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Creation of Theoretical Road Traffic Noise Model with the Help of GIS

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Abstract. Road traffic noise, as a form of environmental pollution, is an important element causing discomfort among inhabitants and leading to the emergence of noise nuisance influencing the shaping of urban space. The basic tool in combating noise is a Strategic Noise Map (SNM), which, understood as a system, constitutes an element of a city's information layer. The system, illustrating the noise situation within a city, is prepared by means of a calculation-measurement method using specialized computer programs. The assessment of road traffic noise begins by defining the amount of noise emissions coming from acoustically-homogenous sections (emission map), and ends with determining the extent of noise propagation in urban space (immission map). The above process is based on the analysis of actual input data describing, in a detailed manner, the analyzed road infrastructure in terms of the characteristics of the road section, information on the volume and type of traffic, and data on the organization of traffic. Under such extensive analysis of the condition of the environment, it is appropriate to apply GIS data as a methodological basis for creating SNMs. GIS data make it possible to unify the rules for collecting and archiving values characterizing the condition of the environment, as well as parameters influencing the level of noise. The aim of work is create a theoretical road traffic noise model with the help of GIS. The scope of information in attribute tables of acoustically-homogenous road sections comprising a GIS thematic layer was described in detail. The above information are the basis for generating digital road traffic noise emission maps as well as being the starting point for assessing road traffic noise in the area of a city in the form of immission maps. The article additionally analyzes the results of data derived from the first phase of noise mapping in Europe, as well as familiarizing the reader with the procedure of modelling road traffic noise emission in accordance with the CNOSSOS-EU which will become binding as of 31 December 2018 throughout the European Union, and which was introduced by the provisions of the new noise directive – Directive 2015/996 of 19 May 2015.

Keywords: emission, road traffic noise, CNOSSOS-EU, strategic noise map (SNM), GIS, Poland.

Conference topic: sustainable urban development.

Introduction

According to data contained in the European Environment Agency (EEA) Report of 2014, road traffic noise is one of the most bothersome forms of environmental pollution. Its negative effects are experienced by one in three European inhabitants, among whom nearly 20 million suffer from irritation and another 8 million have problems sleeping due to road traffic noise. The results of the EEA report (2014) moreover confirm that, due to incomplete reporting concerning the delivery of noise data to the European Commission by member states of the EU, the above number may actually be at least twofold higher. This means that the general effects of road traffic noise on European inhabitants anticipated by WHO and EEA is in fact significantly higher. Own studies carried out on the basis of data contained on the website of the Noise Observation and Information Service for Europe (NOISE) show that nearly 16% of the European population residing in agglomerations of over 250 thousand inhabitants is at risk of exposure to harmful levels of noise (NOISE 2012). In comparison, the effect of air traffic noise and industrial noise is only at the level of 0.1%, while railway traffic noise – 1.0% (Szopińska, Krajewska 2016b). The level of noise deemed as being a nuisance was assumed as 60 dB for daytime hours and 50dB for night-time hours. The above levels, based on the scale for assessing noise comfort (Szopińska, Krajewska 2016a), cause great noise nuisance and can induce defence mechanisms in the body. The smallest percentage of the population exposed to road traffic noise was noted in Italy, Estonia, France, Germany and Portugal. Over half of the population of Slovakia, Ireland and Bulgaria is at risk of the harmful effects of noise derived from road vehicles. In Slovakia, 82.1% of the population residing in cities of over 250 thousand inhabitants is at risk of exposure to the harmful effects of road traffic noise (NOISE 2012). The above is also confirmed by the results of the EEA (2014) report, in which we read that, for cities with over 100 thousand inhabitants, in countries such as Austria, Estonia, Ireland, Lithuania, Romania, Spain or Sweden, over 50% of the inhabitants are at risk of exposure to road traffic noise at a level of over 55dB for the day-evening-night noise indicator. Also in Poland, the nuisance posed by road traffic noise is very high. The results of own studies carried out in 2012 indicated that nearly 40% of Poles residing in agglomerations of over 250 thousand inhabitants are at risk of exposure to road traffic noise above the level of 60dB. The highest nuisance was noted in Warsaw, where nearly half of the population is at risk of exposure to this type of noise. More promising results were obtained for the cities of Bydgoszcz and Gdynia (20% of inhabitants). The lowest percentage of residents at risk of exposure to road traffic noise resides in Polish cities such as: Łódź – 8.6%, Kraków – 7.75%, Poznań – 6.3% and Szczecin – 7.5% of the inhabitants (NOISE 2012).

Due to the fact that road traffic noise as a form of environmental pollution constitutes a significant element causing discomfort among the inhabitants and leads to the emergence of nuisance, European countries have devised common legal regulations in the scope of activities connected with protection against noise. In Europe, the basic legal act is the Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise – Official Journal of the European Communities L 189 of 18 July 2002 – termed the Environmental Noise Directive (END). The main aim of the directive was to consolidate, within the member states, activities aimed at decreasing the level of noise in the environment (END 2002). Within Poland, the implementation of END is reflected by the provisions of the Act of April 27, 2001 Environmental Protection Law (Act 2001). In accordance with END, the main tool for fighting noise is a Strategic Noise Map (SNM), which specifies areas affected by harmful noise in the environment. The process of creating SNMs begins with an analysis of data on the spatial-operational structure of the area and demographic information, and ends with generating a series of noise maps (SNM system) using advanced computer programming used to model noise in space, e.g. CadnaA, SoundPland, IMMI, ArcAkus, etc. Data and conclusions arising from the SNMs are the basis for city authorities to undertake activities concerning protection against noise. The assessment of road traffic noise begins by defining the volume of sound emissions derived from homogenous noise sections (emission map) and ends with determining sound propagation in urban areas (immision map) (Kwiecień, Szopińska 2013). The above process is based on the analysis of actual input data, which, in a detailed manner, describe the analyzed road infrastructure in terms of the characteristics of a given road section, information on the volume and type of traffic, and data on the organization of traffic. In the case of such extensive analysis of the condition of the environment, it is advisable to use GIS data as the methodological basis for creating SNMs. GIS data allow for introducing unified guidelines for collecting and archiving values characterizing the state of the environment (Kwiecień 2016), as well as parameters influencing the level of noise.

In connection with the above, the work presents a theoretical road traffic noise model with the help of GIS. The scope of information contained in attribute tables for road sections that are acoustically homogenous, comprising a GIS thematic layer, was described in detail. The information presented in the work are the basis for generating digital road traffic noise emission maps for the day-evening-night noise indicator – L_{DEN} (A-weighted long-term average sound level, determined over all the 24-hour periods of a year) and night noise indicator – L_N (A-weighted long-term average sound level, determined over all the night periods of a year), and are the starting point for calculating the value of propagation, which is used when assessing road traffic noise within the area of a city (END 2002).

Modelling road traffic noise emission − European view

The process of noise modelling in Europe began in the late 60s and early 70s of the twentieth century. In Poland, the first much simplified maps of road traffic noise were created at the end of the 1970s. Due to the lack of adequate technological solutions and poor social awareness, it was not until 1997 that at the Invitational Conference for Future Noise Policy was it declared that it is extremely important to introduce common systemic solutions regarding protection against noise. One of the proposed protective measures was developing noise maps based on assessment indicators common for all of Europe, as well as precise and tested analytical and measurement methods giving the possibility to compare data and carry out the assessment of noise nuisance. The above led to the adoption of the END Directive in 2002. END aimed to introduce common legal regulations in terms of noise policy. Thus, uniform indicators of noise assessment, i.e. L_{DEN} and $L_{N,}$ were introduced, and member states of the EU became obliged to prepare, every five years, SNMs for all agglomerations within them (END 2002). Works on SNMs were divided into a few phases. The first phase, finished in 2007, concerned the preparation of noise maps for agglomerations of over 250 thousand inhabitants as well as main roads with a traffic intensity of over 6 million vehicle passages per year. The second phase, finished in 2012, involved the realization of noise maps for agglomerations of over 100 thousand inhabitants as well as main roads with a traffic intensity of over 3 million vehicle passages a year (King, Murphy 2016). The EEA report (2014) shows that the completeness of noise data passed on to the European Commission derived from SNMs (phase I and II) amounts to merely 44%.

Unfortunately, uniform methods for assessing noise were not presented in END. This resulted in a certain freedom of their selection. Member states, prior to introducing uniform methods, made use of national methods adapted to the methods indicated in pt. 2.2 of Attachment 2 to END, referred to as interim methods (END 2002). They became the methodological basis for calculating the level of noise in the first and second phases of creating SNMs. When modelling road traffic noise maps in Europe, the French calculation method "NMPB-Routes – 96 (SETRA-CETRU-LCPC-CSTB)", specified in "Arrêté du 5 mai 1995 relatif au bruit des infrastructures routières, Journal Officiel du 10 mai 1995, art. 6" and French standard XPS 3l-l33 – updated to NMPB 2008, was used. In accordance with the presented method, input data for calculating the emission of road traffic noise was obtained in accordance with "Guide du bruit des transports terrestres, fascicule prévision des niveaux sonores, CETUR 1980". The above methods required a validation procedure each time. Noise calculations of road traffic noise in the French method were carried out in accordance with the following procedure (XPS 31-133:2001, NMPB-Routes-96, Abbaléa *et al*. 2009, Besnard *et al*. 2009):

- a linear source of noise ought to be divided into point sources,
- for each of the created point sources, the level of sound power ought to be determined,
- between the point source and the reception point, the path of sound propagation ought to be sought (direct path, reflected and/or bent path),
- for each of these paths, the following ought to be determined: absorption for favourable conditions, absorption for uniform conditions, and calculations of the long-term level,
- calculations of the total level ought to be carried out for each of the specified paths.

In accordance with the assumed model, indicating the level of road traffic noise in space necessitates the division of tasks into two parts. Firstly, road traffic noise emission ought to be calculated (Task 1); the second stage involves calculating the propagation of road traffic noise (Task 2). The present article focuses on Task 1.

The accepted model requires calculating the emission of sound derived from a single vehicle driving down an acoustically-homogenous road section. An acoustically-homogenous section is to be understood as a fragment of road infrastructure for which the generation of noise by traffic will not undergo changes or will change insignificantly, and the cross-profile along the considered section makes it possible to apply the same manner of dividing the source into elementary sources. According to the above principle, the analyzed road infrastructure is to be divided into acoustically homogenous sections for which the parameters characterizing a given section of road are unchangeable (constant). The detailed scope of the above parameters has been presented in Figure 1 (block termed: content of attribute table for the emission of road traffic noise). Thus, calculations of road traffic noise emission require a detailed understanding of the analyzed road infrastructure. Moreover, in accordance with the presented method, the created road model must account for information on road traffic in such a way that enables it to reflect variation in the noise source over time. Thus, data regarding the number of vehicles per hour, number of heavy goods vehicles, percentage share of heavy goods vehicles, or category of vehicles ought to be given in accordance with the defined time periods of reference. The above period of ought to account for daily differences in traffic volume and ought to allow for carrying out noise assessment for the day-evening-night indicator – L_{DEN} and night – L_N indicator. In accordance with the definition of long-term noise assessment indicators, at leastthree time periods of reference ought to be distinguished: day (06^{00}–18^{00}) evening (18^{00}–22^{00}) and night (22^{00}–06^{00}). Moreover, the changeability of road traffic during the different times of day ought to be accounted for, and volume determined for morning and afternoon rush hour traffic, as well as in the period outside of rush hour. When constructing the above model of the road serving as the starting point for calculating road traffic noise emission, a GIS database should be used, facilitating the precise determination of parameters for the defined acoustically-homogenous sections.

As suggested by the results of the EEA (2014) report, the applied interim methods, which were based on different models for each country, contributed to the emergence of unjustified differences in the results. Therefore, in 2008, the European Commission assumed works on developing the methodological frameworks for generating SNMs (Kephalopoulos *et al*. 2014, 2012). The works were completed by adopting, in 2015, a following noise directive – Commission Directive 2002/49/EC of the European Parliament and of the Council (Text with EEA relevance) (Directive 2015). The new directive replaces only Anex II to END, and thus, as of currently, two noise directives are equally binding in the EU. Common methods of assessing noise are known under the name of Common Noise Assessment Methods in EU (CNOSSOS-EU) and, in accordance with the provisions of the directive (2015), member states are obliged to apply the indicated methods as of 31 December 2018. In connection with the above, in the following – III phase of SNM mapping (2017), interim methods will continue to apply. New common methods of noise assessment – as obligatory – will become the methodological basis for phase IV of the mapping process, in the year 2022. Importantly, in the case of generating road traffic noise, the new directive fully confirmed the possibility of applying the French calculation method NMPB-Route-96 – an updated version of NMPB 2008 (Abbaléa *et al*. 2009, Besnard *et al*. 2009). In accordance with the new law, the above method can be applied not only for determining road traffic noise, but also for railway traffic and industrial noise. Moreover, the CNOSSOS-EU method assumes familiarity with the geometry of the source and its acoustic parameters. It therefore assumes a similar procedure to the method applied for phase I and II of mapping in terms of obtaining data necessary for determining road traffic noise emission.

The source of noise in the CNOSSOS-EU method is established by totalling noise emission derived from each vehicle passing down a given road section. Thus, the method describes five different categories of vehicles, i.e. (Besnard *et al*. 2009):

- Cat. 1 – light motor vehicles (e.g. passenger cars, light commercial vehicles under 3.5 tons),
- Cat. 2 – medium goods and commercial vehicles (e.g. medium goods and commercial vehicles > 3.5 tons),
- Cat. 3 – heavy goods vehicles (e.g. heavy goods vehicles, tourist coaches, buses with three or more axles),
- Cat. 4 – two-wheel motor vehicles (e.g. two-, three- and four-wheel mopeds and motorcycles with or without a sidecar),
- Cat. 5 – open category, optional, reserved for new types of vehicles constructed in the future (e.g. electric or hybrid cars, differing significantly in terms of noise emission from vehicles in cat. 1–4).

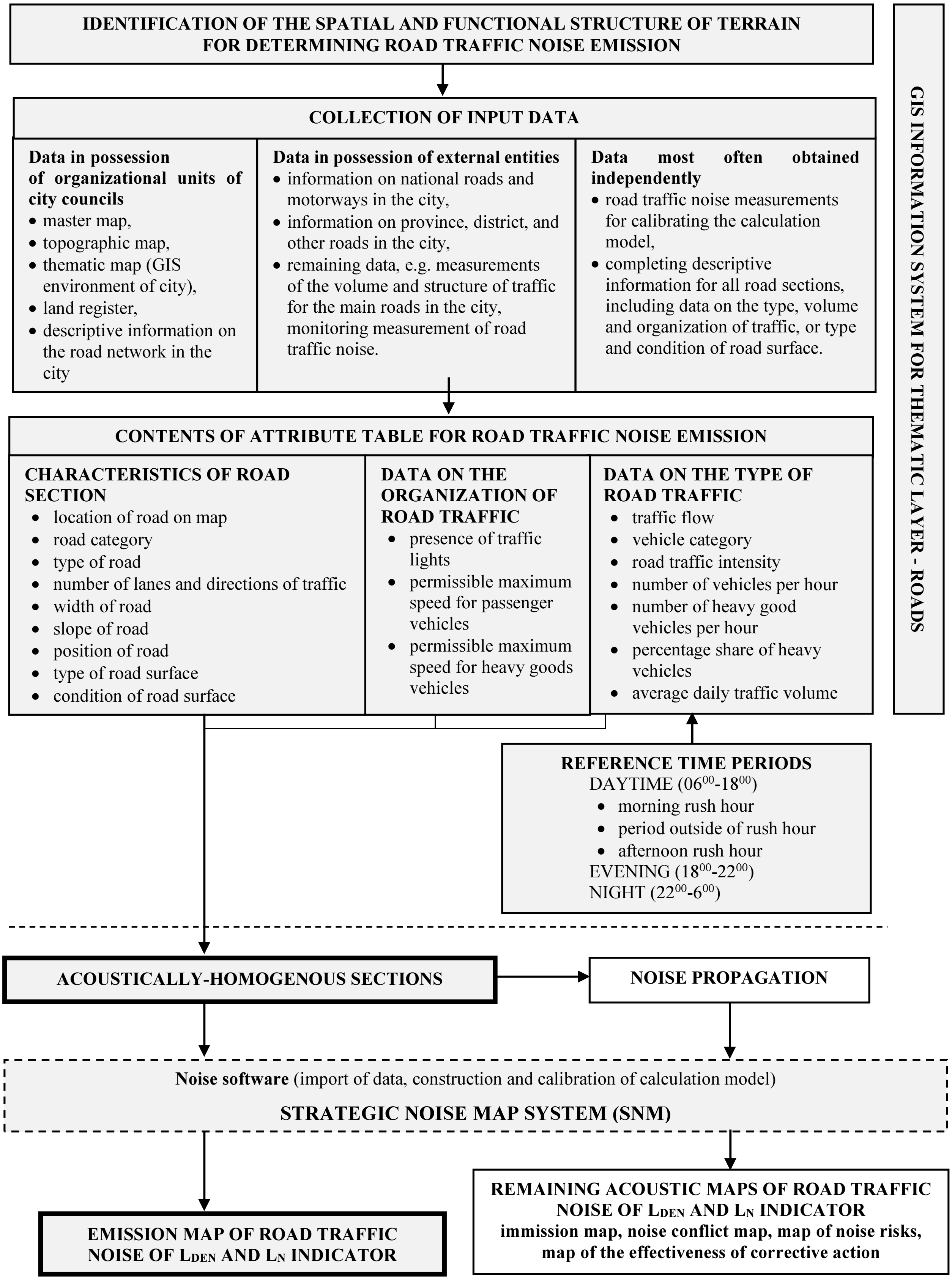

Fig. 1. Diagram of creating road traffic noise emission maps in the SNM system using GIS data
(Source: own elaboration)

In the presented method, the sound power of the source is calculated as the sum of the power of sound emissions from individual vehicles passing down the given linear section of road. Thus, the calculations ought to include noise derived from rolling, caused by the interaction of the tyre and road surface. For categories 1–3 of vehicles, the total sound power of the linear source includes noise derived from rolling and the drive unit. For category 4, it is indicated solely based on the level of noise given off by the drive unit. Moreover, information on the speed of the vehicle, type of movement, temperature of the environment, or information on the characteristics of the actual linear sound source, e.g. the type and conditions of the road surface, age of the surface, moisture content of the surface, or slope of the road, ought to be obtained for the calculations.

GIS for the process of creating road traffic noise emission maps in the SNM system

Due to the necessity of collecting and processing large amounts of noise-related and non-noise-related data, the effective realization of road traffic noise emission maps is possible using GIS data as well as an appropriate system of relational databases, which will become the starting point for generating a geometric-noise model, essential during the creation of digital noise maps (see Szopińska 2014). The process of creating road traffic noise emission maps in the SNM system has been presented in Figure 1. The figure describes the GIS information system, which serves as the starting material for defining road traffic noise emission maps in the noise program in a detailed manner (see Fig. 1 – gray block). The presented scope of attribute tables, accounting for time periods of reference, serves as the basis for defining homogenous noise sections. Their identification is essential to generating road traffic noise emission maps. Moreover, upon accounting for noise propagation, the defined homogenous noise will allow for generating remaining maps of the SNM system, such as: the road traffic noise emission map, map of noise conflicts, or the map of noise risk for long-term indicators (see Fig. 1 – white block). A further part of the work describes the scope of GIS data necessary for generating road traffic noise emission maps.

Constructing a GIS database ought to be preceded by detailed familiarization with the spatial and functional structure of the analyzed terrain. For this purpose, an assessment of the current conditions should be carried out. For purposes of creating the database, it is suggested that objects in space be divided into three groups, which include objects creating noise nuisance, objects which are sensitive to noise, and objects which are neutral in terms of noise. The subject of the studies is road traffic noise, thus the existing road sections should be included in the first group. Included in the second group are objects for which permissible noise levels have been set in accordance with the law. The third group includes objects influencing sound wave propagation in space (e.g. building structures not qualified in the second group, forested areas, cliffs, areas of technical infrastructure). Upon defining the objects in space, the interrelations between the presented groups should be analysed, places of potential conflicts between areas of different uses located, and the terrain analysed in detail in terms of possible noise hazards.

In accordance with the provisions of the directive (2015), all input data influencing the level of road traffic noise emission ought to be indicated reflecting actual values with an accuracy of at least the level of uncertainty of +/– 2 dB(A) at the level of emission from the source. Collecting the above input data is the most difficult part of realizing the GIS database. It is often also the most costly. As a result of this, it is essential to gain an understanding of what data and in what institutions have already been collected or are going to be collected in the nearest future. When constructing GIS databases for generating noise emission maps, data pertaining to sources of road traffic noise (information about the type of traffic and categories of vehicles passing down individual road sections, information on the organization of road traffic, characteristics of road sections), cartographic documents, data from the land registration system, results of noise measurements, results of studies on the road traffic volume, as well as information obtained during field trips, completing or updating the collection of input data, should be used. The more materials in digital form are obtained, the easier and faster the work on creating road traffic noise maps will be, guaranteeing better calculation quality. When generating a GIS database for the assessment of road traffic noise emission, a thematic layer (for example called "roads") should be created, presenting the analyzed road infrastructure divided into acoustically-homogenous sections. Generating the presented thematic layer is possible by the integration of the digital map with a descriptive database on sources of road traffic noise. For this purpose, special computer software for spatial analyses, enabling all elements of the system to be combined as well as obtaining the intended end results, should be used.

Defining road traffic noise emission requires the road infrastructures to be divided into acoustically-homogenous sections, for which parameters determining the level of noise are, for the most part, constant. Objects found in this layer should possess adequate data in attribute tables of the GIS database allowing for the level of road traffic noise to be analyzed. The scope and detailed description of the data has been presented in Table 1. It is recommended that data presented in the table for each acoustically-homogenous section be obtained in accordance with the following guidelines:

- the location of the axis of existing roads ought to be determined using the digitalization of the master map and field survey,
- for two-way roads, the axis ought to be drawn down the middle of the road,
- for one-way roads divided by a greenbelt, the axis ought to run down the middle of each road,

- for each road section, data on the traffic volume and structure of traffic for three reference periods (day, evening and night), data on the permissible speed limits, the type of traffic, and parameters characterizing the road section ought to be given.

Table 1. Scope of information in the attribute table for determining road traffic noise emission (Source: own elaboration)

Scope of data	Description
CHARACTERISTICS OF ROAD SECTION	
Location of axis on map	section identifier, name of section, identifier and name of street at the beginning of the section, identifier and name of street at the end of the section, node at the beginning of the section, node at the end of the section
Road category	national “n”, district “d”, province “p”, commune “c”, unspecified “u”
Type of road	service road “s”, main “m”, access “a”, local “l”, other “o”
Number of lanes and traffic directions	Values determined in accordance with source materials
Road width	Size indicated in accordance with road axis and edge of road
Slope of road	horizontal route “0”, ascending route “1”, descending route “–1” (data can be read from the relief of the land)
Type of surface	asphalt with very good condition of road – “1”, dirt road – “3”, concrete slab, concrete sett paving – “5”, cobblestones/asphalt of poor road quality – “6”
Condition of surface	good (dobry) – “d”, average (średni) “s”, warning (ostrzegawczy) – “o”, poor (zły) “z”, dirt road/ lack of data”
Age of road surface	numerical values confirming the age of the road surface
Presence of traffic lights	YES/NO
Location of road	at ground level “0”, in a trench “1”, under a viaduct “2”, on an embankment “3”
DATA ON THE ORGANIZATION OF ROAD TRAFFIC	
Presence of traffic lights	YES/NO
Maximum permissable speed	for passenger vehicles V [km/h]/[m/s], for goods vehicles V_c [km/h]/[m/s]
DATA ON THE TYPE OF ROAD TRAFFIC	
Road traffic volume	identifier of source data, type of data source
Number of vehicles per hour	this is the sum of vehicles determined for the assumed reference times, values ought to be determined based on direct traffic measurements or data contained in relavant reports
Number of heavy good vehicles per hour	this is the number of vehicles >3.5 tons determined for the assumed reference times; the values ought to be determined based on direct traffic measurements or data found in relevant reports
Percentage share of heavy goods vehicles	this is the ratio of heavy goods vehicles > 3.5 tons to the number of actual vehicles (all motor vehicles) determined for the assumed reference times; the values ought to be determined based on direct traffic measurements or data contained in relevant reports
Traffic flow	smooth “0”, pulsating “1”, accelerating “2”, decelerating “3”
Average daily traffic volume	on a two-way section in the direction of the city center, and away from the city center

Conclusions

At present, according to the regulations of European Union Law (END 2002) road traffic noise is determined using the SNM system. This system is based on noise calculations prepared using specialized computer programs and a theoretical road traffic noise model with the help of GIS. Generating a road traffic noise emission map takes place based on the characteristics of the source of noise (parameters describing acoustically-homogenous road sections and data on the volume and type of traffic, which ought to be described for the various defined categories of motor vehicles) (see Szopińska 2014). Moreover, when calculating the sound power of a linear noise source (road), noise derived from rolling, caused by the interaction of the tyre and road surface as well as noise coming from the drive unit should be accounted for. Such extensive analysis of the condition of the environment, necessary for calculating road traffic noise emission, indicates the appropriateness of using GIS technology as the methodological basis. The GIS database functioning in a city's information resources serves as the input material for the process of creating road traffic noise emission maps in the SNM system. In this process, graphic data (e.g. road axes, contours, escarpments) as well as descriptive data (e.g. the characteristics of the transportation network, volume of road traffic) are used. Based on the information presented above, the SNM system makes it possible to generate a spatial geometric-acoustic model enabling the visualization of road traffic noise emission maps of the L_{DEN} and L_N indicator. The remaining maps of the system, such as immission maps, noise-sensitivity maps, or maps of exceeded road traffic noise levels, as well as analyses carried out accounting for detailed demographic data, can be generated based on the above maps (accounting for noise propagation).

In the case of generating road traffic noise, the new directive (2015) fully confirmed the possibility of applying the theoretical road traffic noise model. The CNOSSOS-EU method assumes a similar procedure to the method applied in END (2002). Common methods for assessing noise termed CNOSSOS-EU, in accordance with the provision of the directive (2015), will not enter into force until 31 December 2018. Thus, new common methods for assessing noise – as obligatory – will become the methodological basis for phase IV of the mapping process, in the year 2022. In connection with the above, all European countries will still be able to make use of interim methods (END 2002), which, in accordance with EEA analysis (2014), provide erroneous (inconsistent) results of noise impact assessments. Thus, the precise determination of the level of noise nuisance posed by individual groups of noise sources to European inhabitants will continue to be impossible. This in turn, due to the numerous negative consequences of noise (Halonen *et al*. 2015; Sørensen *et al*. 2013; WHO 2011), can lead to the deterioration of the quality of life and health among the European society, as well as influencing the lessened attractiveness of noise sensitive areas (Trojanek 2014; Szopińska, Krajewska 2016a).

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