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Uncertainty of noise mapping prediction related to Dynamap project

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ABSTRACT

Dynamap is a European Life project, which aims at developing a dynamical acoustic map in a large urban area such as the city of Milan and the motorway surrounding Rome. We developed a method for predicting the traffic noise in an extended area using a limited number of monitoring sensors and the knowledge of traffic flows. In the case of Milan urban area, traffic and noise measurements have been performed in order to confirm both the non-acoustic parameter chosen to attribute a generic road to a specific cluster (traffic flow) and the noise predicted by our statistical model. Comparison showed that our predictive model is, in general, affected by two sources of error: statistic and systematic. In the case of Rome, noise measurements revealed the presence systematic errors in the noise map configuration. In both cases, their origin is analyzed and a method for their compensation and reduction is proposed.

Keywords: Noise mapping, Environment, Annoyance
I-INCE Classification of Subject Number: 30

1. INTRODUCTION

Dynamap, a co-financed project by the European Commission through the Life+ 2013 program, aims at developing a dynamic approach to noise mapping, owing to its capability to update environmental noise levels through a direct link with a limited number of noise monitoring terminals. Dynamap has been developed in the city of Milan and the motorway surrounding Rome [1]. The project has been also studied in terms of vehicle speed recognition [2-3]. As for Milan, all network stretches have been grouped in clusters roads sharing similarities among the 24-h continuous acoustic monitoring of the hourly equivalent $LAeq_{1h}$ levels [4-6].

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From this analysis, we developed a model for predicting the traffic noise of an arbitrary road stretch by means of a non-acoustic parameter [7-9]. We divided the whole set of about 2000 road stretches, the pilot area of the city of Milan is made of, into six groups, each one represented by a noise map. The updating of the noise map is obtained with the information from the traffic noise taken from 24 monitoring stations appropriately distributed over the urban pilot area of Milan [10-11]. The initial tests of calculation reliability and of correction of systematic errors, inherent the calculation scheme are reported in [12-14].

As for the case of Rome, the pilot area is located along the motorway surrounding the city (A90 o GRA – Grande Raccordo Anulare). In this case, 19 monitoring sensors have been installed in representative sites together with four weather stations. The road infrastructure has been divided into 19 traffic flow homogeneous areas (road paths between two successive junctions), to which a monitoring sensor has been assigned. For the entire pilot area of Rome a total of 228 base maps have been adopted [15].

In this paper, we provide the latest results about the uncertainty of noise mapping prediction related to Dynamap system in the pilot area of Milan named District 9 and the motorway surrounding Rome. This work is integrated in phase B7 of the "System Test and Fault Analysis" task of Dynamap project.

2. OPERATIONS OF DYNAMAP IN MILAN

An acoustic map has been assigned with each group of roads g (six base maps), the pilot area of Milan has been divided into. Operatively, each noise sensor i (24 for Milan) records a signal after filtering the anomalous events [16-18]. The signal is integrated to obtain an equivalent level Leqτ,i over a predefined temporal interval τ (τ = 5, 15, 60 min). Thus, we get 24 Leqτ,i values every τ min, each one corresponding to a recording station i. To update the acoustic maps, we deal with variations $\delta^{\tau}_{g,j}(t)$, where the time t is discretized as t = nτ and n is an integer, defined according to

$$\delta^{\tau}_{g,j}(t) = \text{Leq}\tau,\text{M(g,j)}(t)(\text{measured}) - \text{Leqref,M(g,j)}(T_{ref})(\text{calculated}) \qquad (1)$$

where Leqref, M(g,j) (calculated) is a reference value calculated from the acoustic map of group g (CADNA model) at the time interval Tref = (08:00–09:00) at the point corresponding to the position of the M(g, j)-th station. CADNA model provides mean hourly Leq values over the entire city of Milan with a resolution of 10 m given a set of input traffic flow data, thus representing a reference static acoustic map. Here, we have chosen the reference time Tref = (08:00–09:00) for convenience, since it displays rush-hour type of behaviour. The temporal ranges within the day are conventionally chosen as

τ = 5 min for (07:00–21:00);
τ = 15 min for (21:00–01:00);
τ = 60 min for (01:00–07:00).

Once all the $\delta^{\tau}_{g,j}(t)$ values have been obtained, the six acoustic maps can be updated corresponding to each group g by averaging the variations in Equation (1) over the four values j in each group, according to

$$\delta^{\tau}_{g}(t) = \frac{1}{4}\Sigma^{4}_{j=1}\delta^{\tau}_{g,j}(t). \qquad (2)$$

The first quantity we need to know is the value of Leqref(g,a) at the point a due to the noise produced by roads in the group g, which is provided by the calculated (CADNA) acoustic base map. The absolute level $Leq_{\tau}^{a}(t)$ at location a at time t = nτ can then be obtained by properly adding the contribution of each base map with its variation δ_{g}^{τ} calculated according to Equation (2).

$$Leq_{\tau}^{a}(t) = 10 \cdot Log \sum_{g=1}^{6} 10^{\frac{\text{Leqref}(g,a)+\delta_{g}^{\tau}(t)}{10}}. \quad (3)$$

We obtain the so called "scaled map" (dynamic map).

2.1 Analysis of Results: Milan's District 9

A preliminary validation of the described procedure has been done by comparing the measurements performed in 13 sites belonging to different groups. As testing measurements, we took into account also the prediction of the recordings from the 24 monitoring stations. The analysis needs the recorded data to be previously cleaned up from eventual anomalous events (ANEs) extraneous to the actual vehicle noise. A dedicated algorithm integrated in Dynamap sensors have been developed to this purpose [19-21]. In Fig. 1, we compare the measurement in Site 15 with the corresponding prediction as obtained by applying Eq. (3). The error band represents the propagation error applied to Eq. (3) and associated with the variability of $\delta_{g,j}^{\tau}$ within each group g. As we can observe, we have a discrepancy between predictions and measurements. The mean error over the 24 hours is 2.4 dB. This may suggest the presence of a systematic error inherent the Dynamap calculation method which is based on the traffic flow used as input in CADNA software for the calculation of each base map.

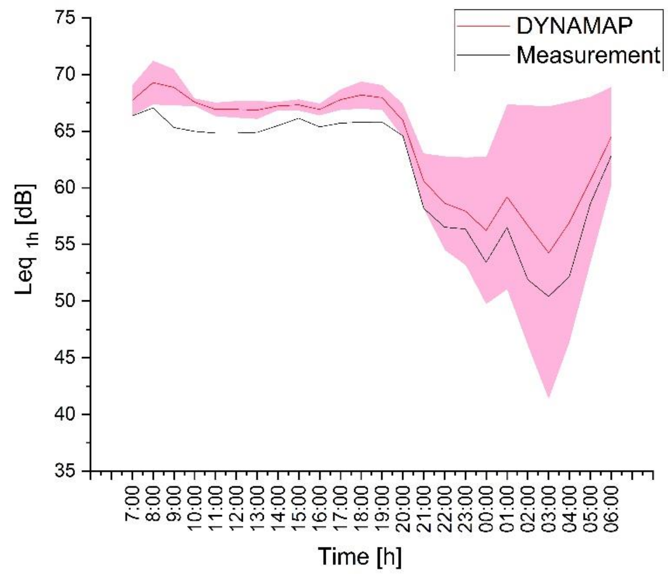

Figure 1. Comparison of traffic noise measurements and Dynamap prediction at Site 15. In the figure, the 1σ confidence level is displayed.

During the measuring campaign, we simultaneously recorded the traffic flows. The comparison between the measured and calculated traffic flow showed that the model provides more reliable results for roads belonging to groups g_2-g_5 and fails for g_1 [see ref. 14].

To quantify this discrepancy, we plotted the relative deviation, ε, defined as

$$\varepsilon = \frac{(\text{Leqmeas} - \text{Leq}^{a})}{\text{Leqmeas}} \tag{4}$$

between mean traffic noise measurements and corresponding predictions against the relative deviation,

$$\varepsilon_F = \frac{\text{Log(Fref meas)} - \text{Log(Fref mod)}}{\text{Log(Fref meas)}}, \tag{5}$$

between the logarithm of traffic flow measurements and the corresponding model calculations at Tref=(8:00–9:00)) and location a. The quantities in Eq. 4, represent the measured equivalent level, firstly averaged over the day (evening-night) period and, secondly over all roads belonging to each group, and the corresponding predicted equivalent level averaged over the same interval, respectively.

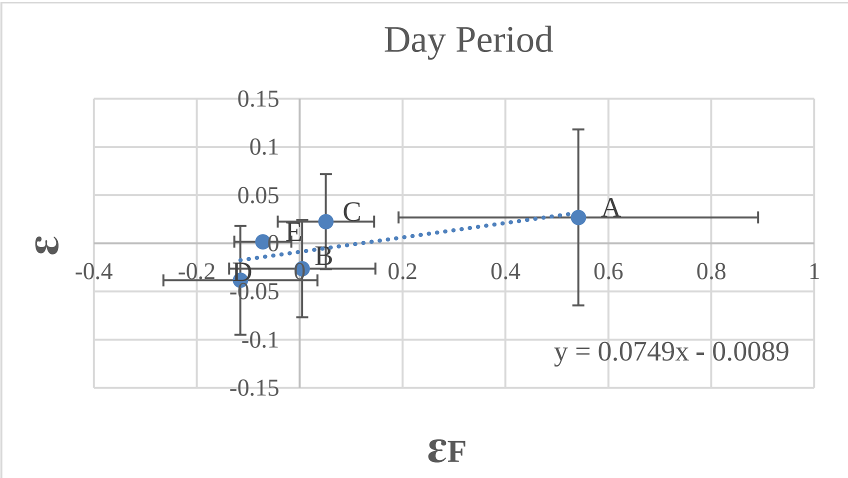

Figure 2. Relative deviation, ε, between traffic noise measurements and the corresponding predictions against the relative deviation, ε_F, between the logarithm of traffic flow measurements and the corresponding model calculations at tref=(8:00–9:00) and location a. Results refer to daytime period.

Figures 2 and 3 illustrate that, in general, higher traffic flow deviations are correlated with higher noise level errors. In particular, group g1 presents both higher values of flow and noise level deviation. We applied a correction to the predicted noise levels in Site 15.

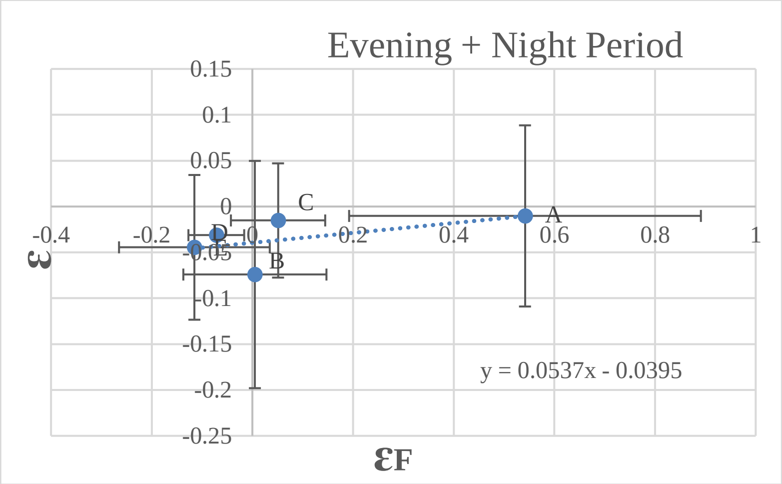

Figure 3. Relative deviation, ε, between traffic noise measurements and the corresponding predictions against the relative deviation, ε_F, between the logarithm of traffic flow measurements and the corresponding model calculations at tref=(8:00–9:00) and location a. Results refer to night-time period.

The corrected prediction for Site 15 is illustrated in Fig. 4. We observe a general improvement of the prediction with a mean error over the 24 hours reduced to 0.2 dB. In this case, the uncertainty band includes both the statistical and systematic errors. In Table 1, the mean prediction error before, ε_P, and after, ε_{corrP}, the systematic error correction for all the available sites is shown. All values are in dB.

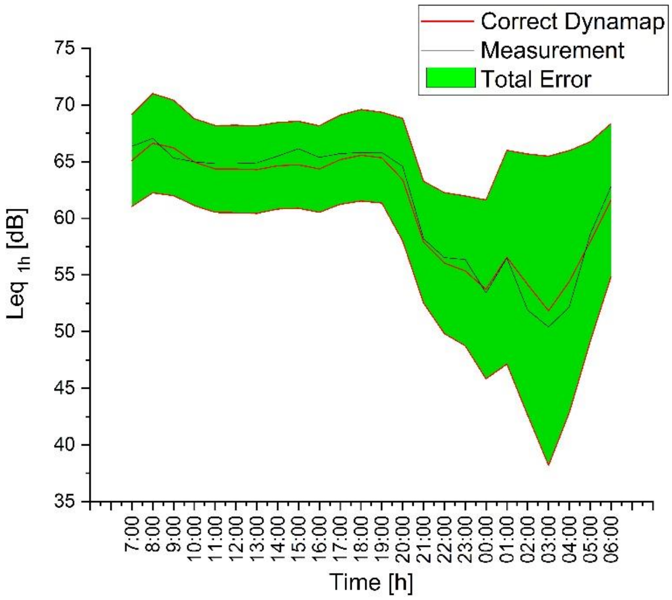

Figure 4. Comparison of traffic noise measurements and Dynamap prediction in Site 15. In the figure, the total error is displayed.

In Table 1, we also report the prediction error after a correction based on the use of median-averaged values in each group g. This quantity is less sensitive to outliers and, consequently, it improves, in almost all case, the corrections. In Table 2, the error averaged over the roads belonging to each group is displayed.

Site	Group	ε_P	ε_{corrP}	ε_{corrPM}
10	g_1	5.2	4.6	3.6
11	g_1	2.5	3.1	4.4
18	g_1	6.2	6.9	8.1
Hb137	g_1	2.2	1.5	0.1
Hb135	g_1	6.8	6.2	4.8
7	g_2	1.3	1.6	0.8
12	g_2	7.1	4.1	6.5
14	g_2	1.6	1.1	1.1
Hb108	g_2	0.8	3.9	1.4
Hb124	g_2	0.6	2.5	0.0
3	g_3	3.6	4.1	3.3
6	g_3	0.9	1.3	0.5
8	g_3	0.1	0.3	0.4
Hb115	g_3	0.7	1.1	0.3
Hb120	g_3	4.9	4.4	5.2
13	g_4	2.3	0.4	0.0
15	g_4	2.4	0.2	0.1
16	g_4	8.2	5.6	6.0
Hb129	g_4	1.4	4.1	3.7
Hb127	g_4	0.0	2.7	2.3
1	g_4	4.6	3.9	5.0
5	g_4	0.9	1.7	0.5
9	g_4	0.3	1.0	0.2
Hb151	g_4	1.1	0.3	1.5
Hb136	g_4	1.6	2.4	1.2

Table 1. Mean prediction error before, ε_P, and after systematic error correction for all the considered sites based on the mean, ε_{corrP}, and median average, ε_{corrPM}. Sites with code Hbxxx refer to the monitoring sensors' locations. All values are in dB.

Group	$\overline{\varepsilon_P}$	$\overline{\varepsilon_{Corr_P}}$	$\overline{\varepsilon_{Corr_{PM}}}$
g_1	4.6	4.5	4.2
g_2	2.3	2.6	2.0
g_3	2.0	2.3	1.9
g_4	2.9	2.6	2.4
g_5	1.7	1.8	1.7

Table 2. Mean prediction error before, $\overline{\varepsilon_P}$, and after the systematic error correction, averaged over each group g, based on the mean, $\overline{\varepsilon_{Corr_P}}$, and median average, $\overline{\varepsilon_{Corr_{PM}}}$. All data are in dB.

3. OPERATIONS OF DYNAMAP IN ROME

In the pilot area of Rome, the Dynamap system is composed of 19 monitoring devices installed along the motorway A90 that encircles the city: one monitoring device for each elementary noise source present in the mapping area. In main roads, an elementary noise source is usually a road stretch with homogeneous traffic conditions.

Since in suburban areas noise levels are affected by meteorological conditions, different basic noise maps must be prepared for each elementary noise source to take into account their influence on sound propagation. In the pilot area of Rome six main sound propagation conditions have been considered: totally homogeneous conditions, totally favourable conditions and four favourable conditions in specific wind sectors (north, south, east and west). As considerable differences in traffic behaviour were also observed in working and weekend days, two additional conditions have been included, leading to a total number of 12 combinations of traffic and weather conditions, corresponding to as many basic noise maps.

Basic noise maps are static maps that report for each point of grid the contribution of the elementary noise sources present in the mapping area. Analytically, a basic noise map is an array reporting on each row the contribution of the whole set of elementary noise sources to one point of the grid. So the first column shows the identification code of the grid point (ID), followed by its coordinates and the contribution of each elementary noise source related to that point. In the last column the overall noise level for each point of the grid is reported.

ID	LAT	LONG	NS1 dB(A)	NS2 dB(A)	NS3 dB(A)	...	NSN dB(A)	Leq_T dB(A)
0001	X0001	Y0001	L_{11}	L_{12}	L_{13}	...	L_{1N}	Leq_{R1}
0002	X0002	Y0002	L_{21}	L_{22}	L_{23}	...	L_{2N}	Leq_{R2}
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
9999	X9999	Y9999	L_{99991}	L_{9992}	L_{99993}		L_{9999N}	Leq_{R9999}

Figure 5. Basic noise map array

The update of the noise map is made by scaling the data present in each columns on the basis of the noise level detected by the monitoring stations. The amount to be scaled is given by the difference between the measured and calculated noise levels at the reference point, corresponding to the position of the monitoring devices. The update of the noise map is carried out with a time frequency of 30 s.

To verify the reliability of Dynamap noise level calculation procedure, a measuring campaign has been performed in September 2018. Ten are the total measurements recorded along the GRA. In four sites, we performed two measurements at different distances and in two sites just in a single position. Before processing, each measurement has been cleaned up from any anomalous event identified during the recording [16-21]. Each recording was one hour long.

3.1 Analysis of results: Rome's GRA

Below, we can see the results obtained for two test sites: Site 3a and 3b. Site 3 is one of the four for whom we have two in-line measurements: 3a at the border of the roadway at about 25 m from the source and with the presence of a plant barrier (as shown in the figure 6). Site 3b is located at about 190 m from the source in an uncultivated field.

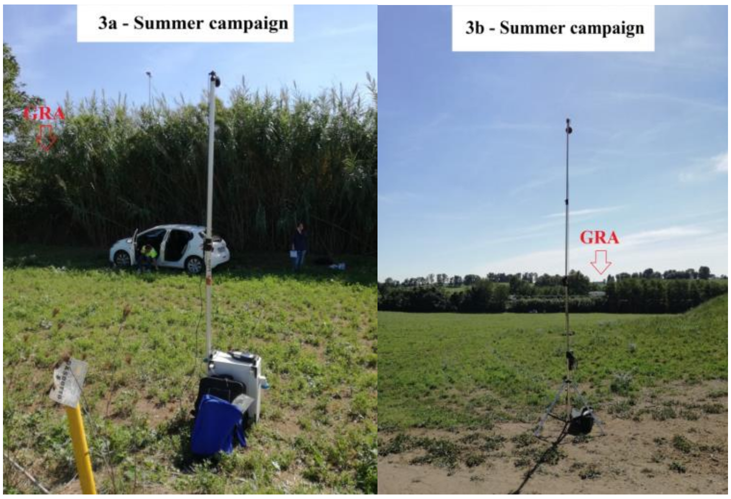

Figura 6. Test Site 3a and 3b during the summer campaign.

In figure 7 and 8, the comparison between Dynamap predictions and measurements are displayed for Site 3a and 3b.

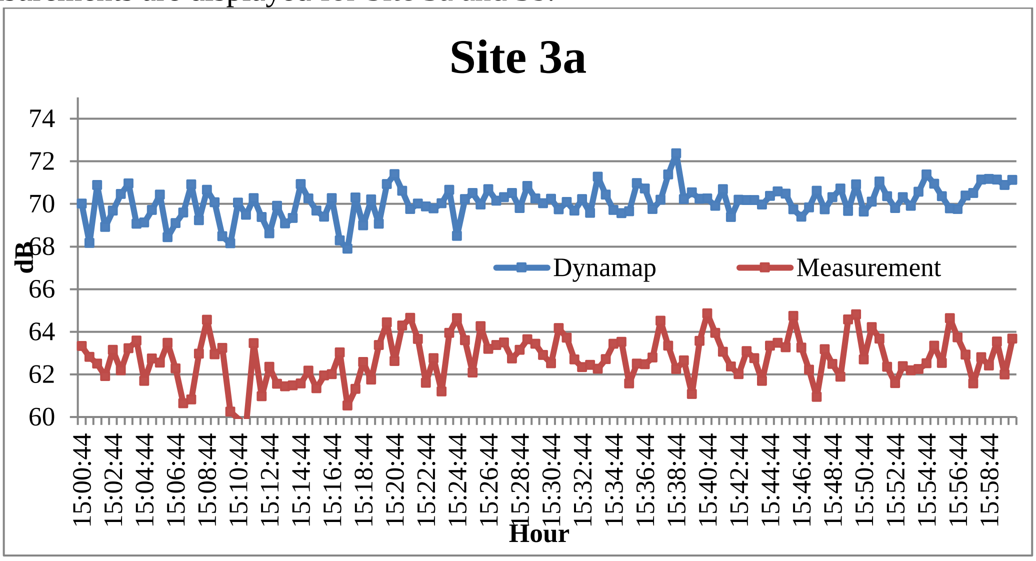

Figure 7. Comparison between Dynamap prediction and measurement for Site 3a.

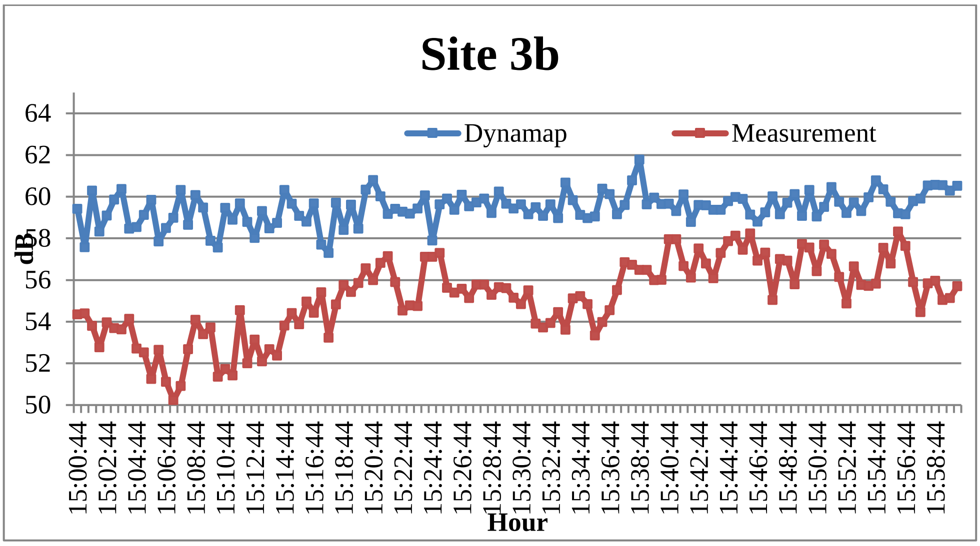

Figure 8. Comparison between Dynamap prediction and measurement for Site 3b.

The mean deviation for Site 3a is 7.33 dB and for Site 3b 4.3 dB. The deviation for the other sites have been found to be in the range between 2 and 10 dB. From these results, we analyzed the possible faults inherent the propagation model employed to describe the noise features around the noise source. Thus, we modified the ground factor attributed to the different types of soil surrounding the motorway and whose influence is greater at greater distances. The ground factor has been modified from an initial value of 0 for all the surfaces to a value of 0 for water surface, 0.8 for cultivated fields and 1 for bushes. What follow are the results of the new predictions (see Figures 9 and 10). In table 3, we report the summary of the results before and after the changes of the model propagation settings in all measurements sites.

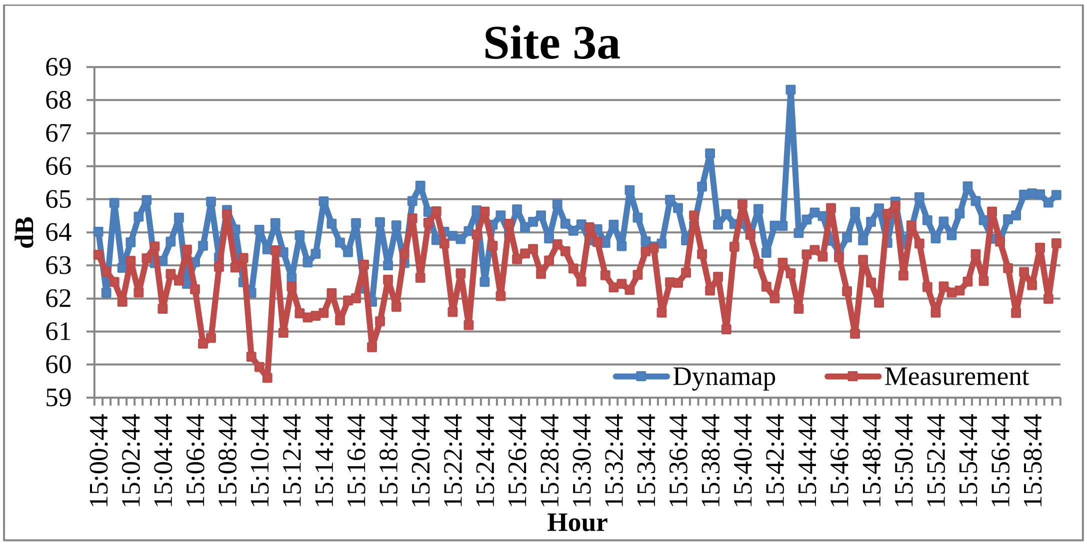

Figure 9. Comparison between Dynamap prediction and measurement for Site 3a after the correction.

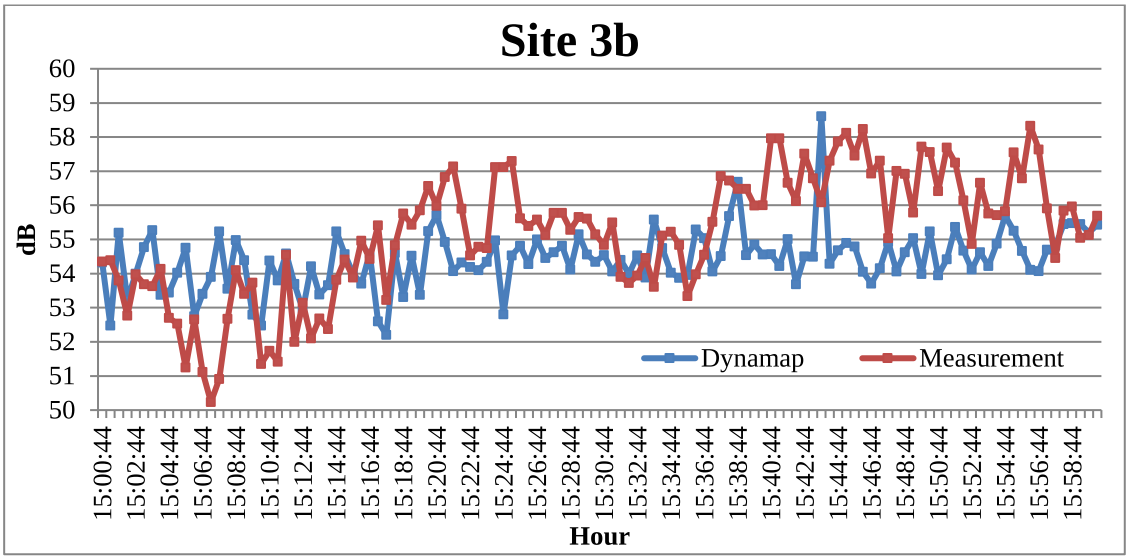

Figure 10. Comparison between Dynamap prediction and measurement for Site 3b after the correction.

Site	Distance from GRA	Mean deviation before model settings	Mean deviation after model settings
1a	15	11.15 ±1.38	1.77 ±0.68
1b	195	10.92±1.73	0.97±0.78
2a	30	1.55±1.09	3.41±1.42
2b	160	2.12±1.51	6.47±1.96
3a	25	7.33±1.24	1.57±1.06
3b	190	4.30±1.74	1.53±1.14
4a	55	7.88±1.14	2.28±1.27
4b	180	5.01±1.27	1.56±1.96
5	90	7.88±1.14	1.34±0.91
6	100	5.01±1.27	2.58±1.11

Table 3. Summary of the results before and after the changes of the model propagation settings in all measurements sites. All data are in dB.

As we can observe, the changes of model propagation settings brought to a better prediction and representation of the real scenario surrounding the GRA.

4. CONCLUSIONS

In this paper, the prediction reliability of Dynamap noise mapping scheme is presented for the pilot area of the city of Milan and the suburban area of Rome.

In the city of Milan, the poor traffic noise description of the real traffic flow made the prediction unsatisfactory. By correlating the Dynamap prediction error to the traffic flow error for each group of roads, we succeeded in reducing the overall Dynamap error. The illustrated method to correct the systematic error is able reduce the predicted noise levels to about 3-4 dB in each group.

As for the city of Rome, Dynamap prediction has been extremely improved after a more careful choice of the ground factor in the propagation model (CADNA). Also in this case, the overall prediction error is on average below 3 dB.

5. ACKNOWLEDGEMENTS

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