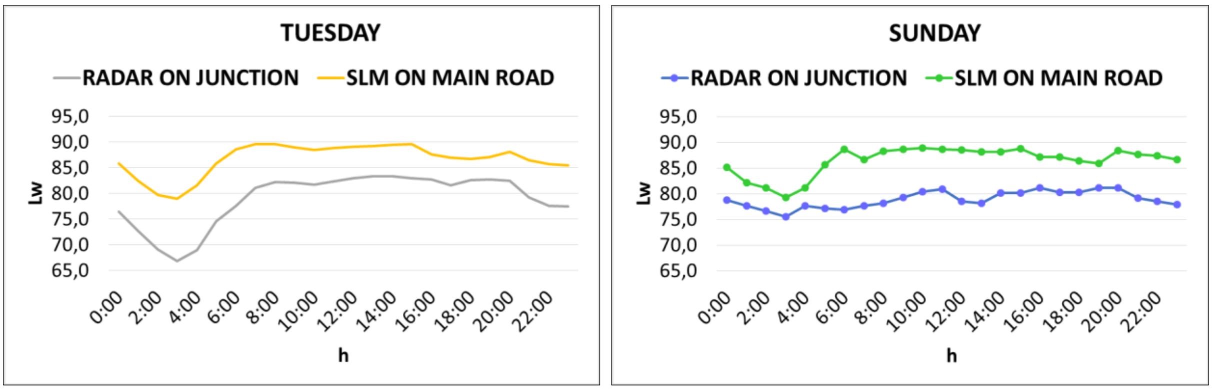


Figure 10. Hourly graph of calculated sound power level on a junction (gray and blue lines) and on the main road axis (orange and green lines) for a working day (left) and for a weekend day (right).

These results clearly show a real possibility of identifying a relationship between the sound power levels measured on the main axis and the related road junctions. Therefore, the method was applied also to the whole pilot area. A monitoring campaign of five days was carried out for each site and the calculation procedure described above was used to determine the sound power levels on monitored and unmonitored junctions.

4.4 Data analysis and discussion

Data collected during the measurement campaign were processed and the sound power level related to each junction was calculated. A statistical analysis was then accomplished in order to identify the sound power level relationships between the main motorway arcs and its junctions, with the final aim of reducing the number of monitoring points and consequently of the basic noise maps to be provided as much as possible. To that end the following steps were performed:

- Calculation of hourly correlation coefficients $\Delta(h)_{i,j}$ related to the *i-th* junction and the *j-th* hour between the sound power levels generated by the A90 motorway and each junction;
- Calculation of daily correlation coefficients $\Delta(d)_{i,j}$ related to the *i-th* junction and the *k-th* day between the sound power levels due to the A90 motorway and each junction;
- Calculation of working days $\Delta(wd)_i$, weekend $\Delta(we)_i$ and weekly $\Delta(w)_i$ coefficients related to the *i-th* junction;
- Clustering of junctions in homogenous classes.

4.4.1 Calculation of hourly correlation coefficients

The hourly correlation coefficients $\Delta(h)_{i,j}$ are given by the difference between the sound power level measured on the A90 motorway main axis and the sound power level calculated on the related junctions. For each junction the hourly coefficient was calculated using the formula (5):

$$\Delta(h)_{i,j} = L_w(A90)_{i,j} - L_w(junction)_{i,j} \tag{5}$$

where:

– $\Delta(h)_{i,j}$ is the hourly coefficient related to the *i-th* junction and the *j-th* hour;
– $Lw(A90)_{i,j}$ is the hourly sound power level related to the *i-th* measurement position on the A90 motorway axis associated to the *i-th* junction and the *j-th* hour;
– $Lw(junction)_{i,j}$ is the hourly sound power level related to the *i-th* junction and the *j-th* hour.

The results achieved show that $\Delta(h)_{i,j}$ coefficient varies from 4 to 11 dB, with an average hourly value of 7.6 dB.

4.4.2 Calculation of daily correlation coefficients

Hourly coefficients $\Delta(h)_{i,j}$ were then reduced to daily coefficients $\Delta(d)_{i,k}$, by calculating the weighing average of the hourly coefficients. Weighing coefficients were given by the ratio between the number of hours related to the day (6-20, 14 hours), evening (20-22, 2 hours) and night (22-6, 8 hours) period and the total daily hours (24 hours).

Figure 11 shows a typical $\Delta(d)_{i,k}$ pattern (black line) and the corresponding standard deviation for each day of the week (light orange area) related to one junction. The average standard deviation related to all junctions was found to be 1.2 dB, and its maximum value 1.9 dB. Therefore, the relationship between the main motorway axis and its junction can be reasonably reduced to a daily coefficient.

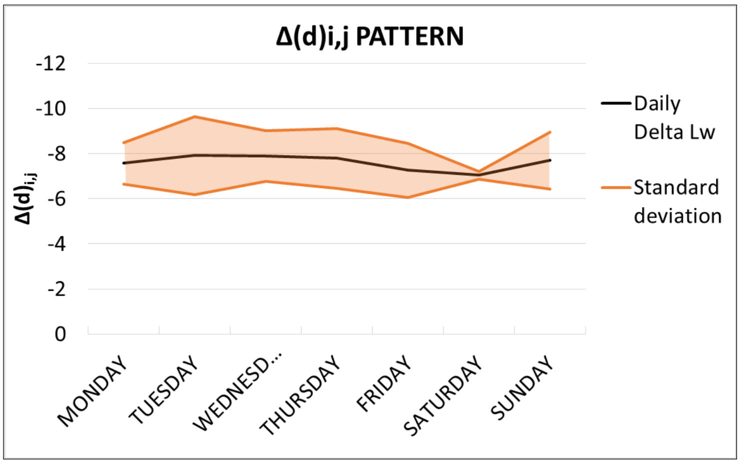


Figure 11. $\Delta(d)_{i,j}$ pattern and the corresponding standard deviation (i = analyzed junction; j = analyzed day).

4.4.3 Calculation of working days , weekend and weekly coefficients

In order to further reduce the number of coefficients linking the main motorway axis to its junctions, daily coefficients were finally analyzed to see if similarities among the different days of the week could be found. The results of this analysis are shown in figure 10. As it can be seen, sound power levels on working days and on weekend seem to have a different trend. In particular, the trend shown by the working days daily coefficients (Monday to Friday evening) are quite similar and can be reduced to a unique coefficient, a working days coefficient $\Delta(wd)_i$ for each junction. Similarly, a weekend coefficient $\Delta(we)_i$ (from Friday night to Sunday) can be extrapolated. Δ values for different junctions and related standard deviations are reported in figure 12. This figure shows that the standard deviation related to the different junctions has a maximum value of 1.2 dB in the working days period and of 1.1 dB in the weekend period. By averaging the standard deviation of all junctions, a value of 0.4 dB for working days and 0.8 dB for weekend days was found.

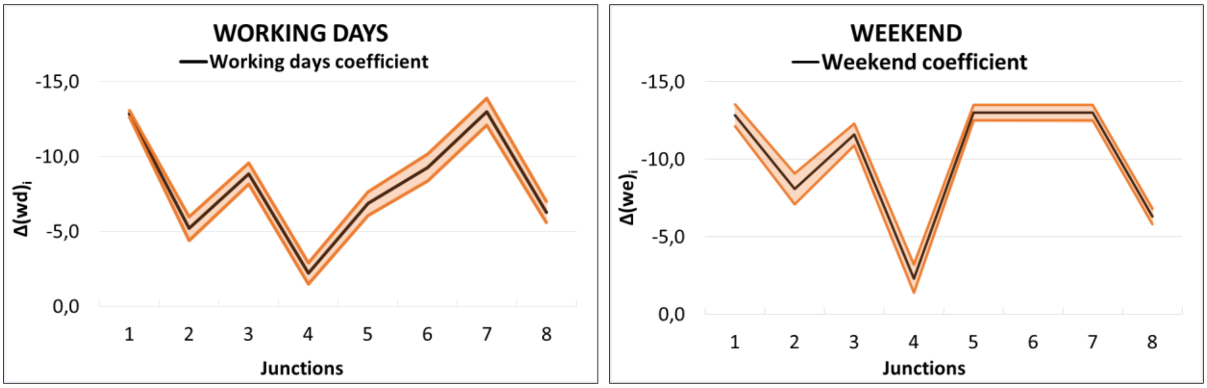


Figure 12. Working days $\Delta(wd)_i$ and weekend $\Delta(we)_i$ pattern and the corresponding standard deviation for different junctions.

As a consequence, the $\Delta(wd)_i$ and $\Delta(we)_i$ coefficients can be applied to each junction without leading to significant errors.

4.4.4 Clustering of junctions in homogenous classes

To further optimize the methodology, the daily coefficients were averaged to achieve a weekly coefficient $\Delta(w)_i$ for each junction (figure 13). As it can be seen from figure 13, in many cases the standard deviation is higher than 2 dB (orange line), therefore in such cases the weekly coefficient can't be considered acceptable.

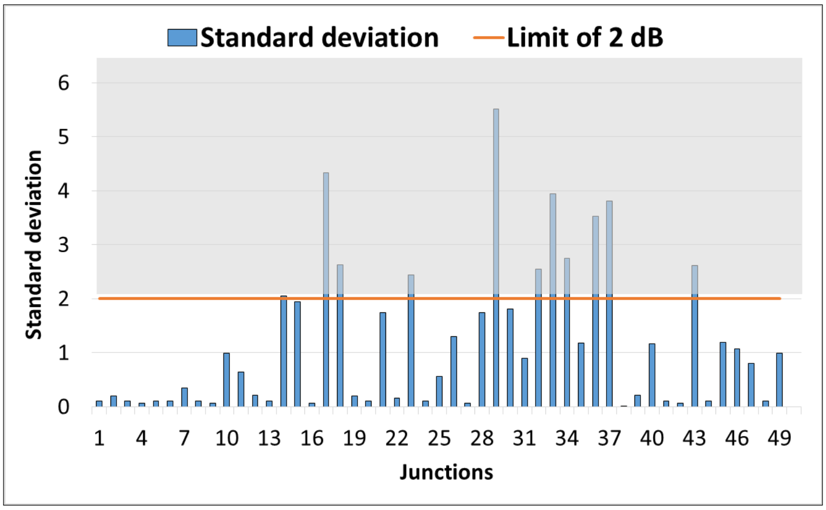


Figure 13. Standard deviation considering a weekly coefficient for each junction.

However, figure 13 also highlights that the junctions set can be split into two clusters, fixing an acceptable threshold of 2 dB:

- Cluster 1: junctions with a standard deviation for weekly coefficients lower than 2dB. In this case, the sound power level of the junctions is given by the formula (6).

$$L_w(junction)_{w,i} = L_w(A90)_{w,i} + \Delta(w)_i \quad (6)$$

  where:

  – $Lw(junction)_{w,i}$ = weekly sound power level for the *i-th* junction;
  – $Lw(A90)_i$ = weekly sound power level for the *i-th* measurement position on the A90 motorway;
  – $\Delta(w)_i$ = weekly coefficient for the *i-th* junction.

  From this assumption it follows that the main road arc and its junctions can be mapped together as a unique elementary noise source using this coefficient, thus reducing the number of basic noise maps to be provided and the monitoring stations necessary to scale the maps.

- Cluster 2: junctions with a standard deviation for weekly coefficient upper than 2dB. In this case, the sound power level of the junction is given by the formulas (7) and (8) and the basic noise maps necessary to scale the contribution of the elementary noise source are two: one for working days and one for weekends.

$$L_w(junction)_{wd,i} = L_w(A90)_{wd,i} + \Delta(wd)_i \quad (7)$$

$$L_w(junction)_{we,i} = L_w(A90)_{we,i} + \Delta(we)_i \quad (8)$$

  where:

  – $Lw(junction)_{wd,i}$ = working days sound power level for the *i-th* junction;
  – $Lw(junction)_{we,i}$ = weekend days sound power level for the *i-th* junction;
  – $Lw(A90)_{wd,i}$ = working days sound power level for the *i-th* measurement position on the A90 motorway;
  – $Lw(A90)_{we,i}$ = weekend days sound power level for the *i-th* measurement position on the A90 motorway;
  – $\Delta(wd)_i$ = working days coefficient for the *i-th* junction;
  – $\Delta(we)_i$ = weekend days coefficient for the *i-th* junction.

More in detail, 8 main arcs and 32 junctions can be ascribed to Cluster 2 and 5 main arcs and 18 junctions to Cluster 1. Thanks to this ploy, it is not necessary to prepare a basic noise map for each junction, but only one or two maps for each main arc and its associated junctions. In particular one basic noise map is foreseen for elementary noise sources belonging to cluster 1 and two basic noise maps for elementary noise sources belonging to cluster 2, leading to a total number of (5x1)+(8x2)=21 basic noise maps. This solution allows to reduce the number of basic noise maps by 75%.

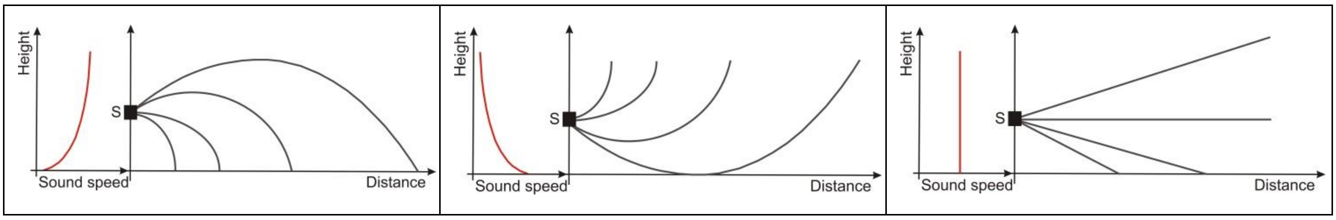
5. BASIC NOISE MAPS AS A FUNCTION OF METEOROLOGICAL CONDITIONS

In suburban areas noise levels at receivers are usually influenced by weather conditions. Depending on the site configuration (geometry, topography, ground characteristics, etc.), wind, temperature and humidity can cause acoustical fluctuations over time and space that might become relevant even at few dozen meters away from the source (road, railway or industrial noise) [17].

Atmospheric conditions alter sound waves propagation through thermal (heat transfer) and aerodynamic (wind profiles) phenomena. These phenomena can induce positive or negative vertical sound gradients. In case of positive vertical sound gradient, the acoustic rays travel downwards and the far field sound level is stronger than without meteorological effects. These propagation features are known as favorable conditions (see figure 14, a).

On the contrary, when the vertical sound gradient is negative, acoustic rays travel upwards. In this situation the far field sound level is weaker than without meteorological effects and propagation conditions are said unfavorable (see figure 14, b).

The sound vertical gradient can also assume a nil value, but this is fairly rare. This phenomenon can occur mainly at sunset and sunrise when the wind speed is totally nil, or when the thermal and aerodynamic effects tend to offset each other. In this case sound waves travel in straight rays (see figure 14, c) and propagation conditions are qualified as 'homogeneous'.



(a) (b) (c)

Figure 14. Acoustic propagation conditions: a) favorable; b) unfavorable; c) homogeneous.

Favorable, unfavorable or homogeneous conditions must be taken into account when preparing the basic noise maps. This entails the study of two different, but strictly connected, aspects:

- the identification of a set of meteorological scenarios, corresponding to as many basic noise maps, as a function of the acoustic model sensitivity to spatial weather variations;
- the definition of a method to correlate weather information to sound propagation conditions in order to allow the selection of the most appropriate basic noise map.

On these two aspects is focused the present chapter.

5.1. Classification of sound propagation conditions - state of the art

Two possible approaches to the classification of sound propagation conditions are currently available in literature: the first one is described in the standard ISO 1996-2 [19], while the second one in the recent NMPB 2008/CNOSSOS calculation model [17].

In the Standard ISO 1996-2 four classes are defined as a function of the parameter D/R_{cur} (see table 2), where D is the horizontal distance of the receiver from the source and R_{cur} is the radius of curvature of the acoustic rays. The calculation of this parameter is quite tricky and requires a series of information that include: wind speed and direction, cloud cover, angle between sound and wind propagation directions. The latter is not easy to be determined and depends on the geometrical features of the source. In case of a non-straight road source, this means that in the same mapping area many different values of R_{cur} should be calculated as a function of road orientation.

Table 2. Meteorological window.

Meteorological windows	D/R_{cur} Range	D/R_{cur} Representative value	Verbal description
M1[a]	< –0,04	–0,08	Unfavourable
M2[b]	–0,04 … 0,04	0,00	Neutral
M3[c]	0,04 … 0,12	0,08	Favourable
M4[d]	> 0,12	0,16	Very favourable

[a] Typical value of vector wind speed component at 10 m, <1 m/s and <–1 m/s at day and night respectively.
[b] Typical value of vector wind speed component at 10 m, 1 m/s to 3 m/s.
[c] Typical value of vector wind speed component at 10 m, 3 m/s to 6 m/s.
[d] Typical value of vector wind speed component at 10 m, >6m/s and ≥–1m/s at day and night respectively.

In the NMPB 2008/CNOSSOS model five classes of propagation conditions are defined, as shown in table 3.

Table 3. Qualitative definition of average acoustic propagation classes.

Propagation class	Propagation conditions	Effect on the sound levels
M0	Very upward refraction	Extremely high attenuation and dispersion
M1	Upward refraction	High attenuation and dispersion
M2	Homogeneous	'Normal' propagation and dispersion
M3	Downward refraction	Major increase and moderate dispersion
M4	Very downward refraction	Extremely high increase and very moderate dispersion

These classes are identified in the UiTi matrix as a function of aerodynamic and thermal conditions, as shown in table 4, where the columns U1 to U5 relate to the atmosphere's aerodynamic characteristics and rows T1 to T5 to its thermal characteristics [17].

Table 4. UiTi grid for the qualitative meteorological analysis of an acoustic situation.

	U1	**U2**	**U3**	**U4**	**U5**
T1		M0	M1		
T2	M0	M1		M2	M3
T3	M1		M2	M3	
T4	M1	M2	M3		M4
T5		M3		M4	

The input criteria for the UiTi grid are indicated in table 5 .They correspond to average values of meteorological conditions observed over a 'short-term' period. The aerodynamic (Ui, i=1 to 5) and thermal (Ti, i=1 to 5) classes are defined in terms of observations and vertical gradients.

Table 5. UiTi grid input criteria and associated values for the vertical wind and temperature gradients**.**

Class		**Regional observations/data**	**Vertical gradients**
U	U1	Strong head wind	$Grad_V V < -0.13 s^{-1}$
	U2	[Light head wind] OR [Only very light head wind]	$-0.13 s^{-1} \leq Grad_V V < -0.05 s^{-1}$
	U3	[No wind] OR [Cross wind]	$-0.05 s^{-1} \leq Grad_V V < 0.05 s^{-1}$
	U4	[Light tail wind] OR [Only very light tail wind]	$0.05 s^{-1} \leq Grad_V V < 0.13 s^{-1}$
	U5	Strong tail wind	$Grad_V V \geq 0.13 s^{-1}$
T	T1	Day AND strong radiation AND dry surface AND no or little wind	$Grad_T < -0.04 K.m^{-1}$
	T2	Day AND [average radiation OR damp surface OR strong wind]	$-0.04 K.m^{-1} \leq Grad_T < -0.02 K.m^{-1}$
	T3	[Hourly duration including sunrise or sunset] OR [dull weather and light wind and non-dry surface]	$-0.02 K.m^{-1} \leq Grad_T < 0.01 K.m^{-1}$
	T4	Night AND [cloudy or no wind]	$0.01 K.m^{-1} \leq Grad_T < 0.15 K.m^{-1}$
	T5	Night AND clear sky AND little or no wind	$Grad_T \geq 0.15 K.m^{-1}$

The classification of propagation conditions based on qualitative weather observations requires the collection of meteorological data, such as wind speed and direction, cloud cover and rain rate, that can be easily measured or retrieved from existing monitoring stations. As an alternative, propagation conditions can be achieved from the measurements of wind speed and temperature gradients at three different heights, typically at $z_1 = 1$ *m*, $z_2 = 3$ *m and* $z_3 = 10$ *m* [18]. This method, although less accurate, is much easier to be implemented.

5.2. Identification of the method to be applied to the Dynamap System

As one of the main objective of the project is to reduce the cost of the system as much as possible, the selection of the method to be applied to the Dynamap system should be based on costs in retrieving or measuring meteorological data, but also on the time needed to process data and prepare the basic noise maps.

If floating free data are used the cost of meteorological information is not more a parameter to be considered. In this case, the choice should be determined by other factors, such as the reliability and accuracy of data, the time needed to process and prepare the basic noise maps.
As for the time needed to process data and prepare the basic noise maps, the following considerations apply:

- The standard ISO 1996-2 requires the identification of prevailing propagation directions. This information can be automatically achieved on the basis of the road segment coordinates and stored in a database for the calculation of the parameter D/R_{cur}. Consequently the identification of propagation conditions is more time consuming, not only when preparing the basic noise maps (calculations of the prevailing propagation directions), but also when processing data (calculation of D/R_{cur} for all the prevailing propagation directions).
- The model NMPB 2008/CNOSSOS provides a qualitative approach for the identification of propagation conditions based on a set of meteorological information (the UiTi matrix), that it is assumed to be less accurate [17], but simpler. In this case only information on the time of the day, cloud cover, wind speed and direction is necessary.

These considerations seem to naturally make converge the choice on the UiTi scheme proposed in the NMPB 2008 model (see table 1).
The UiTi matrix can be further simplified taking into account that currently available acoustic models are unable to manage unfavorable conditions, so that they are replaced by homogeneous conditions. This simplification tends to overestimate the actual sound levels, but it contributes to improve receivers protection [17].
In the simplified UiTi matrix (table 6) only three states are achievable: homogeneous conditions [H], favorable or homogeneous conditions in specific wind sectors [F or H] and favorable conditions in all directions [F]).

Table 6. Simplified matrix UiTi, where H states for homogeneous conditions, F or H for favorable or homogeneous conditions in specific wind sectors and F for favorable conditions in all directions.

Time of day	**No wind**	**Light wind (ws≤3 m/s)**	**Strong wind (ws> 3m/s)**
Day time	H	H	F or H
Sunrise or Sunset	H	F or H	F or H
Night AND cloudy	F	F or H	F or H
Night AND clear sky	F	F	-

It follows that at daytime propagation conditions are always homogeneous, unless there is strong wind. In the latter case homogeneous conditions become favorable in specific wind sectors. At sunrise and sunset propagation conditions are usually homogeneous, but in case of wind they can become favorable in specific wind sectors. At nighttime, propagation conditions are generally favorable, except when is windy and the sky is cloudy.
As a consequence, the classification of propagation conditions can be achieved from information on wind speed and direction, and cloud cover. These data can be retrieved from existing weather stations publishing free data on the web with a sufficiently short time frequency (at least 1 hour), or from additional local meteorological stations.
Data provided on site by local meteorological stations can guarantee more reliable and accurate results, but in this case, their contribution to the whole system cost can’t be neglected. This contribution depends on the number of sensors needed. The simplest and, consequently, cheapest way to identify propagation conditions is that based on the simplified UiTi matrix shown in table 7, where only two or three temperature sensors positioned at different heights and an anemometer are necessary to measure thermal conditions and wind features. Using this approach, the measurement of cloud cover is not necessary.

Table 7. Simplified UiTi matrix, where H states for homogeneous, F or H for favorable or homogeneous conditions in specific wind sectors and F for favorable conditions in all directions.

T	Thermal conditions	No wind	Light wind (ws≤3 m/s)	Strong wind (ws> 3m/s)
T1	$Grad_T < -0.04 K.m^{-1}$	H	H	-
T2	$-0.04 K.m \leq Grad_T < -0.02 K.m$	H	H	F or H
T3	$-0.02 K.m^{-1} \leq Grad_T < 0.01 K.m^{-1}$	H	F or H	F or H
T4	$0.01 K.m^{-1} \leq Grad_T < 0.15 K.m^{-1}$	F	F	F or H
T5	$Grad_T \geq 0.15 K.m^{-1}$	F	F	-

As a last step of the system configuration design phase, the spatial representativeness of weather information was investigated. This last step was necessary to finally define the amplitude of the wind sectors and consequently the number of basic noise maps to be prepared for each elementary noise source. In order to check how sensitive is the simplified UiTi matrix to spatial weather variations, a sensitivity analysis was applied to local meteorological data available for the pilot area of Rome.

5.3. Sensitivity of the model to spatial weather variations

The Rome pilot areas is composed of many test sites distributed along the motorway A90, as shown in figure 15, corresponding to as many critical areas [11]. Consequently, each site should be associated to reliable meteorological information. As one of the main objective of the project is to lower the cost of the system as much as possible, weather data should be preferably retrieved from existing monitoring stations. Two official monitoring weather stations are available in proximity of the motorway A90. Both are managed by the Italian Air Force and provide reliable data. The first meteorological station is located inside the airport area of Roma-Urbe, in the northern part of Rome, while the second one is located in the southern part of the town, inside the airport area of Ciampino (see figure 15).

Data from the meteorological station of Roma-Urbe are available with a time frequency of one hour, whilst those from the meteorological station of Ciampino are published with a time frequency of 30 minutes. As a matter of fact, data from Ciampino airport are used by the main forecast meteo websites to calibrate their models. Therefore, the possibility of feeding the Dynamap System with forecast data has been investigated as well.

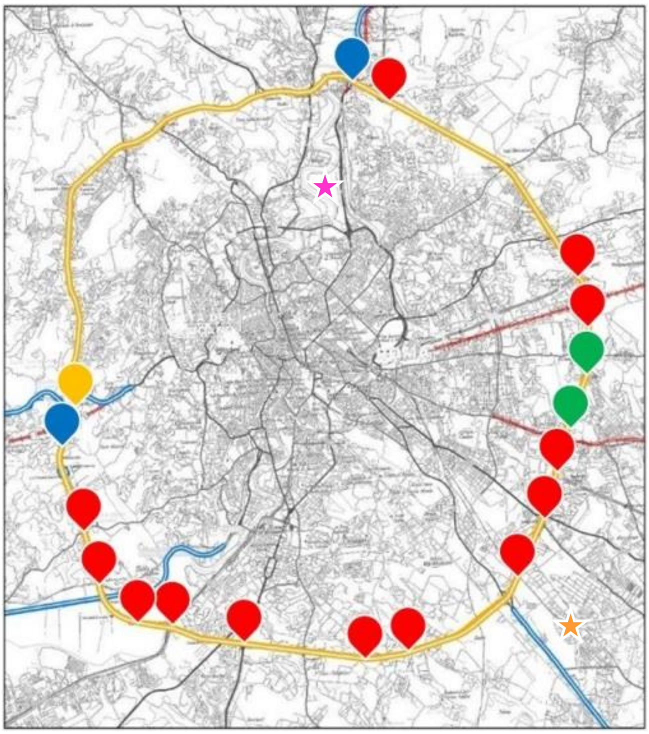
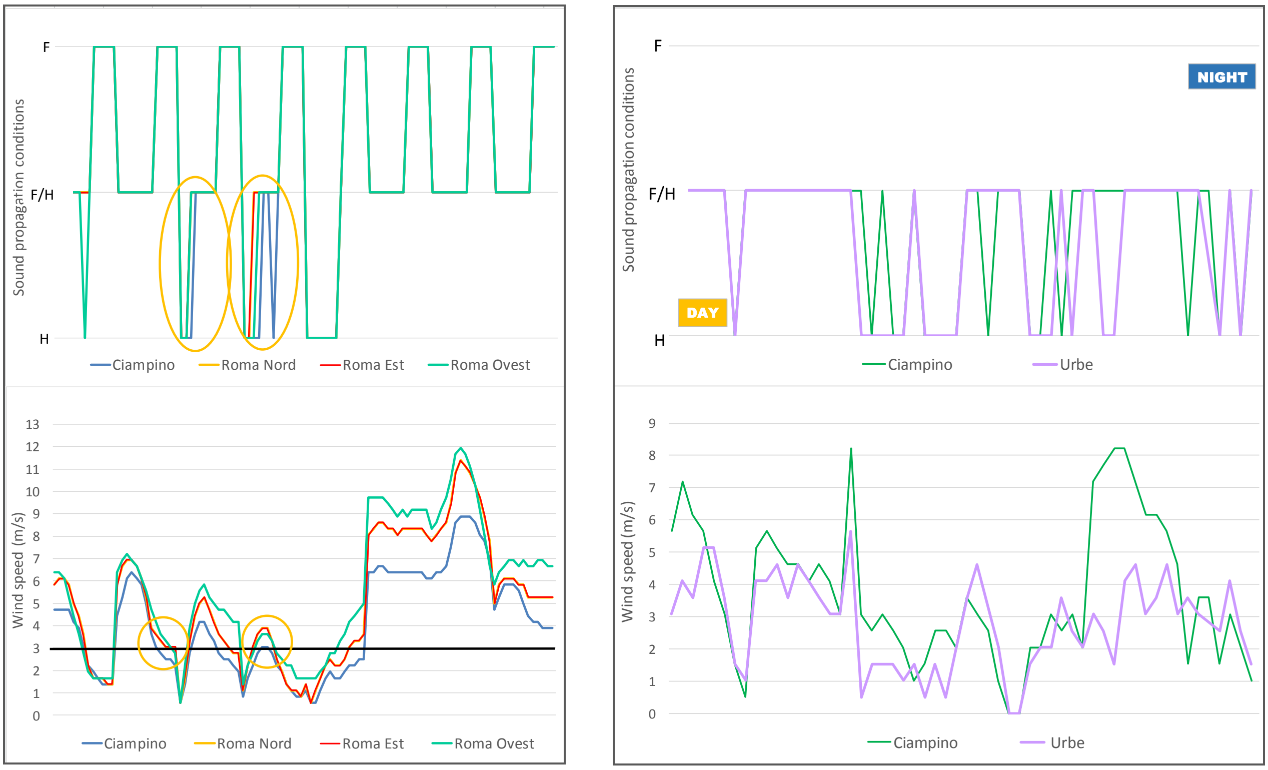


Figure 15. Position of Rome pilot area test sites and of the two weather stations located at the airports of Roma-Urbe (purple star) and Ciampino (yellow star).

For this reason the sensitivity of the model to spatial weather variations was verified using both forecast and measured values.
As for forecast data, four zones (Ciampino, Northern Rome, Western Rome and Eastern Rome) were compared for 7 days and their influence in terms of propagation conditions was calculated using the simplified UiTi matrix.

5.4. Sensitivity analysis results and discussion

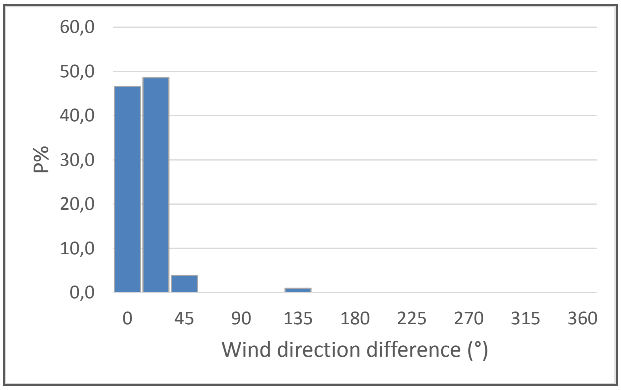
The results of the sensitivity analysis related to forecast and measured data are shown in figure 16 (a) and (b) respectively. In figure 16 (a) the upper graph reports, for each zone, the trend of sound propagation conditions in the time interval ranging from 12:00 to 24:00 hours for seven days. As it can be seen, the four curves are almost superimposed everywhere, except in two cases when the wind speed is crossing the threshold of 3 m/s that separates light from strong wind speed conditions (lower graph). These results highlight that sound propagation conditions are the same in 95% of cases and that the model used is quite insensitive to small weather variations.
Weekly data measured by the two meteorological stations of Roma Urbe and Ciampino were also compared to check their difference. In this case, the study was limited only to daytime, as weather data from Roma Urbe were not available at nighttime. As shown in figure 16 (b) the actual situation is a little bit less favorable and the accuracy drops down to 92%. Also in this case differences are mainly due to measured wind speed values close to the threshold of 3 m/s.



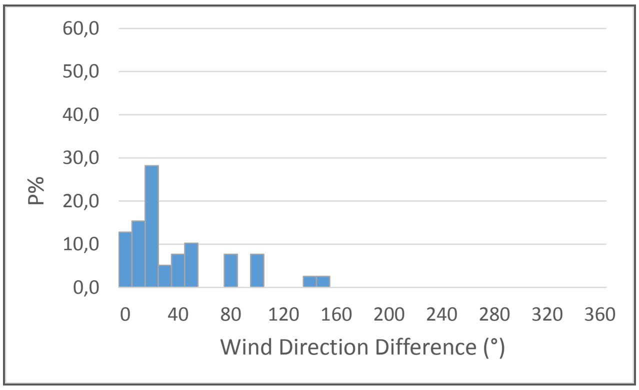
(a) (b)

Figure 16. Results of the sensitivity analysis applied to forecast (a) and measured data (b). The upper graphs report the results related to the classification of sound propagation conditions achieved using the simplified UiTi matrix. The lower graphs show the wind speed predicted in the four investigated zones (a) or measured (b) by the two weather stations of Roma Urbe and Roma Ciampino.

These results lead to the main conclusion that information gathered by one meteorological station can be considered sufficiently accurate to classify sound propagation conditions in the whole pilot area.
The same analysis was then carried out to see how sensitive is the model to wind direction. Also in this case the analysis was applied to both forecast and measured data. As for forecast data, figure 17 (a) shows that the difference in wind direction of the four investigated zones is substantial only in a few cases and the probability that the difference is less than 22.5° is 95%.



(a)



(b)

Figure 17. Cumulative distributions of wind direction differences related to forecast data (a) and measured data (b).

The difference in wind direction that can be attributed to measured data is less favorable, as it can be seen from figure 17 (b). In this case the differences are distributed in a wider range, varying from 0° to 150°. A probability of 90% can be assumed for differences ranging from 0 to 90°.

Nevertheless, the uncertainty associated to wind direction can be reduced by widening the wind sectors. Wind sectors are usually defined by steps of 20°, leading to a total number of 16 wind sectors, therefore increasing the amplitude of wind sectors from 20° to 90° can bring to more reliable and stable results, as in this way most of the differences in wind direction can be absorbed (error ≤ 1%). This solution allows to considerably reduce the number of basic noise maps to be prepared, as only four wind sectors (North, East, South and West) are necessary for each elementary noise source (see figure 18).

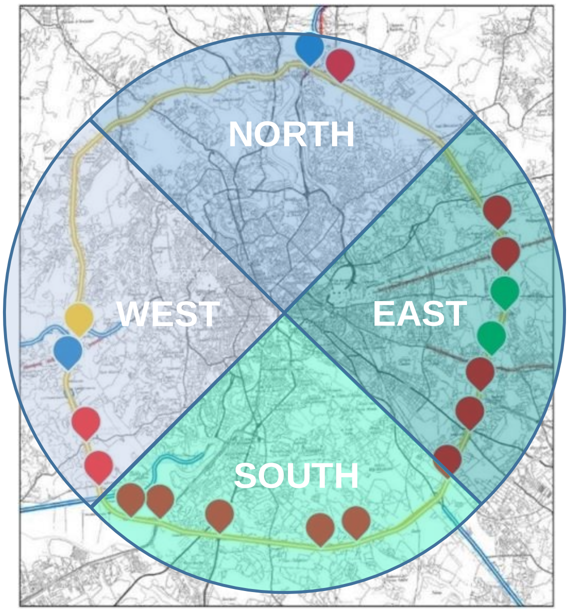


Figure 18. The four wind sectors of the pilot area of Rome.

These results lead to the main conclusion that a reasonable number of 6 basic noise maps for each elementary independent source are needed: one for totally homogeneous conditions, one for totally favorable conditions and four maps for favorable conditions in specific wind sectors (see figure 19).

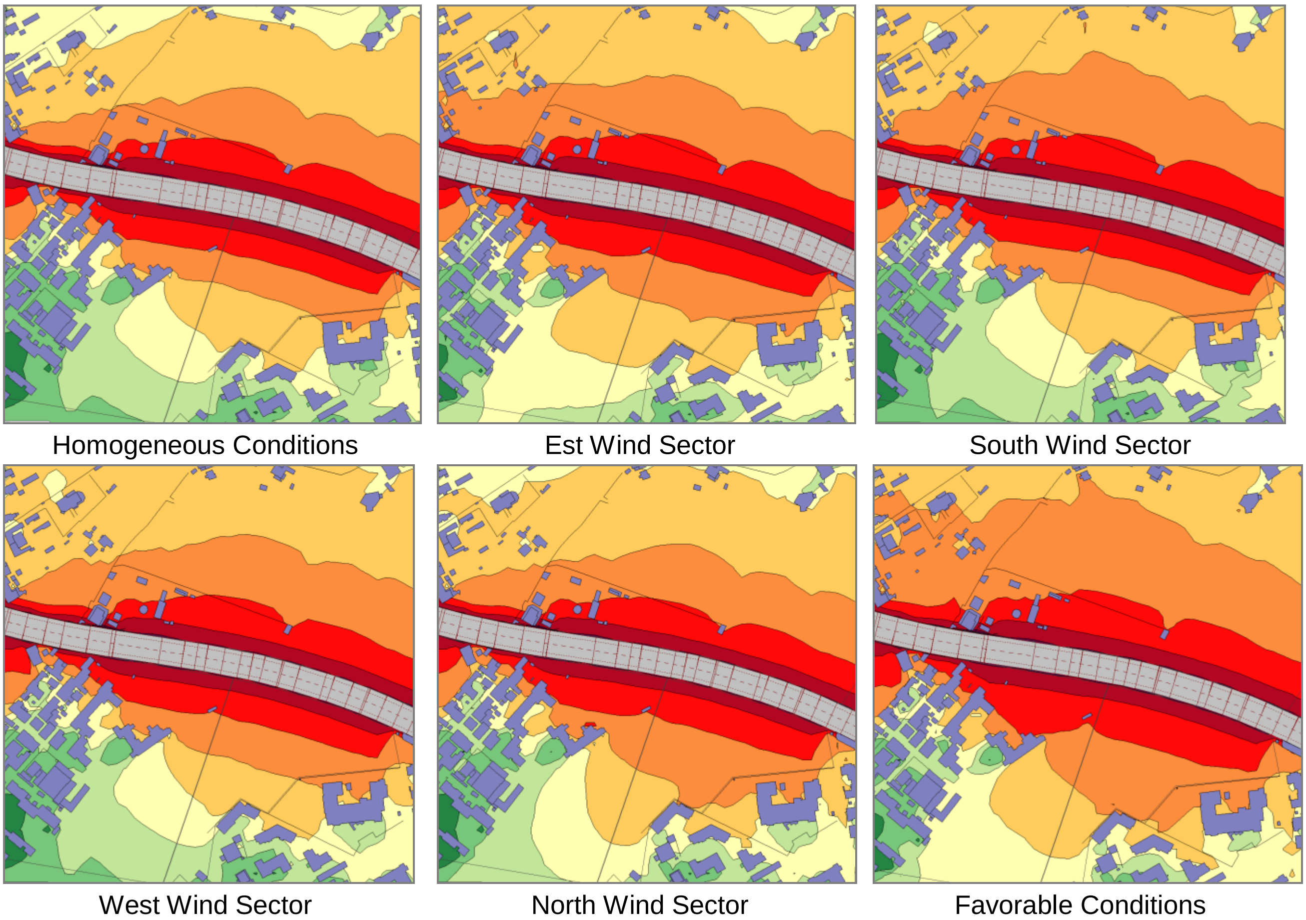


Figure 19. Basic noise maps sample related to the four wind sectors and to homogeneous and favorable conditions.

6. Conclusions

The main goal of the Dynamap project is to demonstrate that noise maps can be automatically updated in real time at low cost using customized sensors and communication devices. The noise levels detected by the sensors are used to scale basic noise maps stored in a database and processed on a general purpose GIS platform, thus eliminating the need for expensive dedicated acoustic software.

The feasibility of the Dynamap project approach will be proved implementing the system in two pilot areas with different territorial and environmental characteristics: an agglomeration (Milan) and a major road (A90 motorway, Rome). Agglomeration and major roads show different implementation requirements, that must be carefully investigated.

In this paper the discussion is focused on the case study of Rome, where the preparation and update of the basic noise maps are influenced by two main critical issues: the presence of additional noise sources and the effect of meteorological conditions on sound propagation.

As for the first issue, according to END separate acoustic maps should be prepared for different noise sources, therefore suitable sites should be identified to place the sensors and smart correlation factors between the main axis and its junctions should be identified, in order to reduce the number of independent elementary noise sources and, as a consequence, of the related basic noise maps. To that end, an extensive monitoring campaign was arranged in order to assess the noise contribution of each source and provide an accurate model calibration. The acoustic characterization of the sources present in the pilot area was accomplished with an experimental methodology based on Kirchhoff's junction rule, using sound level meters and traffic counters. The outcomes of the monitoring campaign have shown that along the A90 motorway traffic flow is more or less equally distributed between the two carriages. This result highlights that noise levels can be detected on the main road axis without significantly affecting the accuracy of the acoustic maps, thus reducing the number of basic noise maps to be prepared and the sensors necessary to monitor the area. The number of basic noise maps was further optimized through the estimate of a correlation factor between the noise levels on the main road axis and its junctions, leading to a total number of 21 elementary

noise sources. A couple of elementary noise sources were added to take into account the contribution of two main roads crossing the A90 motorway, thus increasing the number of elementary noise sources to 23.
As for the second issue, related to the influence of weather conditions on sound propagation, the attention was focused on finding a low cost suitable solution to retrieve or measure meteorological conditions, so as to define a reasonable number of propagation classes to be taken into account when preparing the basic noise maps. The criteria used to select the most appropriate solution were based not only on costs to gather meteorological data, but also on the time needed to process information and prepare the basic noise maps.
The outcome of this study has shown that, on the basis of the main acoustic models currently available, only three propagation conditions can be simulated: homogeneous conditions, favorable or homogeneous conditions in specific wind sectors, favorable conditions in all directions. This assumption led to the main conclusion that detailed weather data are not necessary and that the information provided by only one meteorological station is sufficient to classify sound propagation conditions in the whole pilot area with an accuracy of 92%. Furthermore, the entire pilot area can be broken down into four wind sectors, thus reducing the variability of sound propagation conditions due to aerodynamic factors and the possibility of basic noise maps conflicts. This simplification allows to cut down to six the number of basic noise maps needed for each independent elementary noise source: one for totally homogeneous conditions, one for totally favorable conditions and four for favorable conditions in wind sectors.
Since the pilot area of Rome is composed of 23 elementary independent noise sources, a total number of 23x6= 138 basic noise maps should be prepared. Further investigations are foreseen to check the possibility of reducing the number of basic noise maps in case of short distance of receivers from the road or in case the sound pressure level difference between the main axis and its junctions at receivers is more than 10 dB.

Acknowledgments
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