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Optimizing localization of noise monitoring stations for the purpose of inverse engineering applications

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Long-term environmental monitoring of noise levels can be done using autonomous measurement stations. Because of the high cost of monitoring systems and management of these stations, it is essential to identify how many of measuring localization points are really required. In cases related to complex noise generation schemes, when there are various noise sources, the differences between calculations and measurements can be difficult to estimate. Therefore, it is vital to find some most appropriate locations for measurement stations which would ensure obtaining an adequate number of measurement results to be employed in the reverse engineering. These measurements can be then utilized to update dynamic noise maps. Furthermore, predictive noise models may be developed accordingly to certain local requirements. This could result in a better accuracy of dynamic noise maps. The paper focuses on defining the proper choice of the measurement points localizations. The experiments described include a comparison between real-life measurement results performed with the Multimedia Noise Monitoring System developed at the Multimedia Systems Department of the Gdansk University of Technology and the noise level prediction results. The optimization of the number and location of noise monitoring points with regard to the measurement accuracy is also discussed.

1 Introduction

Several software can be used to analyze long-term environmental noise. These can be MITHRA, SoundPLAN, LIMA, CadnaA or the other one. There are many of them, but the problem is to choose these with the best accuracy. Researchers wish to have such programs, which produce the most reliable noise map for a particular area. The past has proven that different software packages based on the same prediction standard give different results even in simple cases [4]. This means, that for different situations it generates noise maps with various discrepancy The aim for noise mapping development is to find the prediction method with low discrepancy in order to draw accurate map for considered area. This is one point of view, which leads up to improve the noise source and propagation model. The other one is to affect calculated noise maps with actual measured noise levels in order to establish dynamic noise maps [3]. Generation of such maps requires the methodology for estimating the influence of real noise measurement results on particular immisions values, located near the measurement points, computed by the noise prediction software. It is possible to correct some parts of map using just a few of measurement stations. This approach is called the reverse engineering method for the noise mapping [9]. The problem of the implementation of this method is lack of designated general rules for optimal locations of measurement stations. To determine such places it is essential to discover differences between real measurement results and calculations.

2 Criteria for optimal measurement points

The knowledge about real causes of inaccuracy is needed to apply corrections to the noise map. This problem is widely considered [6, 11]. Using reverse engineering gives the possibility to correct the predicted noise level value not only for the measured point but also in some area near that point. Because the number of measurement points is many times lower than the number of generated noise immision points on the map [3], drawing a dynamic noise map requires well-advised measurement points in the city [10]. It should be noticed that inaccuracies between the real noise levels and model output can affected by many factors for example: inconsistency of the considered noise sources, complexity of the propagation part, the general configuration of the model like the number of reflections and other [1].

Corrections can be divided into two groups. The first one is to collect areas with similar sources configuration. This is the most obvious type of correction, but it must be remembered that each noise model is based on two parts: source and propagation. To generate dynamic noise maps it is not enough just to take into consideration the source part of prediction model. That is why the second correction group is joined with the propagation part. It requires that all the mapping area are divided into spots with the same types of acoustic conditions.

It is essential to classify the sort of place – whether it is a city or just a road across the field. In the context of reverse engineering methodology location and number of measurement points are fundamental. For a particular city it will be unique parameters. For the city of Gdansk, Poland, considering just communication noise, the number of measurement stations can be estimated by analyzing the configuration of noise sources and topography. Gdansk has several arterial roads, one main railway and one airport. For the considered city and its noise source configuration the exemplary distribution of the monitoring station can be specified as below:

- Two stations for railway (because of two different flow characteristics)
- One measurement station for airport
- Several stations for road noise.

The number of stations for monitoring of the road noise is hardest to estimate. It could be done by taking into account the traffic flow density. The proposed numerical formula was given by equation 1.

$$N = \left\lfloor \log_q \frac{y}{s} + 2 \right\rfloor \tag{1}$$

where:
N – number of stations needed (for roads only)
q – indicator of the accuracy range (2 for 3 dB range or 1.26 for 1 dB range)
y – maximum flow in the city (for roads)
s – starting point (the assumed minimum flow)

The roads can by classified in some categories, for example: less than 1000 vehicles per hour, 1000 – 2000; 2000 – 5000; and so on. The other classification can depend on the noise level generated by the road. It can correspond to theoretical acoustic range of noise generation for this sources - for example 3 dB intervals for doubling number of vehicles passing-by or 1 dB intervals for increasing number of vehicles passing-by of 26 %. For the first situation that will give 7 and for the second one there will be 18 categories. The exemplary ranges of traffic flow for particular categories for 3 dB and 1 dB intervals were shown in table 1.

3dB ranges		1dB ranges	
Numbers of vehicles	Class No.	Numbers of vehicles	Class No.
0 - 999	1	0 - 999	1
1000 - 1999	2	1000 - 1259	2
2000 - 3999	3	1260 - 1587	3
4000 - 7999	4	1588 - 1999	4
8000 - 15999	5	2000 - 2519	5
16000 - 31999	6	2520 - 3175	6
>32000	7	3176 - 4001	7
		4002 - 5041	8
		5042 - 6352	9
		6353 - 8004	10
		8005 - 10085	11
		10086 - 12707	12
		12708 - 16011	13
		16012 - 20174	14
		20175 - 25420	15
		25421 - 32029	16
		32030 - 40357	17
		> 40358	18

Table 1 Exemplary ranges of traffic flow for particular categories for 3 dB and 1 dB intervals

The choice depends on the required accuracy level. For 1 dB range 21 measurement stations are required (including air and rail noise). The next step is acknowledgement of propagation part of the model. It depends on several parameters, but generally in Gdansk there can be proposed five types of locations: flat ground with/without buildings, diversified ground with/without buildings and near the water (sea, river). If all of the described situations exists, the number of needful positions amounts to 105 stations. It is hard to think that all of these locations occur for all types of sources. For airport there is one area type, and for the railway two types can be taken into consideration. That gives 95 stations for Gdansk monitoring system. We can reduce the number of stations for road, so for 18 categories of road sources there will be 18 stations, because there are very few locations near the sea, and some for other location types do not exist, for example for the first (<1000) and last category (>40,000). Use of one station for each category can be insufficient. For that reason the multiplication of monitoring station number is needed. It will increase credibility of the corrections confections for all dynamic noise map. Assuming installation of the three stations per category the number of required stations is 77 for Gdansk. This city is 262 square kilometers in area. This means that we need one station for every 0.88 square kilometers. The question is if these stations can be uniformly distributed within the city area.

3 Scenarios of setting measurement stations

Uniform distribution of the stations can result in missing of monitoring noise sources that are significant and should be monitored. For that reason it is important to consider different ideas to locate measurement stations. Three various approaches can be taken into consideration. The first one bases on simple situations, when it is very probable that the highest measurement conformity with model calculations will occur. The second one is the opposite to the first one. It is found in complex situations with several types of sources. These can be situations on junction, or parallel line sources with intersection. These situations will probably have high inaccuracies between calculations and measurements. Researchers from Romania have eliminated these situations [3]. The last option is to concentrate on “key interest areas”. For now eleven main areas have been chosen. This third alternative is a mixture of previous options. Similar point of view is given in [9]. The areas are presented in Table 2. It is obvious that all the source types must be represented with suitable location to determine the difference between measurements and model computations [2, 5]. There are some simple situations, where it is required to know how good is the source model. More complex situations are needed to estimate difference between simple single source modeling and situation with accumulation of these sources. This gives us knowledge if there is any difference between simple and complex situations.

No.	Description of area
1	Complex situation with several source types with some intersection on flat ground
2	Like No. 1 but with ground diversification
3	Single source on flat ground, the distant building line
4	As a No. 3 but with ground diversification
5	Silence zone
6	High population density
7	High M indicator [12]
8	High noise level of excess
9	No noise level of excess
10	Intermittent noise source – railway
11	Intermittent noise source – airport

Table 2 Description of area of interest

To assess the placement of the long-term measurement stations, some noise measurements were made. The obtained measurement values were later compared with the modeling results achieved using CadnaA software according to recommendations of the European Directive on the Assessment and Management of Environmental Noise, 2002/49/EC. This problem was examined by few researchers [2, 5, 7, 8].

4 Measurements

Two series of measurements were performed in the selected locations in the city area. The equivalent A-weighted noise level was obtained in each point. The detailed measurements conditions were presented in table 3. Description of measured sources were shown in table 4. The measurement microphones were mounted 4 meter above the ground surface, with one exception for microphone number 5 in first location (near to Gdansk University of Technology). In this cease the microphone was placed 1.6 meter above the ground. The measurements were made using PULSE measuring system and sound level meter type 2260 Investigator, both produced by Brüel&Kjær.

Date	25 IV 2008	30 IV 2008
Temperature	18 ^{o}C	13 ^{o}C
Relative air humidity	35 %	92 %
Cloudiness	medium	very high
Atmospheric pressure	1020 hPa	1000 hPa
Period	50 min	56 min

Table 3 Atmospheric conditions for both measurements

date	25.04.2008	Gdansk University of Technology		
source type				
	car	**truck**	**motor**	---
road 1 Traugutta Street	919	23	7	---
road 2 Sobieskiego Street	941	26	9	---
date	30.04.2008	Gdansk Oliwa		
source type				
road	**car**	**truck**	**motor**	---
	1020	33	3	---
railway	**suburban**	**passenger**	**intercity**	**Freight**
	7	3	2	1
tramway	**short**	**long**	**repair**	---
	13	5	1	---

Table 4 Number of measured sources

5 Results of modeling

The real noise sources properties and weather conditions were precisely reconstructed in the CadnaA software. The alignments of the set of microphones were shown: in figure 1 for location 1 and in figure 2 for location 2. The computed noise maps for considered location were shown in figures 3 and 4.

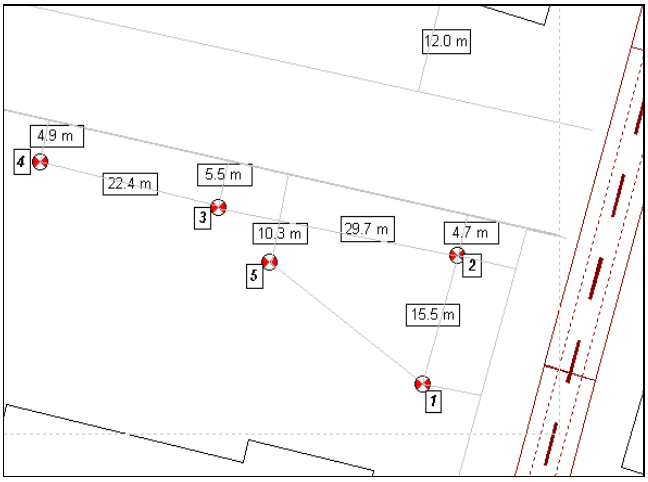

Fig. 1 Microphone set up for location in Gdansk University of Technology

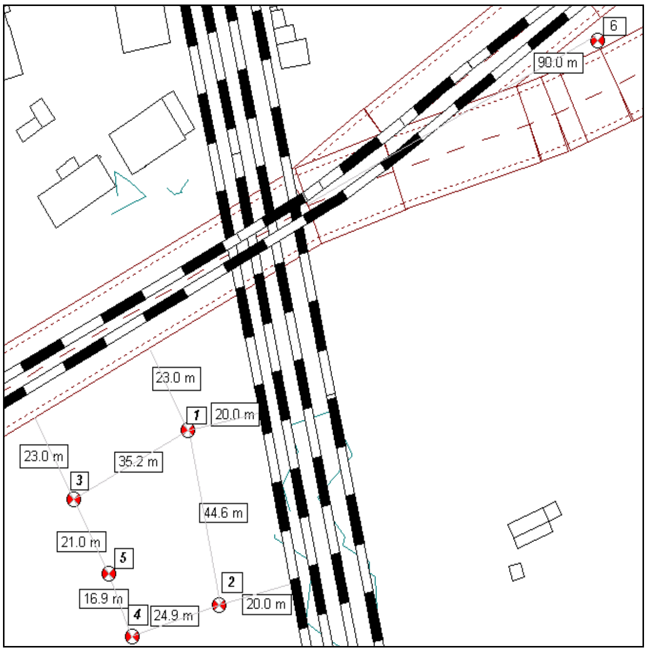

Fig. 2 Microphone set up for location in Gdansk Oliwa

The results for all 5 microphones in first location were collated in table 5. If the distance between the measurement microphone and source location is increased the discrepancy is getting higher. Furthermore, when the distance between second (noiseless) road is bigger, the discrepancy is lower, so when single source is dominating the modeling is better.

Mic. no.	Day noise level (dBA)		Discrepancy
	Measured $L_{Aeq,M}$	Computed $L_{Aeq,C}$	$L_{Aeq,C} - L_{Aeq,M}$
1	68.2	67.6	-0.6
2	67.5	67.7	0.2
3	59.4	63.4	4.0
4	56.1	62.5	6.4
5	58.6	61.8	3.2

Table 5 Comparison of computed and measured equivalent noise levels for Gdansk University of Technology location

The comparison of measured and computed value for second location for each microphones were collated in table 6. In the most cases the value of measurement was greater than modeling result. The largest convergence was observed for microphones situated nearest to the road (points 1 and 6). Rail noise level calculated by model turned out to be considerably lower than the measured one (points 1 and 2). Similarly to the first measurement series, the largest differences appeared for microphones situated the farthest away from the noise sources (points 3, 4, 5). Moreover, the significant difference was observed at the crossing of noise sources (point 1). Discrepancy in this point was a result of underestimation of the rail noise.

Mic. no.	Day noise level (dBA)		Discrepancy
	Measured L_{dM}	Computed L_{dC}	$L_{dC} - L_{dM}$
1	71.7	63.6	-8.1
2	68.9	59.5	-9.4
3	65.6	62.4	-3.2
4	67.8	57.7	-10.1
5	65.7	59.3	-6.4
6	67.4	69.4	2.0

Table 6 Comparison of computed and measured equivalent noise levels for the Gdansk Oliwa location

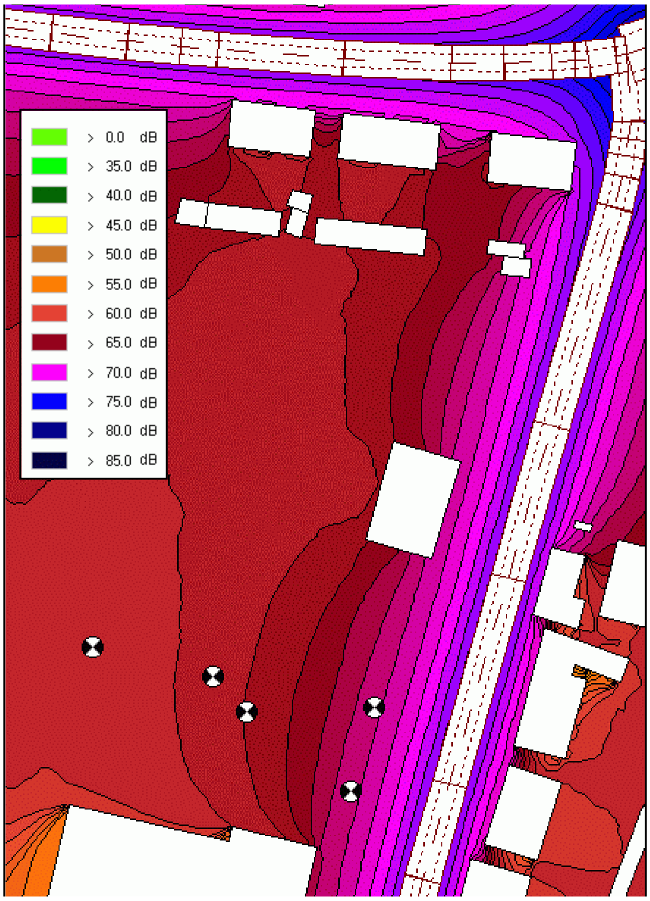

Fig.3 Noise map for first location (Gdansk University of Technology)

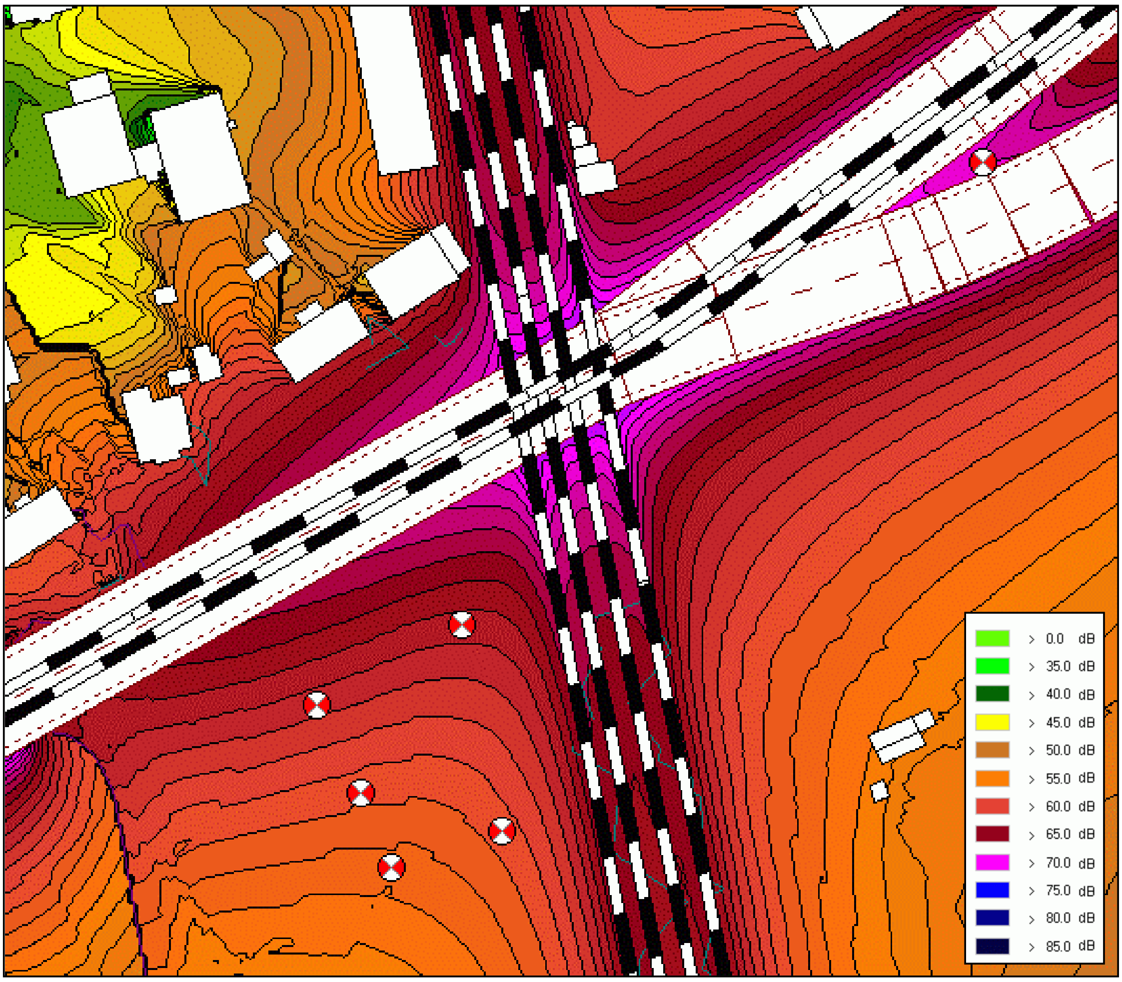

Fig. 4 Noise map for the second location (Gdansk Oliwa)

6 Conclusion

This paper presents the criteria of selection the number of the measurement stations and their deployment for purpose of updating the dynamic noise maps. On the basis of conducted research aimed for compare between the real measurements results and the outcomes of modeling it was stated that the largest coincidence of values was achieved for points situated nearest to the road noise sources. The discrepancies were mainly result of the work of a propagation part of the model used. Moreover, large differences was observed for the rail noise and at the crossings of different noise sources.

In practice, for reliable projection of the acoustic conditions there is a necessity of supporting the most accurate data of a given noise source to the model. Additionally, it should be noticed that the applications for noise modeling does not meet the untypical acoustical events like the passing of special vehicle using a horn. Application of correction coefficients, collected in the process of comparison of the measurement and the model will allow to increase the accuracy of data presented by the updated dynamic noise maps.

Acknowledgments

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References

[1] E. Aramendia, I. Nagore, D. Pérez, R. San Martín, M.L.S. Martin, M. Arana, How many reflections must be considered in urban noise mapping?, INTER-NOISE 2007 Proceedings, ISTANBUL, TURKEY, 28-31.08.2007.

[2] J. van den Brink, *Permanent measurement stations for railway noise*, Euronoise 2006, Tampere, Finland, 30 May – 1 June 2006.

[3] D. Comeaga, B. Lazarovici, G. Tache, *Reverse engineering for noise maps with application for Bucharest city*, Inter-noise 2007, Istanbul, Turkey, 28-31 August 2007.

[4] E. Hartog van Banda, H. Stapelfeldt, Software implementation of the harmonoise/imagine method, the various sources of uncertainty, INTER-NOISE 2007 Proceedings, ISTANBUL, TURKEY, 28-31.08.2007.

[5] H.G. Jonasson, *Determination of* L_{DEN} *using measurements*, Euronoise 2006, Tampere, Finland, 30 May – 1 June 2006.

[6] T. Loyau, *Uncertainties due to the measurement surface (angle and impedance) and to the number fo microphones for the A-weighted sound power level determination using sound pressure measurements*, Euronoise 2006, Tampere, Finland, 30 May – 1 June 2006.

[7] J. Lub, *Web processing and presentation of railway noise monitoring data*, Euronoise 2006, Tampere, Finland, 30 May – 1 June 2006.

[8] Panu P. Maijala and Ossi T. Ojanen, *Long-term measurements of sound propagation in Finland*, Inter-noise 2006, Holonulu, USA, 3-6 December 2006.

[9] D. Manvel, E. Aflalo, *Reverse engineering: guidelines and practical issues of combining noise measurements and calculations*, Inter-noise 2007, Istanbul, Turkey, 28-31 August 2007.

[10] D. Manvell, L. Ballarin Marcos, H. Stapelfeldt, R. Sanz, *SADMAM – Combining Measurements and Calculations to Map Noise in Madrid,* The 33rd International Congress and Exposition on Noise Control Engineering, Inter-noise 2004, Prague, Czech Republic, 22-25 August 2004.

[11] F. Wittekamp,J. Kamer, *Uncertainty in measurements and calculations of noise levels: A case study in the city of Amsterdam*, Inter-noise 2006, Holonulu, USA, 3-6 December 2006.

[12] http://www.gios.gov.pl/halas/2.pdf (*in Polish*)