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MANAGEMENT OF ENVIRONMENTAL NOISE – THE CRACOW EXAMPLE

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The aim of this article is describing the management of an environmental noise system. The main part of the system are information layers, which are based at a SoundPlan, Integrated Noise Model and MapInfo programs. The layers present maps of noise emitted by: road traffic, rail traffic, industrial activity sites and the airport Cracow – Balice. The strategic noise maps were performed according to the demands of the Directive of the European Parliament and of the Council of the European Union and National Law Acts. The System is working on available measurement data. It is impossible to eliminate environmental noise so it is necessary to reduce the number of noise exposed people. The problem is to get right information about the sources, levels of each source, the number of people living in a given are and the results of the noise reduction action. Every inhabitant should have the access to this information, especially when his decisions can affect the acoustical climate. From the other side, law makes it duty to serve noise pollution information to everybody (especially via internet). This article describes such a system which consists of two parts: database and presentation.

Keywords: management of environmental noise, noise map, acoustic climate.

1. Introduction

The project discussed in this work is implemented in the special grant "The System for Acoustic Climate Management in Large Cities on the Example of Cracow".

The purpose of this Project is to "develop an acoustic climate assessment and management in a large urbanized area, which will allow to reach suitable acoustic comfort in an urban environment due to the fact that all environmental noise factors are taken into consideration, and a practical implementation of this system".

Because of economic reasons, it is extremely hard to reduce noise in the years to come and to reach even relatively liberal standards. Therefore, the problem is to work out such an approach, which would ensure effective operations while economical rationality is maintained. In many countries, there have been long-standing programs for

environment protection against noise that satisfied this requirement. Thus a designed program of action, covering all areas threatened with noise, allows for a rational management of financial resources allocated for protection projects, and their successive transfer as they become available. However, the diversification in time of a resource allocation requires the development of clear criteria for their allocation and a continuous acoustic climate monitoring. The system of the acoustic climate management will allow to introduce a feedback element to the noise-related policy, to rationalize its implementation, and to introduce continuous improvements in the compliance with the TQM rules.

The acoustic climate management system may constitute one of the fundamental elements in the program for environment protection against noise and, at the same time, it affects its effectiveness. The necessity to take measures aimed to provide protection from noise and their expected costs (acoustic screens, acoustic protection for selected buildings, fitting the system for continuous noise monitoring) are the reasons why it is advisable to develop a complex system allowing to monitor continuously the undertaken operation results, and ensuring a suitable city development and functioning strategy (ring road construction, rational location-related decisions, removal or severe penalties for facilities that generate noise in excess of standard values).

The implementation schedule involves the execution of the following partial tasks:

- Development of an environment acoustic climate model,
- Adjustment of the model,
- Rudiments for the acoustic climate assessment and management,
- System for acoustic climate monitoring,
- Connecting of the monitoring model with the policing service monitoring,
- An integrated acoustic climate management system,
- Development of a road traffic management system taking into account acoustic hazards,
- Implementation of the city acoustic climate management system.

2. Environment acoustic climate models

The battle against environmental noise pollution has been fought for many years now. In spite of some achievements in this field, it was impossible to make cities silent and quiet, which would ensure a full comfort of life. The existing trends show that the situation is systematically getting worse.

In order to counteract, a whole range of tasks has been taken up, from responding to noise-related complaints to making acoustic maps, from incidental measurements and continuous monitoring to actions aimed to reduce the noise and to determine areas of particular risk. We may distinguish here three major approaches:

- ***Separate approach (conventional)***
  a separate solution is found for each problem;

- ***Combined approach***
  each problem has its own solution, but the data may be exchanged and accepted methods reused; example: use of data obtained from the noise monitoring system for control and information purposes (primary objective) and for an acoustic map update (additional objective);
- ***Integrated approach***
  the system solution, in which data obtained from various sources would be collected and archived in a database (with tight or dispersed structure), and used for various purposes after processing; it is therefore possible to achieve better efficiency and rational management of resources. Response to complaints, noise maps, noise monitoring, noise forecasting and reduction may be executed on the grounds of the same, once the data are obtained.

In the scope of the above-mentioned special grant, in this study an integrated noise management system for the City of Cracow has been developed.

In order to discuss it in more details, let's first answer the questions: what is the acoustic climate and which elements affect it?

3. Acoustic climate analytical model

We may say that the acoustic climate is a combination of phenomena occurring in the environment, and caused by noise sources existing in that environment or beyond of it. As the result, one may speak about a natural acoustic climate (noise sources are related to natural processes and behaviours of living beings in that environment: sea swoosh, tree swoosh, singing of birds), and a man-made acoustic climate.

In general, the environment acoustic climate means a combination of partial phenomena occurring in the environment and described by

$$K_A = f\left(K_1, K_2, K_3, ..., K_N\right), \tag{1}$$

where K_A – acoustic climate, K_1, K_2, K_3,...,K_N – partial acoustic climates.

A partial acoustic climate refers to the type of noise polluting the environment, such as: road noise, railway noise, industrial noise, high voltage line noise, communal noise, etc. Each of these partial climates is characterized by values describing the noise related to a particular partial climate. The acoustic climate is characterized by the equivalent level.

$$L_{AeqT} = 10\lg\left(\frac{1}{t_2 - t_1}\int\limits_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}\mathrm{d}t\right), \tag{2}$$

where p_A is the t – weighted sound pressure, p_0 is the reference pressure, t_2–t_1 is the time interval, and by the sound exposure level with t_0 =1s:

$$L_{AE} = 10\lg\left(\frac{1}{t_0}\int\limits_{t_1}^{t_2}10^{0.1L_A(t)}\mathrm{d}t\right), \tag{3}$$

is L_{AE} sound exposure level with $t_0 = 1$s.

In order to evaluate the population exposure to noise, it is necessary to make use of the exceeded threshold and acceptable noise levels during the daytime and at night. The regulation of the Minister of Environment issued on October 14th, 2002 (Journal of Laws – Dz.U.02.179.1498) provides a precise tool that helps to evaluate the population exposure to noise. The M index shall decide on the order of actions related to the protection from noise:

$$M_i = 0.1 m_i \left(10^{0.1\Delta L_i} - 1\right), \tag{4}$$

where M_i – index value, ΔL_i – value of the exceeded acceptable noise level [dB], m_i – number of people located in the area.

When $\Delta L_i \leq 0$, the M_i index value is 0.
Consequently, we introduce the acoustic climate index:

$$K_{A\_i} = \frac{M_i}{M_{DOPi}}, \tag{5}$$

where M_i – value of the noise exposure index, M_{DOPi} – maximum value of the noise exposure index, which occurs at a noise level equal to the threshold level [11].

The partial acoustic climate may be characterized by K_{A_i} ranging from 0 to 1. Climate is deemed acceptable for $K_{A\_i} = 0$, and unacceptable for $K_{A\_i} = 1$.

The most important noise types in contemporary cities are as follows: road, railway, industrial, air, communal, high voltage line noises.

Assuming that acceptable values of K_{A_i} may be exceeded both in the daytime and at night, we receive a collective measure, which characterises the acoustic climate as a sum of indexes,

$$K_A = \sum_{i=0}^{6} (K_{\mathrm{A\_ROAD}},\, K_{\mathrm{A\_RAIL}},\, K_{\mathrm{A\_INDUS}},\, K_{\mathrm{A\_AIR}},\, K_{\mathrm{A\_COMM}},\, K_{\mathrm{A\_HVL}}). \tag{6}$$

Thus, the calculated index K_A may range from 0 to 6 for day (0 to 12 for day and night).We may call this index a total analytical model of the acoustic climate.

The measure introduced is determined only for areas inhabited by people, it allows to determine the number of people exposed to noise. The index K_A allows to compare easily areas of different appropriation (for which the noise level threshold and acceptable values may vary).

This measure can not be applied to recreational areas. Of course, it is possible to avoid this obstacle by estimating the number of people staying in that area as well as by using only values applicable to daytime.

4. Acoustic climate numerical model

The acoustic climate may be characterized not only using analytical methods, but with a numerical model as well. In this study a numerical model has been developed and many analyses and noise a map of Cracow [2] have been done.

The **descriptive part** of this map characterizes noise sources that create the acoustic climate in the area of Cracow. Moreover, acoustic determinants resulting from the local spatial development plan have been identified. The population exposed to noise has been determined and an analysis of expected trends in the environment acoustic has been done.

The **graphic part** consists of maps characterizing noise emitted from individual sources (traffic-related noise – road, railway, air, industrial and communal noise), maps of areas exposed to noise, and areas with noise exceeding the limit levels.

Figure 1 shows an example of the traffic-related noise map for District I at night.

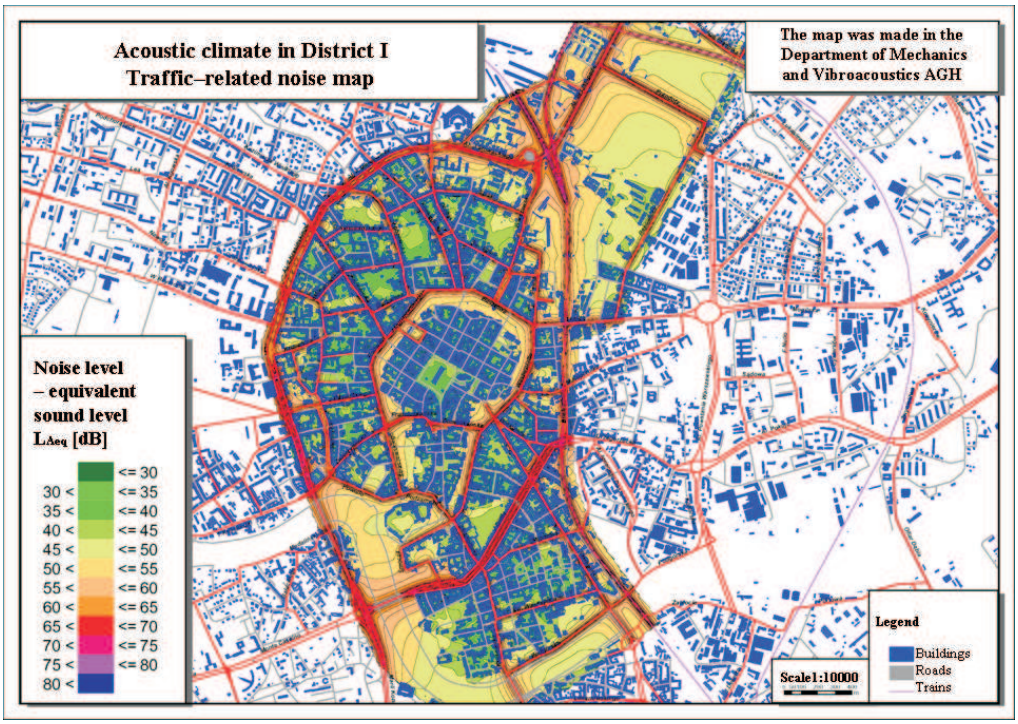

Fig. 1. Acoustic climate in District I – traffic-related noise map.

The purpose is to get an acoustic map of Cracow functioning as an independent information system (basic option), or as an integral Spatial Information System module for the City of Cracow (recommended option). These expectations shall be satisfied by the acoustic climate management system designed and continuously developed.

Figure 2 shows the acoustic climate in the Cracow – traffic-related noise map.

Figures 3 and 4 show selected acoustic maps of noise generated by the public transport services in Cracow, separately for the road transport and rail transport.

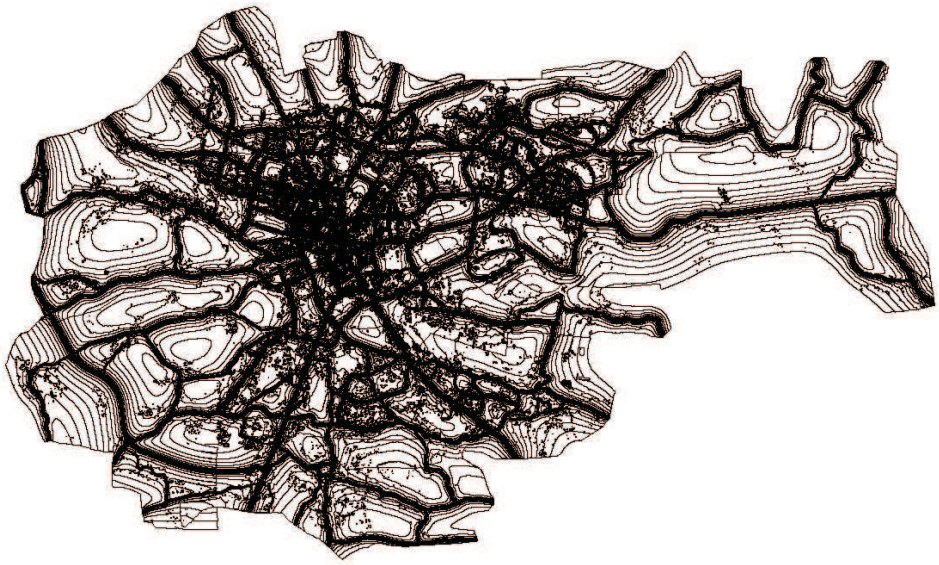

Fig. 2. Acoustic climate in Cracow -Traffic-related noise map.

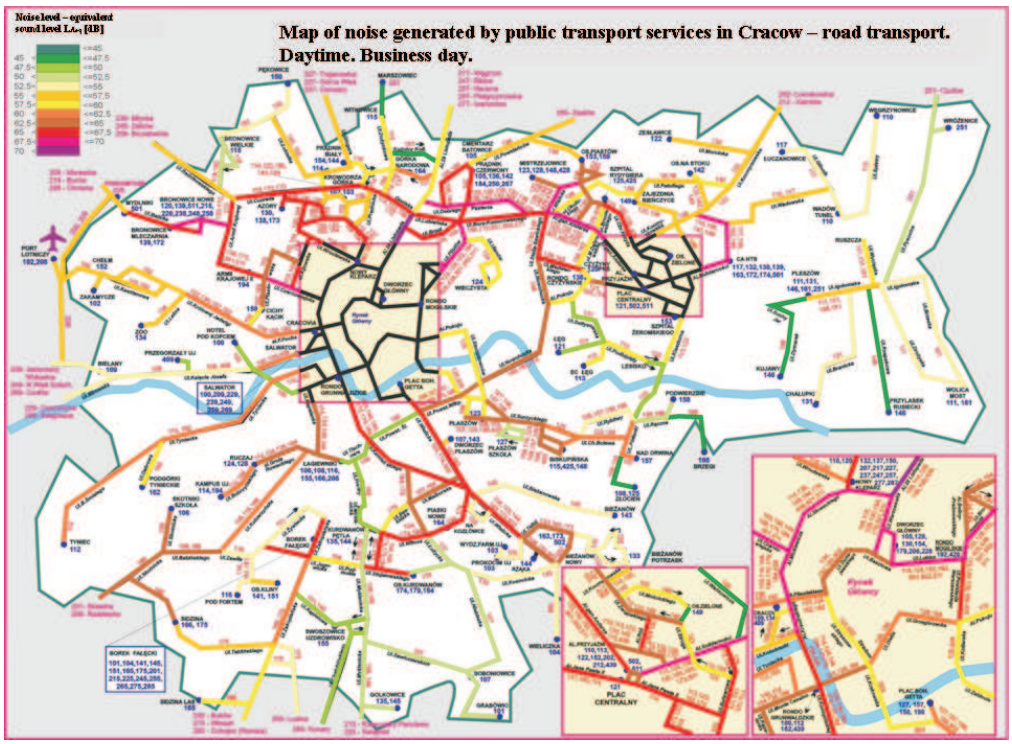

Fig. 3. Map of noise generated by public transport services in Cracow – road transport. Daytime. Business day.

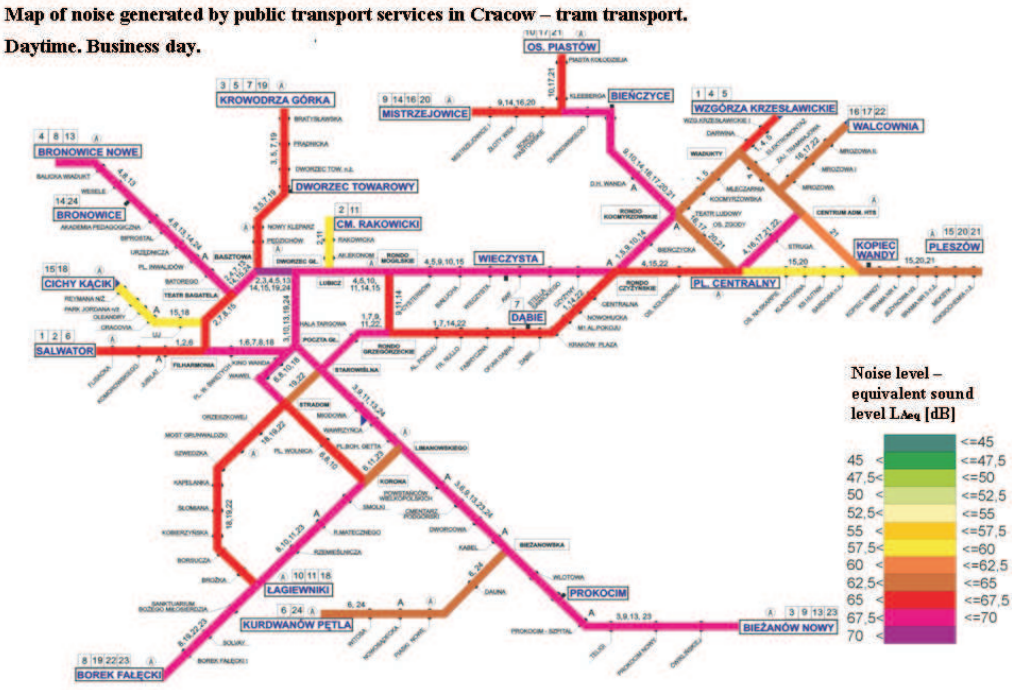

Fig. 4. Map of noise generated by public transport services in Cracow – rail transport. Daytime. Business day.

5. Acoustic climate management system

The control system consists of technical and non-technical (legal and administrative) elements. Control is carried out by making administrative decisions [1].

In order to exercise the acoustic climate control, we decided to use the spatial information system technology (GIS) (Fig. 5).

The integrated system of acoustic climate control will include ultimately internal and external rings provided with numerous subsystems and equipment.

The external ring will be made up of data collection and processing systems, which will include systems operating on acoustic and non-acoustic data. Those are video systems – camera units and road traffic monitoring systems: loop installations, piezoelectric sensors etc. The acoustic data will come from stationary and mobile noise monitoring stations.

The external ring includes also very important local and global acoustic climate control systems, i.e. variable content characters, smart light signaling systems and satellite or radio transmission systems transmitting data to the individual consumer (GPS, GALILEO, GSM – GPRS, UMTS). Variable content characters and smart light signaling will allow to control the local stream of vehicles. The radio or satellite systems will allow to control the traffic globally within the town or urban agglomeration.

DISTRICT	B	STREET	No_HOUSE	No_PEOPLE	autocad_elevator	L_eq_DZIEŃ	L_dop_DZIEŃ	delta_L_DZIEŃ	M_DZIEŃ	L_eq_NOC	L_dop_NOC	delta_L_NOC	M_NOC
I	30	WARSZAWSKA	1	38	0	70	65	5	7,7842	62,5	55	7,5	16,6443
I	24	SŁOWACKIEGO	1	19	0	67,5	65	2,5	1,47873	62,5	55	7,5	8,78449
II	37	RAKOWICKA	1	19	0	67,5	65	2,5	1,47873	57,5	55	2,5	1,47873
II	37	RAKOWICKA	1	19	0	67,5	65	2,5	1,47873	57,5	55	2,5	1,47873
II	78	CZYŻYŃSKA	1	10	0	65	65	0	0	55	55	0	0
I	8	KRAKOWSKA	1	26	0	65	65	0	0	62,5	55	7,5	12,0209
I	22	CZARNOWIEJSKA	1	21	0	62,5	65	0	0	55	55	0	0
II	41	NA SZANIEC	1	2	0	62,5	65	0	0	55	55	0	0
II	39	OLSZYNY	1	3	0	62,5	65	0	0	57,5	55	2,5	0,233484
II	43	PÓŁKOLE	1	2	0	62,5	65	0	0	55	55	0	0
I	13	RADZYMIŁOWSKA	1	1	0	62,5	65	0	0	57,5	55	2,5	0,0778279
I	13	RADZYMIŁOWSKA	1	1	0	62,5	65	0	0	57,5	55	2,5	0,0778279
VII	175	ZAMKOWA	1	5	0	62,5	65	0	0	60	55	5	1,08114
II	33	BRODOWICZA	1	63	0	62,5	65	0	0	55	55	0	0
I	22	RAJSKA	1	4	0	60	65	0	0	52,5	55	0	0
II	34	MISIOŁKA	1	7	0	60	65	0	0	55	55	0	0
II	41	NA SZANIEC	1	3	0	60	65	0	0	55	55	0	0
II	49	RZEŹNICZA	1	44	0	60	65	0	0	55	55	0	0
I	27	SPASOWSKIEGO	1	29	0	60	65	0	0	55	55	0	0
I	11	STAROMIŚLNA	1	37	0	60	65	0	0	55	55	0	0
I	11	STAROMIŚLNA	1	37	0	60	65	0	0	50	55	0	0
I	9	STRADOMSKA	1	1	0	60	65	0	0	55	55	0	0
II	34	ZALESKIEGO	1	2	0	60	65	0	0	55	55	0	0
II	55	BŁĘKITNA	1	10	0	60	65	0	0	52,5	55	0	0
I	3	JÓZEFA	1	47	0	60	65	0	0	55	55	0	0
I	12	BONEROWSKA	1	6	0	57,5	65	0	0	50	55	0	0
I	32	KĄTOWA	1	27	0	57,5	65	0	0	52,5	55	0	0
II	38	NORWIDA	1	3	0	57,5	65	0	0	52,5	55	0	0
I	21	PODWALE	1	40	0	57,5	65	0	0	52,5	55	0	0
II	47	SĄDOWA	1	232	0	57,5	65	0	0	50	55	0	0
I	32	ZELAZNA	1	20	0	57,5	65	0	0	52,5	55	0	0
I	18	KOSSAKA	1	54	0	57,5	65	0	0	55	55	0	0
I	7	ŚWIĘTEJ KATARZYNY	1	34	0	57,5	65	0	0	52,5	55	0	0

Fig. 5. Selected information from database of the acoustic climate management system.

The core of the internal ring is a computer-distributed system controlled by a central control unit – a server controlling the Acoustic Climate of the Environment. Particular units of the system will support the preprocessing and final processing of input and output system data. Static and dynamic information layers will be the kernel of the system. They will make the extended database include all the most important elements affecting the acoustic climate of the town, urban agglomeration, communes etc.

The information layers include static layers (noise maps) – generally unchanging in a long run.

They include layers representing road noise, urban transport noise – buses, railway and tramway, industry, airplane, HV lines, municipal noise etc.

Extremely important are the layers representing excess of admissible noise limits and noise thresholds for all the above mentioned noise categories for different time periods (day time, evening and night). The information layers include also the number of residents exposed to a particular type of noise and M indices.

Exceedingly important are the layers characterizing the existing and newly designed vibroacoustic protections. This group includes the existing acoustic screens, vibroinsulation – railway and tramway sleepers, "silent" asphalts, replaced windows etc. Highly important is the economical layer [7] – i.e. cost consumption of the anti-noise investment.

The dynamic layer, i.e. the photograph of the acoustic climate of the town at the current moment, includes fluctuating acoustic conditions. Those changes may relate to the fluctuation of the climate over the day, week, month or season. They can be formed as a result of modernization of a railway or tramway line, road reconstruction, construction of new arterial roads etc. The changes monitored in real time and correlated with the static layers decisions.

Acoustic climate control, and thereby sound control in large areas, will be performed by a program based on genetic algorithms and the graph theory.

The system will be founded on numerous constant and variable symptoms which maintain correct and even comfortable acoustic climate conditions.

At present, the construction of the internal ring is at the final stage. A prototype software capable of generating static and dynamic layers was developed. The outer and inner rings are also at an advanced stage.

6. Adjustment of the acoustic climate management system

The adjustment of the system means a continuous adaptation of system model (both analytical and numerical) to changing legal-administrative conditions, and conditions occurring in the urban environment.

The first ones will relate to changes regarding legal rules, regulations, designs, standards and directives valid in the country. The second ones will depend on changes occurring in the urban environment. They are connected with new houses and housing estates, urban parks and other areas under special protection and with solutions applied for roads and railways: designs of new roads, new traffic solutions: roads, arteries, roundabouts, intersections, parking lots etc., as well as continuous noise source monitoring.

The system adjustment will involve operations carried out in three complementary directions. The first of them will be a continuous analysis of the existing acoustic climate (Fig. 7), the second one will include the improvement of already existing acoustic conditions, while the third one will involve forecasts of the acoustic climate (Fig. 8) which will prevail in the city because of new roads, traffic arteries, acoustic screens etc.

The number of residents exposed to noise is presented in Fig. 6.

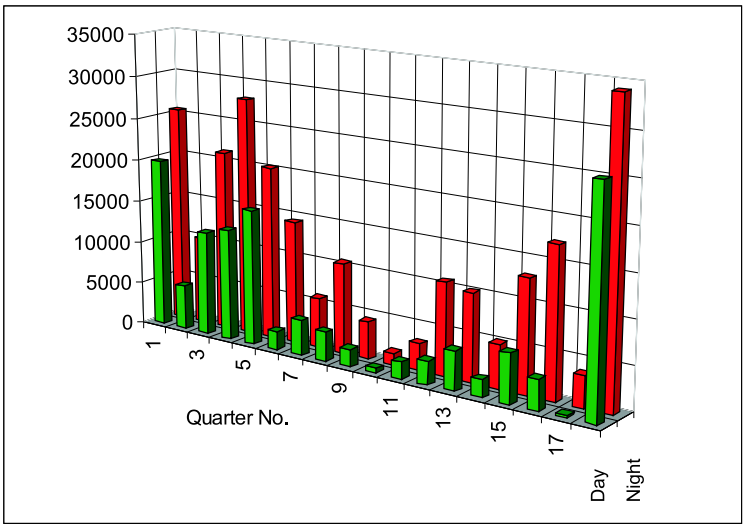

Fig. 6. Number of residents exposed to noise in particular quarters of Cracow.

Fig. 7. Example of incorrect design and construction of acoustic screens.

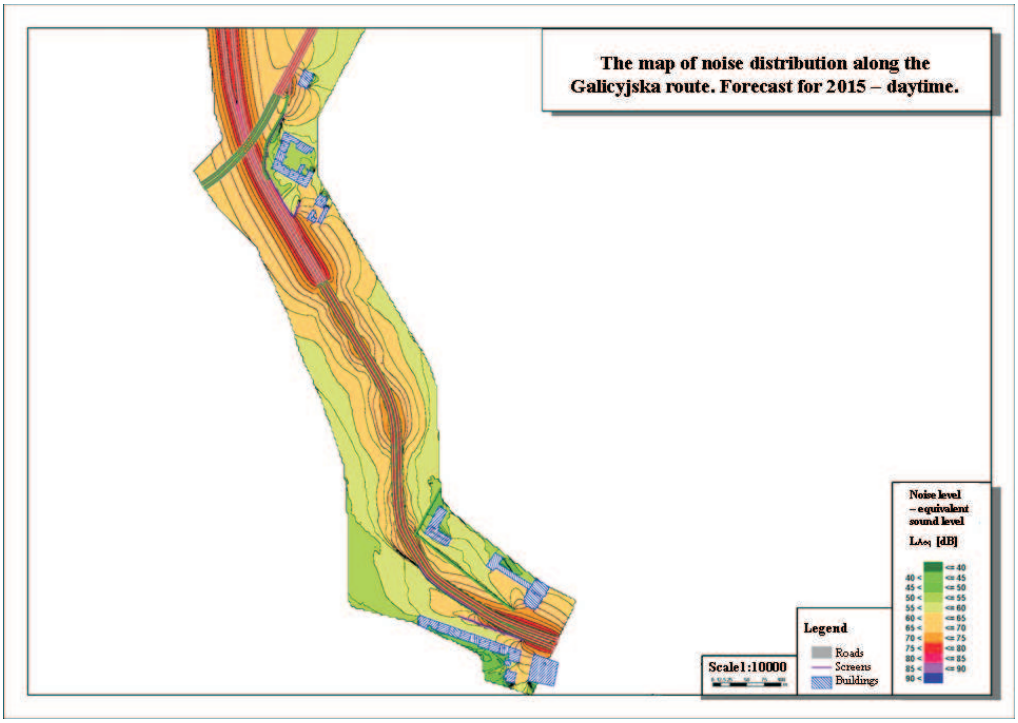

Fig. 8. The map of noise distribution along the Galicyjska route. Forecast for 2015 – daytime.

7. Conclusions

This paper shows an acoustic climate control system applied for the City of Cracow. The system core are information layers made in the SoundPlan, INM application and Mapinfo software.

These layers show maps, which characterize the noise emitted from individual sources (traffic-related noise – road, railway ,air, industrial and communal noise), and maps of areas exposed to noise and those with noise exceeded limit levels. The layers have been made pursuant to valid legal acts [9–12].

The spatial information system technology (GIS) was used. Two application programs have been designed and developed, which allow to work in public data communication networks and locally, independently of the hardware platform and operating system.

In the future, the system for the city acoustic climate management designed and developed systematically will become an integral element of the general management system for urban areas. It will allow making very convenient and extremely quick decisions related to the acoustic climate.

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