Road Traffic Noise Forecast (RTNF) in the Process of Creating Urban Space - Case Study of Poland

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Abstract. Road traffic noise is one of the main nuisance factors in a city. This creates the necessity of determining and monitoring not only its level in relation to the existing urban structure, but also precisely determining and monitoring the level of noise over time, accounting for the designed spatial and functional solutions. In Poland, issues connected with noise are taken on in ecophysiographic reports and forecasts of its impact on the environment, which are a component of the local spatial development plan (LSDP) creation processes. Unfortunately, studies carried out on the noise environment are done in a selective manner, while environmental reports assume the consistency of nuisance phenomena over time. In connection with the above, the present article focuses on the problem of noise nuisance derived from a planned road solution while making a planning decision in the process of creating an LSDP. The specific aim is to present an original Road Traffic Noise Forecast (RTNF) understood as an element of the procedure of choosing an optimal spatial and functional solution for noise sensitive areas in terms of maintaining noise-level standards. The above will be illustrated on the example of a selected LSDP of the Polish city of Bydgoszcz.

1. Introduction

Spatial planning deals with the organization of planning space. This is an ongoing process based on adapting spatial components in regards to each other and aiming to restore an optimal design in the event of it being disturbed by the effect of developmental factors [1]. It is also an action aimed at creating such a state of the natural environment in which the functions it serves result from the necessity of fulfilling people's needs while accounting for the principles of ecological development. Noise is one of the main factors degrading the environment. It is commonly encountered in urbanized areas, causing discomfort among the people and having a negative influence on the management of the city's resources, as well as lowering the value of real estate within the vicinity of areas generating noise [2]. The influence of noise on the human body has been the topic of many scientific publications. A number of studies confirm the relationship between the level of environmental noise and the occurrence of many adverse health effects, which include: ischaemic heart diseases, arterial hypertension [3], diabetes [4], stroke [5], or sleep loss and problems with concentration [6]. Noise derived from road traffic is included in the most bothersome group of noise sources [7]. Inhabitants of big cities are particularly at risk of its negative effects. This is the result of, above all, the strong expansion of urbanized areas, ever-shrinking planning space, and ineffective noise policy [8]. The increasing urbanization of cities, which is strongly connected with industrialization, may contribute to generating noise nuisance in noise sensitive areas, the aim of which is to ensure proper noise conditions, where noise levels specified by the legislator are not exceeded. In accordance with Polish legislation [9], during the planning of urban space, matters of protection against noise ought to be
considered. Authorities of Polish cities fulfill this requirement in ecophysiological studies as well as a forecast of the impact on the environment, which constitute an element of the local spatial development plan (LSDP) creation process [10]. Unfortunately, the above studies of the noise environment are carried out selectively, while environmental reports assume the consistency of nuisance phenomena over time. As a result of this, all proposed actions regarding noise protection are the result of incomplete analyses. This often leads to the erroneous localization of noise sensitive areas and contributes to the emergence of social conflicts. Due to noise sensitive areas being located in the direct neighborhood of roads, the above especially concerns nuisance generated by planned transportation solutions.

Thus, the aim of this article is to offer an insight into the subject matter of protection against road traffic noise and draw attention to the problem of noise nuisance derived from a planned road solution while making the planning decision in the process of creating an LSDP. The detailed aim is to present an original Road Traffic Noise Forecast – RTNF, understood as an optimizing tool of the planning phase of the LSDP creation process, facilitating the minimization of noise pollution derived from the planned road solution in noise sensitive areas. The above will be illustrated on the example of the Local Spatial Development Plan of the Akademickie-Wscho neighborhood in the Fordon District of the Polish city of Bydgoszcz [11]. The research will be used to verify the study hypothesis of whether the introduction of the planned road solution to the city space will affect the acoustic conditions prevailing in the vicinity of the planned noise sensitive areas. The research was realized using the following study methods: studies of literature and laws regarding the protection of the environment against road traffic noise, studies of source materials, including planning documents (http://mpu.bydgoszcz.pl/), information from land and building registers, the strategic noise map (SNM) of Bydgoszcz [12] and a base map of the study area, as well as data presented on the web portal – http://geoportal.mojregion.info/. Moreover, the following computer software was used for analyses: GeoMedia Professional (program for spatial analyses) and CadnaA (program for noise analyses).

2. Problem of Road Traffic Noise in Light of Binding Polish Legal Regulations

In Europe, the basic legal act regulating issues of protection against noise is the Environmental Noise Directive (END) [13]. The main aim of the directive is to unify, in the member states, actions involving the reduction of the level of noise in the environment. In Poland, the implementation of the above directive is reflected in the provisions of the Environmental Protection Law Act [10]. In Poland, protection against noise relies on ensuring the best possible noise state of the environment by maintaining the level of noise at values not exceeding those of two acceptable groups of indicators. The first of them is applied when determining and controlling the conditions of using the environment in relation to a single day \(L_{AeqD}\) – equivalent level of noise \(A\) for daytime, from 6\(^{00}\) to 22\(^{00}\), and \(L_{AeqN}\) – equivalent level of noise \(A\) for the time of night, from 22\(^{00}\) to 6\(^{00}\). The second group of indicators is applied in the long-term policy dealing with the protection of the environment against noise pollution and developing strategic noise maps. This group includes \(L_{DEN}\) – long-term average level of noise \(A\) expressed in decibels (dB) determined during all days and nights in a year, and \(L_{N}\) – long term average level of noise \(A\) expressed in decibels (dB) determined during all hours of the night in a year (from 22\(^{00}\) to 6\(^{00}\)). Out of concern for people’s health, the acceptable levels of noise in the environment have been specified in each EU member state. Acceptable values of the individual indicators depend on the source of noise and intended land use. In Poland, depending on the type of land, sensitivity and type of noise source, the permissible level oscillates between 50-70 dB during the daytime hours and 45-65 dB during night-time hours. For example, the following acceptable levels of road traffic noise apply for residential areas [14]: for single family housing real estate: \(L_{DEN}=50\text{dB}\), \(L_{N}=45\text{dB}\), for multi-family housing real estate: \(L_{DEN}=68\text{dB}, L_{N}=59\text{dB}\). The maximum values are laid out in the national provisions of EU member states, as there are no common legal regulations in this scope [15]. Each country has a different definition of a noise sensitive area, imposes different limits, and realizes noise policy aims in different ways. In the majority of countries, areas zoned for residential development, as well as hospitals and areas of healthcare facilities are subject to protection against noise. In certain countries, e.g. Belgium, Germany or the United States, permissible noise levels are set out for the current situation as well as the anticipated state.
The basic tool for tackling noise is a SNM, which specifies the areas of reach of harmful sounds in the environment. A SNM falls into all key areas of the noise protection policy. As a GIS system, it is included in the informative layer of city management [16]. The process of creating SNMs is a time-consuming analysis of demographic data as well as data regarding the means of land management and use. It is realized using advanced computer software intended for modeling noise in space. Noise calculations can be carried out using programs for noise analyses, e.g.: CadnaA, SoundPlan, ArcAkus, etc., based on the GIS database. Data and conclusions stemming from SNMs (in the form of emission maps, exceedance maps, and maps of sensitive areas) are the basis for preparing and updating the Program of Environmental Protection Against Noise - PEPAN. Directive [13] requires the member states to periodically (every five years) prepare SNMs for all agglomerations in their area, as well as relay data to the European Commission. As of currently, three phases of works on SNMs have been completed. Phase 1 covered the preparation of SNMs for cities of over 250 thousand inhabitants (completed in 2007). Phase 2 covered works on SNMs for all cities of over 100 thousand inhabitants, along with updating data from 2007 (completed in 2012). Phase 3 was completed in mid-2017. In Poland, in the year 2013, additional updates were carried out, resulting from changes in the permissible levels of noise in the environment.

3. Problem of Protection against Road Traffic Noise in the Process of Creating Polish Cities

In Poland, under the current legal situation, LSDPs play the main role in shaping urban space. Their main purpose is to establish the intended land use in such a way that meets the economic needs of various fields, and is known and predictable, as well as socially accepted, while abiding by the principles of sustainable development or environmental protection, including protection from environmental noise pollution. An LSDP realizes the above aim, above all, by indicating areas of various land use functions and providing regulations as to their development, including noise sensitive areas. In Poland, areas covered by noise protection include, among others, areas intended for residential and residential-commercial development, buildings connected with the permanent or temporary stay of children and youth (e.g. schools, kindergartens, preschools), or areas zoned for hospitals or nursing homes [14]. In an LSDP, in addition to indicating areas of various intended use, the borders of and means of developing areas subject to protection arising from separate regulations are provided; special conditions for their development are set out, along with limitations in their use. In the context of issues connected with noise, quiet areas (e.g. recreational and leisure areas in cities) or limited use zones surrounding airports may serve as examples. Their basic aim is to maintain a good quality of the noise environment as a result of introducing limitations in the use of real estate or the requirement of applying technological solutions enabling the noise comfort in a building to be maintained.

In the event of the occurrence of an excessive level of road traffic noise resulting from a conflict at the meeting point of residential and transportation land uses, corrective measures are severely limited. The complete elimination of noise nuisance generated by roads is not possible. Reducing road traffic noise at the stage of city planning is extremely difficult due to the occurrence of existing, strictly specified spatial structures which significantly limit planning activities. Keeping this in mind, in order to minimize noise, modernization- or investment-based forms of noise protection are applied, which, in connection with a proecological approach to city planning, make it possible to maintain a proper noise environment. Such actions include promoting the notion of sustainable city transport, which meets social and economic expectations and, at the same time, has a positive influence on the environment; decreasing the transportation intensity by the proper organization of urban space (e.g. the construction of ring roads around areas of residential housing development); creating zones restricting or calming road traffic by changes in the organization of traffic and decreasing speed limits; applying quiet road surfaces, a feature of which is reducing the noise level to even as little as 10dB; locating roads in deep trenches or between earthen mounds; constructing soundproof tunnels over a road; road traffic noise shielding using noise screens, buildings and structures, as well as green belt; installing sound-proof windows along with air-conditioning in areas exposed to excessive levels of noise.

All of the above actions must be based on objectively existing and disclosed evidence. Ecophysiographic studies as well as the forecast of environmental impact, which undertake the topic of protection against noise, especially in the context of designed spatial and functional solutions, are to
be used for this purpose when creating an LSDP. In the above reports, information regarding the noise environment is derived, above all, from the Provincial Inspectorate of Environmental Protection (PIEP), contained in reports on the state of the environment. In these documents, analyses of road traffic noise are carried out selectively. Moreover, PIEP, when realizing the tasks of National Environmental Monitoring, carries out noise measurements using automatic and mobile stations only at selected points. The obtained results are, therefore, not representative of the entire city, and do not account for noise derived from all sections of the road network. Moreover, all of the carried out studies assume the consistency of parameters over time. As of currently, changes in the intensity and the structure of road traffic by type over time on the existing and planned road sections are not accounted for when creating LSDPs. Also not accounted for is road traffic noise generated from neighboring areas, which can influence how the noise environment of the planned space is shaped (including data regarding the parameters of road sections, intensity and structure of road traffic, or changes in the transportation needs of the inhabitants influencing the choice of a specific transportation system or road section), as well as the time needed to fully realize the provisions of the LSDP.

4. Road Traffic Noise Forecast (RTNF) as an Optimizing Tool for Planning Polish City Space

Looking for an optimal spatial and functional solution ought to include noise forecasts, which will allow for the level of noise generated by the planned transportation solutions to be determined in a precise manner. For this purpose, it is recommended that new tools such as Road Traffic Noise Forecasts (RTNF) be accounted for when planning the structure of a city. Their findings will be the basis for making planning decisions and will influence the selection of an optimal spatial and functional solution for noise sensitive areas in terms of meeting noise requirements resulting from binding legal regulations. The concept accounts for using SNM resources along with making use of geoinformation data. An RTNF requires a series of activities which, accordingly to Figure 1, have been assigned to the following points:

- Action 1 – identifying the spatial and functional structure of the area for the existing and planned state.
- Action 2 – carrying out RTNFs based on the GIS database along with a program of remedial actions in the form of variants of spatial and functional solutions for noise sensitive areas based on the results of the RTNFs.
- Action 3 – selecting the optimal spatial and functional solution for areas of sensitivity based on the results of RTNFs.

In Poland, it is recommended to account for RTNFs in the process of creating LSDPs using SNM resources by the design solutions shown in Figure 1. Data on the level of road traffic noise derived from SNM information resources of the city ought to be included in the input materials of the procedure for creating local spatial development plans (Stage 0). When preparing the Environmental Impact Forecast, the results of RTNFs should be accounted for (STATE 1, STATE 2, STATE 3) (Stage III). The new element has been presented in the Figure 1 in red. The results of the RNF have been presented in the Environmental Impact Forecast and ought to serve as the basis for once again analyzing the decisions made in the drafted local spatial development plan in terms of maintaining noise standards for noise sensitive areas (Stage III).

The spatial and functional structure of the land (Action 1) for the planned state should be realized in accordance with the findings of the spatial and functional solution proposed by the city planners. Immission maps for three states of road traffic noise should be generated within the framework of the presented RTNF (Action 2), accounting for various spatial solutions of the area. These states are:

- STATE 1 – existing road solution accounting for current traffic intensity.
- STATE 2 – planned road solution accounting for the current traffic intensity.
- STATE 3 – planned road solution accounting for future traffic intensity.
In accordance with the presented algorithm for the spatial and functional solution proposed by city planners, the level of road traffic noise generated by existing road solutions ought to be assessed. Data regarding the current traffic intensity should be obtained in the year of making the planning decision (STATE 1). Next, the level of noise generated by the planned road solution ought to be determined. For this purpose, the planned stretches of road should firstly be considered for the existing traffic intensity for which the data were obtained in the year of making the planning decision (STATE 2). Due to the fact that the time necessary to carry out the spatial and functional solutions proposed by city planners should be accounted for in the studies, STATE 3 was introduced to the presented algorithm. It accounts for future traffic intensity determined in the assumed time frame, which enables the full realization of all activities in the urban space. The forecast period introduced to STATE 3
ought to account for the time necessary to carry out the proposed tasks while accounting for economic, technical, social and environmental aspects. In this way, a forecast showing the noise generated by a planned road solution accounting for the future traffic intensity will be created. Moreover, in the framework of Action 2 for STATE 1, STATE 2 and STATE 3, analyses of spatial and functional solutions for noise sensitive areas ought to be carried out, and the program of remedial actions, which will become the basis for selecting the optimal solution, presented (Action 3).

Below, we present the results of introducing a Road Traffic Noise Forecast to the process of drafting a selected LSDP. For the purposes of the research, the Local Spatial Development Plan of the Akademickie-Wschod neighborhood in the Fordon District of Bydgoszcz, dominated by multi-family residential buildings dating back to the 1980s, was selected. Bydgoszcz, located in the northern part of the country, is one of the largest centres of settlement in Poland. The city is populated by nearly 360,000 inhabitants and situated on the Brda River and Bydgoszcz Canal, with its eastern part bordering the Vistula River. In Poland, it is the tenth largest city in terms of area (176 km²) and the eighth in terms of population (Fig. 2).

![Figure 2. Road network of the city of Bydgoszcz marking the analyzed LSDP.](image)

In accordance with the provisions of the selected LSDP [11], the investigated territory will have new noise sensitive areas, covering a total area of 15.09 ha (25% of the total area of the LSDP), with planned construction of 37 residential buildings (Fig. 3). In addition to this, there are plans to extend the existing road system. Such modernisation includes the construction of new roads and the extension of existing roads (Fig. 3b and Fig. 3c). In order to see whether the planned extension of the road system (referred to as the “projected road solution”) would contribute to a change in the acoustic conditions within the area of the projected noise sensitive areas, the author created a GIS database, and then, using Cadna A, created a set of immission maps for the L_{DEN} indicator of road noise, taking into account various spatial solutions. Figure 3a shows a road traffic noise immission map for STATE 1, with the existing roads characterized by traffic loads as of 2011. Figure 3b shows an immission map for STATE 2, where existing roads have the traffic load predicted for the year 2035. Figure 3c presents an immission map for the noise generated by the projected road solution and the traffic predicted for 2035. Figures 3a,b,c indicate the noise level (L_{DEN} indicator) for each of the situations. As shown, including the road solution projected by the planners within the structure of the investigated area contributes to a change in the noise level within the area of the projected housing estate. These findings are confirmed by the L_{DEN} indicator, which changes according to the situation and is highest for STATE 3 (see Table 1).

| State | Noise Level - L_{DEN} Indicator |
|-------|-------------------------------|
| STATE 1 | Low                             |
| STATE 2 | Medium                         |
| STATE 3 | High                           |

Table 1. Road traffic noise level - L_{DEN} indicator for three states.
| Measuring point | Road traffic noise level $L_{DEN}$ [dB] |
|-----------------|-------------------------------------|
| 1               | STATE 1: 63.7  | STATE 2: 68.2  | STATE 3: 69.1 |
| 2               | STATE 1: 58.9  | STATE 2: 68.7  | STATE 3: 69.2 |
| 3               | STATE 1: 64.6  | STATE 2: 59.8  | STATE 3: 60.7 |
| 4               | STATE 1: 56.8  | STATE 2: 66.2  | STATE 3: 67.1 |
| 5               | STATE 1: 60.2  | STATE 2: 559   | STATE 3: 54.7 |
| 6               | STATE 1: 63.9  | STATE 2: 58.6  | STATE 3: 57.5 |
| 7               | STATE 1: 64.1  | STATE 2: 64.3  | STATE 3: 64.7 |
| 8               | STATE 1: 62.9  | STATE 2: 63.4  | STATE 3: 63.7 |
| 9               | STATE 1: 54.9  | STATE 2: 63.5  | STATE 3: 64.7 |
| 10              | STATE 1: 60.1  | STATE 2: 63.8  | STATE 3: 64.2 |

Figure 3. Analysis of the spatial and functional solutions in accordance with the investigated spatial development plan for a) STATE 1, b) STATE 2, c) STATE 3.

5. Conclusion

The fact that noise research of the forecasted state is not taken into account while creating local spatial development plans often leads to noise sensitive areas and areas of noise nuisance being located at distances which contribute to the emergence of spatial and social conflicts. The above data are confirmed by the research, which in turn support the initial hypothesis. Including the projected road solution in the investigated area contributed to a change in the noise levels in the environment, which in turn has an influence in the acoustic situation in the vicinity of the projected areas of noise sensitivity. Introducing the original Road Traffic Noise Forecast to the process of creating LSDPs using SNM resources will make it possible to determine the spatial and functional structure of noise sensitive areas while maintaining noise standards specified by the legislator. Accounting for the results of RTNFs will prevent the common practice of applying vague statements regarding the quality of the noise environment in studies accompanying the development of LSDPs. Reliable information in terms of changes in the environmental noise levels is essential to making appropriate investment decisions. Due to the fact that the presented RTNF refers to the means of adopting local plans, municipal self-
governments are the main recipients. In this view, the presented tool may influence the shaping of urban space in accordance with the principles of sustainable development and spatial order.

6. References

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