ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 31 no. 4 pp. 123 - 132 2005

PL ISSN 0324-8461

METHODOLOGY FOR SPATIAL CLASSIFICATION OF TRANSPORT ROUTES IN THE VIEW OF THEIR IMPACT ON THE ACOUSTIC CLIMATE OF THE ENVIRONMENT

JANUSZ KOMPAŁA

Central Mining Institute
pl. Gwarków 1, 40-166 Katowice

Keywords: ecology, vibroacoustic, environment, noise, method.

METODYKA PRZESTRZENNEJ KLASYFIKACJI TRAS KOMUNIKACYJNYCH W ASPEKCIE ICH WPŁYWU NA KLIMAT AKUSTYCZNY ŚRODOWISKA

Zaproponowana metoda przestrzennej klasyfikacji dróg pod względem ich uciążliwości akustycznej może być wykorzystana przy sporządzaniu map akustycznych miast. Klasyfikacja dróg pod kątem stopnia zagrożeń akustycznych umożliwia, już w początkowej fazie tworzenia map akustycznych, identyfikowanie obszarów potencjalnie zagrożonych nadmiernym hałasem. Obszary takie wymagają podjęcia natychmiastowych działań naprawczych zmierzających do obniżenia hałasu. Istotnym problemem przy rozpatrywaniu propagacji hałasu w terenie silnie zurbanizowanym jest wybór miejsc, w których dokonuje się pomiarów emisji hałasu źródła celem określenia jego parametrów akustycznych dla kalibracji przyjętej metodyki. Rozwiązanie tego zagadnienia pozwala na stosowanie jednolitych metod obliczeniowych. Rozwój zaproponowanej metody i uzupełnienie tworzonych warstw tematycznych o kolejne, zawierające informacje o zasięgu oddziaływania drgań od tras komunikacyjnych czy wpływie eksploatacji górniczej na stan dróg i budowli, według zaproponowanej metodyki, umożliwi jednoznaczną kategoryzację tras komunikacyjnych w aspekcie ich wibroakustycznego wpływu na środowisko.

Summary

The above-presented methodology for spatial classification of roads in relation to their acoustic annoyance can be used in preparing acoustic maps of towns. The classification of roads with the view of the level of acoustic hazard enables, just in the initial phase of acoustic map preparation, to identify the areas potentially endangered with excessive noise. These areas need taking immediate corrective actions, aimed at reducing the noise level. An important problem, when analyzing the propagation of noise in a highly urbanized area, is the selection of locations in which the measurements of emission of the noise source are performed with the aim to determine its acoustic parameters for calibration of the assumed methodology. Solving this problem makes it possible to use uniform methods of computation. The development of the proposed method and supplementing the layers with next ones, containing information about the range of influence of vibration generated by roadway transport routes, or information on the effects of mining on the roads and building structures, using the proposed methodology, will enable to make an unambiguous categorization of transport routes in the aspect of their vibro-acoustic impact on the environment.

INTRODUCTION

In the perspective of the next several years, the main objectives in the road transport system will be directing the through traffic out of the centers of urbanized areas, by constructing ring roads, improving the condition of the surface of streets and local roads. In the places where, in spite of taking the above-mentioned actions, the street traffic will still be a source of excessive noise and pollution, the technical action will be undertaken in relation to the protection of the population against the negative effects of the urban transport [2, 7, 13, 14, 19, 20].

The modern methods of land development planning and preparing the acoustic maps or making assessment of the impacts on the environment need connecting the measurement data and computational methods applied with the maps of the area subject to assessment [5, 7, 9, 13].

To realize such tasks it is advisable to use the numerical information related to the picture of the map of the area, in which an investigated object is located. In this field the GIS (Geographical Information System) techniques are applied, which link the cartographic maps with the databases (utilizing the GPS system), and enabling to make an accurate location of spatial and linear resources, and to determine precisely the places in which the measurements or observations shall be conducted [4, 5, 8, 9, 11, 15].

The digital maps of the area, used in acoustic studies are characterized by several important features, the main of which is the vectorization, which makes it possible to change smoothly the map scale. The properties of the computer graphics enable to split a digital map into a number of layers which include defined information being of importance for a given analytical section. This makes it possible to group the objects in such a way so as to neglect (exclude) the information being insignificant or useless to the selected analytical section. The presentation of the area map in the geographic co-ordinate system enables to represent accurately the location of the objects in the area. As mentioned above, the GIS systems include, apart from digital maps, also computer databases, in general easily configured into the local requirements. Apart from the digital data relating, for instance to measurement results, text data, e.g. description of the investigated objects, addresses, the data bases often make it possible to perform simple computations, for example those connected with finding the lines of equal noise level [9, 12, 15].

From the author's own practice it follows that the most useful form of processing is the creation of information data which contain the selected objects and a database related to them. Here, the layer is considered as a set of objects of a certain class providing the base which is characterized by defined common features, for instance protected objects, points of measurements, additional descriptions, etc. Creating the layers is an effective method of grouping elements with similar properties, the more so as each of them can be displayed independently. The possibility of making a selective choice of the layers enables to compose the maps with a given content, and to perform various analyses through overlapping the selected layers [9, 12].

Assuming such a type of management of the objects makes it possible to show a clearer picture (map), as it will contain a smaller piece of information, the remaining data being placed in the hidden layers. Moreover, it is easier to manage the object when they are grouped in accordance with a defined category.

For the needs of preparing the considered method of classification of transport routes,

the following layers should be analyzed on the basis of the GIS program:
Layer 1 – map base (screen),
Layer 2 – administrative division,
Layer 3 – urban development characterizing the type and density of houses
Layer 4 – topographic, characterizing the shaping of the area between the source and protected object,
Layer 5 – road network, division into: national, regional and county roads from the point of view of the structure and intensity of traffic,
Layer 6 – demographic, characterizing the population density.

Using the information contained in the above thematic layers, one can prepare the other ones:
Layer 7 – emission layer, characterizing the acoustic power of the source,
Layer 8 – immission layer, defining the course of isolines of normative layers.

With the aim to prepare more and more accurate model, it is possible to use in the method of road classification the next layers which contain other types of information, e.g. on the distribution of meteorological conditions. A larger piece of information makes the assumed transport route classification model more detailed and realistic.

In the investigation of environmental noise, there is more and more often a need to perform spatial visualization of the acoustic field distribution. Three-dimensional maps with the marked information are much more complex both in the preparation and interpretation phases. In addition, they require very efficient computer equipment [15].

The above presented possibilities of using the GIS techniques in the evaluation of the effects of vibro-acoustic hazards in the environment point, in the view of the own author's experience, at their high usability, in particular in the investigations including larger areas, in which there is a need to conduct measurements and analyses in a great number of measurement points. Particular usability of the discussed techniques is observed in the course of preparing acoustic maps of towns and road transport trains. The possibility of connecting the maps with the relation databases makes it possible to collect in one place all the information about the analyzed area and objects located in it. This enables performing various transformations and analyses. They also provide much better and faster analytical and presentation possibilities of the conducted investigations.

The spatial structure of the proposed classification is obtained through taking into account in the investigations conducted all the available data relating both to topography of the area, course of transport routes themselves and architectural variety of the analyzed area.

METHODOLOGY OF ACOUSTIC COMPUTATIONS

Accurate recognition of the noise-hazard condition is a basis for taking actions aimed at either elimination or minimization of such hazards. Nevertheless, just on the basis of noise analyses performed so far at selected streets playing a major role in the transport systems of individual towns, one can take the values of equivalent noise level as exceeding standard ones, and qualifying the acoustic climate of towns as annoying to the population.

The methodology for computing the noise emitted by road transport trains into the outer environment should be consistent with the PN ISO 9613-2 standard [16]. This document specifies the engineering methods used for computing the noise present at defined distances from either a single source or group of sources. The PN ISO 9613-2 standard provides a basis for computational standards used in many European countries. A computational standard for road traffic noise recommended for creating computation models in the transit period is the French NMPB method [1, 6, 10].

There are several methods used for modeling of the acoustic field. Among the modeling methods most frequently used in the acoustics of open areas, one can count, at present, the geometrical models based on the radial method and the method of apparent sources.

The applied radial method, currently used in all modern computation algorithms is based on the assumption that a continuous acoustic wave is considered to be a set of the so-called sound radii. The individual sections of the acoustic wave are substituted with corpuscles, that are hypothetical point objects, which move in a given environment with the velocity of sound, and their trajectories meet the requirements of geometrical acoustics. The trajectories of the corpuscles are called the radii of sound. Their reflections from the obstacles result in decreasing of the carried energy in proportion to the absorption properties of the reflecting barriers. This energy is further reduced in consequence of absorption by the medium in which the corpuscles propagate. It should be additionally noted that the energy drop caused by the increasing distance from the source is included in the method through the decrease of the number of radii reaching the receiver, depending on a distance. In the applied special software, the acoustic computations are realized through sending from the observation point a bundle of radii, in accordance with the radial method.

The modeling of noise propagation in an open area, but also is a built-up zone, should integrate all the parameters, which influence this propagation, i.e. topography, building structures, screens, type of base, heterogeneity of the atmosphere, meteorological conditions. The software includes in a common algorithm such parameters as buildings, screening by the obstacles and absorption in the atmosphere, as recommended by ISO standardization [16]. The software is based on the algorithm of fast search for the propagation route of the radii between the source of noise and the receiver. The propagation routes are presented as direct, refracted and reflected radii (by walls of buildings, which are assumed vertical), or a combination of these routes.

The software operation cycle can be divided into:

- loading of data (loading of the map base and its registration, loading of road and railway traffic parameters, and parameters connected with industrial noise, and other data necessary for computation),
- search for routes between the points of reception and noise sources,
- acoustic computation.

With the aim to develop the classification method for road transport routes, the software is used which performs computations in accordance with the method recommended by ISO 9613-2 [16], and the recommended NMPB96 method [20]. The algorithm of search for the propagation routes between the source and receiver is based on the following assumptions:

- irrespective of the type of the urban development space, it is assumed that all reflecting surfaces are vertical,
- noise sources are assumed linear, corresponding with individual roadways or lanes, and whose acoustic power is defined in relation to the unit length. Also railways are considered to be linear sources.

In the first computation stage, a certain number of radii are sent from the observation point in all directions, in a horizontal plane. Each of the sent radii is an axis of the angular section dq. The route of each radius is defined by a sequence of collisions with the encountered obstacles. Each of the collisions is an intersection of the radius with the segment of the analyzed area. Therefore, it is necessary to consider all possible propagation routes of the radii:

- radius runs over the obstacle (with or without diffraction), this means that the radius intersects a given section of the area,
- radius is reflected by a vertical plane, this means that that the radius undergoes mirror reflection by a section of the area.

In this way, starting from the point of radius emission, the division of its route is changed each time when the radius encounters on its way a segment of the area which contains a vertical plane. This division ends when a specified „route branch" exceeds the limits of the analyzed area.

In the computations, the CADNA A, version 3.2 of DataKustik was used [3]. The program is provided with a user's graphical interface, and most operations are performed on a visible map base. The extensive part of data import and export enables transfer of the information from and to other systems. The program database being its integral part is ready to store both acoustic and non-acoustic data. A part of the data is only of informative character, but most of it is used in the course of performed computations.

Emission layer

The principal quantity that characterizes the source of noise is the level of acoustic power. The noise coming from the sources of a linear character is represented by a set of equivalent point sources with a defined acoustic power and direction of action.

In the computations performed, the acoustic power per 1 meter of the path length has been determined [18] from the relationship:

$$L = L_o + 10 \log\left(\frac{n + n_c(E-1)}{v}\right) - 30 \qquad (1)$$

where:
L_0 – acoustic power of a single vehicle;
n – a number of all vehicles per hour;
n_c – a number of heavy vehicles per hour;
v – average velocity of vehicle stream (km/h);
E – conversion factor of heavy-to-light vehicles.

The acoustic power of a single vehicle is determined from the relationship:

$$L_0 = 46 + 30 \log v + C \qquad (2)$$

C = 0 – for fluent traffic,
C = 2 – for pulsed traffic,
C = 3 – for high acceleration traffic.

The results presented in Table 1 provided a basis for determining the range of noise impact depending on the type and appropriation of the road.

Table 1. Computation results of acoustic power levels for various types of roads depending on the intensity and structure of vehicle traffic

Number of vehicles per day Q_{day}	Average velocity of traffic [km/h]	EQ	Number of vehicles per hour		Portion of heavy vehicles [%]		Level of acoustic power dB (A)	
			Day-time	Night-time	Day-time	Night-time	Day-time	Night-time
20 000	100	5	1090	320	15	25	88.4	84.0
15 000	100	5	810	240	15	25	87.1	82.8
10 000	100	5	540	160	15	25	85.3	81.0
5 000	80	7	270	80	10	13	80.3	75.5
3 000	80	7	160	50	10	13	78.1	73.5
2 000	80	7	110	30	10	13	76.5	71.3
1 000	60	10	50	20	5	5	69.8	65.6
500	60	10	30	10	5	5	67.4	62.6

Thematic layers

A basis for preparing a spatial classification of transport routes considering their vibro-acoustic annoyance is the creation of an immission layer. The layer is developed through overlapping on the emission layer of thematic layers (topographic, urban development, meteorological) which characterize the way of propagation of noise in the environment.

The equivalent noise level A present in any point of the space is a sum of sounds coming from all the points and apparent sources [16], and its value is calculated from the relationship:

$$L_{eq} = L_W + D - A \tag{3}$$

where:

L_W – level of acoustic power of a point source expressed in dB (A) – emission layer,

D – coefficient of directionality of the source,

A – parameter defining the effect of the layers (topographic, urban development, meteorological) on the way of noise propagation.

The parameter A being a result of overlapping of consecutive layers and corresponding physical phenomena occurring on the way of propagation can be written in a general form:

$$A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{inne} \tag{4}$$

where:

A_{div} – damping due to geometrical divergence;

A_{atm} – damping due to atmospheric absorption – meteorological layer;

A_{gr} – damping introduced by the ground surface – topographic layer;

A_{bar} – damping resulting from diffraction at the obstacles appearing on the way of propagation of the acoustic wave (screening) – urban development layer.

The correctness of the method has been checked taking as examples the main roadway transport routes in the area of the Silesian Voivodeship.

In the calculations, also the characteristics and geometrical parameters of evaluated road trains were included:

- roads with traffic intensity above 10000 vehicles per day – 2 roadways with 2 lanes 3.5 m wide each, with a 3 m-wide separating belt; average velocity of passenger vehicles – 100 km/h, of goods vehicles – 80 km/h;
- roads with traffic intensity from 2000 to 10000 vehicles per day – 2 roadways with 2 lanes 3.0 m wide each, without a separating belt; average velocity of passenger vehicles – 80 km/h, of goods vehicles – 60 km/h;
- roads with traffic intensity below 2000 vehicles per day – 2 roadways with 2 lanes 3.75 m wide each, without a separating belt; average velocity of passenger vehicles – 60 km/h, of goods vehicles – 60 km/h.

In the course of execution of individual stages of the project, in accordance to the earlier mentioned analyses, the results of measurements for the year 2000 (provided by the town), and the author's own investigations and observations were used. The following average values were used:

- motorway 20 000 vehicles/day on the average, portion of heavy vehicles, 15% in day-time and 25% in night-time;
- national roads in Silesian Voivodeship: 12 000 vehicles/day on the average, portion of heavy vehicles, 15% in day-time, and 25% in night-time;
- regional roads in Silesian Voivodeship: 4 000 vehicles /day on the average, portion of heavy vehicles, 10% in day-time and 13% in night-time.

Table 2 presents the ranges of noise impact with the threshold [17] and permissible values [18]. The computations were performed taking into account the effects of the topography of the area, sort of base and meteorological conditions on noise propagation conditions.

Table 2. Ranges of noise impact for roads with various traffic intensities determined at the height of 4 m above the base

Number of vehicles per day	Range of impact of threshold value isolines [m]		Range of impact of permissible value isolines [m]	
	Day-time – 75 dB (A)	Night-time – 67 dB (A)	Day-time – 60 dB (A)	Night-time – 50 dB (A)
20 000	8	19	135	365
15 000	5	14	110	315
10 000	0	10	85	230
5 000	0	0	37	100
3 000	0	0	23	70
2 000	0	0	17	47
1 000	0	0	0	17
500	0	0	0	8

Classification of road transport routes

The degree of acoustic annoyance of the road with vehicle traffic depends, apart from the acoustic power of the source (i.e. road), on the distance of the first line of building development to the edge of the road. Classified in Table 3 are the roads, by introducing the following categorization:

++++ – roads of extremely high annoyance which make, at the same time, the threshold values exceeded in day and night;

+++ – roads of high annoyance which make, the threshold values exceeded only in night;

++ – roads of elevated annoyance which make the permissible value exceeded both in day and night;

+ – roads of medium annoyance which make the permissible value exceeded only in night;

- – roads with no annoyance; both the threshold- and permissible levels are not exceeded.

With the aim to prepare the classification of roads, the computation results of the ranges of noise effects given in Table 2 were used.

Table 3. Classification of acoustic annoyance of roads depending on the intensity of vehicle traffic and distance between the first line of building development and road edge

Number of vehicles per day	Distance of the first building development line from the road edge									
	10 m	20 m	50 m	100 m	150 m	200 m	250 m	300 m	400 m	above 400 m
20 000	++++	+++	++	++	++	+	+	+	+	-
15 000	++++	+++	++	++	+	+	+	+	-	-
10 000	+++	++	++	++	+	+	+	-	-	-
5 000	+++	++	++	+	+	+	-	-	-	-
3 000	++	++	+	-	-	-	-	-	-	-
2 000	++	++	+	-	-	-	-	-	-	-
1 000	+	+	-	-	-	-	-	-	-	-
500	+	-	-	-	-	-	-	-	-	-

For instance, the inhabitants of buildings located at a distance of 10 meters from the edge of the road at which the traffic intensity is higher than 5000 vehicles per day, are exposed to the impact of noise exceeding the threshold values. At the intensity higher than 15 000 vehicles per day, such a hazard is present at the wall of buildings located even at a distance of 20 meters from the road. The range of noise influence with the permissible level of 50 dB (A) during night-time, for a number of vehicles above 10 000 per day is within the limits of 300–400 meters. Occasional vehicle traffic (about 500 vehicles/day) can cause the acoustic annoyance only at night, to people in the buildings located at a distance less than 10 meters from the edge of the road.

CONCLUDING REMARKS

The spatial classification of road transport routes relies on linking the emission layers with the layers that characterize the conditions of propagation of noise in the outer environment. The parameter defining the source of noise is its level of acoustic power presented as an emission layer. The remaining overlapped layers: topographic, types of base layer, urban development and meteorological layers, etc., all have an effect on the range of emitted noise. The sum of all layers produces the noise immission layer making it possible to evaluate the size of noise annoyance in the environment (the layer often called an acoustic map).

A general procedure when classifying road transport routes is, in accordance with the method developed, as follows:

- using available layers and map bases with the aim to create an emission layer which characterizes the noise level of the source,
- determining the method of noise propagation in the environment including the topographic and urban development layers,
- selecting in the urban development layer of the objects a subject to acoustic protection,
- performing computations with the aim to create the immission layer,
- preparing classification of road transport routes in view of their acoustic annoyance.

The quantity that characterizes the "noisiness- emission" of the road itself is the level of acoustic power falling per one meter of its length. The emission layer characterizes an acoustically uniform section of the road, while this uniformity relates mainly to the parameters of traffic and geometry of the road. Often, in the studies relating to road traffic noise hazard, noise measured at a distance of 1 meter from the road edge is compared with the permissible values. This is acceptable in the case when the building development is located very close to the edge of road (central parts of a town). In the case of its larger distance, the topography and land shape between the source and protected object become important. In the case when the road runs across highly urbanized areas, of importance is to connect the emission layer with the building development layer. For roads running out of town centers, where typically one has to do with detached houses and dispersed building development, of major importance is to link the noise emission layer with the layer that characterizes the land shape around the road. This factor affects mainly the range of noise impact, also that which exceeds the standards. Shortly speaking, the road is annoying when, within the immission layer in the range standard-exceeding noise impact there are objects liable to acoustic protection. When there are no such objects, it is difficult to prejudge its annoyance, unless the study serves the prediction purposes.

The above-presented methodology for spatial classification of roads in relation to their acoustic annoyance can be used in preparing acoustic maps of towns. The classification of roads with the view of the level of acoustic hazard enables, just in the initial phase of acoustic map preparation, to identify the areas potentially endangered with excessive noise. Of major importance is the specification of the objects subject to protection, for which, due to location and intensity of traffic, the threshold of noise can be reached. These areas need taking immediate corrective actions aimed at reducing the noise level. An important problem, when analyzing the propagation of noise in a highly urbanized area, is a selection of locations in which the measurements of emission of the noise source are performed with the aim to determine its acoustic parameters for calibration of the assumed methodology. Solving this problem makes it possible to use uniform methods of computation.

The development of the proposed method and supplementing the layers with next ones, containing information about the range of influence of vibration generated by roadway transport routes, or information on the effects of mining on the roads and building structures, using the proposed methodology, will enable to make an unambiguous categorization of transport routes in the aspect of their vibro-acoustic impact on the environment.

REFERENCES

[1] Directive of the European Parliament: *Directive on the Assessment and Management of Environmental Noise*, 2002/49/WE.

[2] Engel Z.: *Ochrona środowiska przed drganiami i hałasem*, PWN, Warszawa 1993.

[3] Instrukcja obsługi programu komputerowego CADNA A, wersja 3.2 firmy DataKustik.

[4] Kompała J., A. Lipowczan: *Quantitative Analysis of Road Noise for Excessive Urban Area for Example Katowice Voivodeship,* [in:] Proceedings of Noise Control 98, Krynica 2–4.06.1998.

[5] Kompała J., A. Lipowczan: *Preparation of the acoustic map of Upper Silesia into account road traffic noise*, [in:] Proceedings of International EAA/EEAA Symposium Transport noise and vibration, Tallinn 06–10.06.98, 327–334.

[6] Kompała J., A. Lipowczan: *Acoustic map of the central part of a typical city in the Upper Silesia agglomeration,* [in:] Proceedings of International EAA/EEAA Symposium Transport noise and vibration, St. Petersburg 2002.

[7] Kompała J., I. Kubik, A. Lipowczan: *System doradczy wspomagania decyzji lokalizacyjnych inwestycji drogowych uwzględniający ekorozwój regionu*, [w:] Materiały XLIV Otwartego Seminarium z Akustyki, OSA 97 Gdynia – Jastrzębia Góra 1997.

[8] Kompała J.: *Assessment of joint hazard to the outer environment from road and industrial noise by the example of the Katowice Voivodeship*, Archives of Acoustics, **23**, 3, 128–137 (1998).

[9] Kompała J.: *The utilization of GIS and GPS systems in creating acoustical databases in the outer environment*, Archives of Acoustic, **27**, 4, 291–302 (2002).

[10] Kucharski R.J., M. Kraszewski, A. Kurpiewski: *Obliczeniowe metody oceny klimatu akustycznego w środowisku*, Wydawnictwo Geologiczne, Warszawa 1988.

[11] Lipowczan A., J. Kompała, W. Mrukwa i inni: *Ocena oddziaływania na środowisko autostrady na przykładzie katowickiego odcinka trasy A-4,* [w:] Materiały seminarium Wpływ autostrad na klimat akustyczny środowiska, MOSZNiL – Liga Walki z Hałasem, Warszawa 1996, 99–112.

[12] Lipowczan A., J. Kompała: *System for Management of Acoustic Revitalisation of Urban Industrial Areas*, [w:] Mechanika – kwartalnik AGH, AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Kraków, **23**, 2, 229–236 (2004).

[13] Lipowczan A.: *Elementy akustyczne przeglądu ekologicznego dużej jednostki administracyjnej kraju, na przykładzie prac realizowanych w województwie katowickim*, [w:] Materiały XLI OSA 94, Prace Naukowe ITiA Politechniki Wrocławskiej, **78**, 17–26 (1994).

[14] Makarewicz R.: *Hałas w środowisku*, Ośrodek Wydawnictw Naukowych, Poznań, 1996.

[15] Myrta G.: *GIS, czyli mapa w komputerze*, Wydawnictwo Helion, 1997.

[16] PN ISO 9613-2: *Akustyka. Tłumienie dźwięku wynikające podczas propagacji w przestrzeni otwartej. Ogólna metoda obliczania.*

[17] Rozporządzenie Ministra Środowiska z dnia 9 stycznia 2002 r. w sprawie wartości progowych poziomów hałasu (Dz. U. nr 8, poz. 81).

[18] Rozporządzenie Ministra Środowiska z dnia 29 lipca 2004 r. w sprawie dopuszczalnych poziomów hałasu w środowisku (Dz. U. nr 178, poz. 1841).

[19] Sadowski J.: *Podstawy akustyki urbanistycznej*, ARKADY, Warszawa, 1982.

[20] Ustawa z dnia 27 kwietnia 2001 r. *Prawo ochrony środowiska*, (Dz. U. nr 62, poz. 627 z późniejszymi zmianami).

Received: June 11, 2005; accepted: November 8, 2005.