ISSN 1392 - 1207. MECHANIKA. 2006. Nr.3(59)

Noise mapping for the management of urban traffic flows

L. Kliučininkas*, D. Šaliūnas**
**Kaunas University of Technology, Radvilėnų str. 19, 50254 Kaunas, Lithuania, E-mail: linas.kliucininkas@ktu.lt*
***Transport and Road Research Institute, E. Kanto str. 25, 44029 Kaunas, Lithuania, E-mail: d.saliunas@tkti.lt*

1. Introduction

Assessment and Management of Environmental Noise have been important issues of the European Parliament and the Council for the last decade. They have aimed to create the basis for the coherent and integrated EU policy. The Council has launched the idea of making EU-wide "noise maps" based on common methods and indicators. Noise mapping covers the whole mapping process starting with from the collection of raw data, the storage and retrieval of this data for computation and modeling, up to the presentation of information related to outdoor sound levels, sound exposure and noise effects or numbers of affected people. These maps should be available for the general public. They should form the basis for the development of action plans and strategies at local, national, and EU levels in order to combat noise pollution [1].

The new EU Directive related to the assessment and management of environmental noise [2] requires a number of actions from the EU Member States to reduce noise levels. Noise maps and action plans are necessary for agglomerations with more than 250,000 inhabitants, major roads, major railways, and major airports. Articles 3, 5 and Annex I of Directive 2002/49/EC define the noise indicators L_{day} (day-time indicator), $L_{evening}$ (evening-time indicator), L_{night} (night-time indicator), and the compound indicator L_{den} (day-evening-night) noise indicator. According to Article 5 of Directive 2002/49/EC, the noise indicators L_{den} and L_{nigh} must be used for the calculation of strategic noise maps. L_{den} is derived from L_{day}, $L_{evening}$ and L_{night} using the following formula:

$$L_{den} = 10lg\frac{1}{24}\left(12*10^{\frac{L_{day}}{10}} + 4*10^{\frac{L_{evening}+5}{10}} + 8*10^{\frac{L_{night}+10}{10}}\right) \quad (1)$$

Considering that noise maps are a powerful zoning and planning resource, reporting the mean spectrum of noise at each selected location at different times have also been carried out [3]. The arguments in favor of its feasibility are given. They show that, in spite of the widespread opinion, costs and required time can be reduced considerably by the use of this low-priced method.

Geographic Information Systems (GIS) play an important role in noise mapping. An appropriate use of GIS in mapping noise effects provides the possibility to optimize quality and efficiency of noise effect studies. Furthermore, GIS can influence in estimation and exposure of uncertainties. The results of different studies can only be combined or compared if the same indicators for noise exposure and the same assessment methods are used. These effect studies support the decision-making process [4].

The self-report of noise exposure was compared with the information on noise maps [5] taking into account measures of self-reported annoyance and noise sensitivity. The data from noise maps is divided into two groups: "exposed" and "not exposed" to transportation noise. The division aims to minimize problems caused by potential misclassification of the data. Finnish authors conclude that self-report of noise-related items can supplement the information on noise maps.

This paper shows both: the practice of road traffic noise mapping according to the EU Directive 2002/49/EC and EC Recommendation C(2003)2807 [6] and noise mapping as a tool for the management of urban traffic flows.

2. Assessment of street traffic flows

Rapidly growing urban traffic flows have been identified as major contributors to the street traffic noise in a number of medium and large size cities. Many cities in the Central Eastern European (CEE) countries have faced consequences of substantial increase of private cars and crisis of public transport through the last decade [7]. In most the cases, the used cars from Western Europe were imported into the CEE countries.

Kaunas, being the medium size city with 373,669 inhabitants (2003) reflects the trends of individual car fleet expansion and collapse of public transport in the CEE countries (Figs. 1 and 2). Most cars are 10-15 years old and are relatively noisy compared with up-to-date equivalents.

The central part of Kaunas city, where administrative, commercial and cultural activities take place, is heavily effected by the intensive traffic flows. The traffic jams became an endemic feature of the city centre due to insufficient street capacity. Majority of the 3-5 storage buildings situated in the city centre aggregate structures directly exposed to traffic noise.

3. Street traffic flows

The street traffic flows analysis related to noise mapping is based on manual counts, as well as on the analysis and automated traffic flows analysis, performed by Transport and Road Research Institute [8]. The study involves measurements of traffic intensity, composition of flows, and driving speed [9].

The analysis of the data sets reveals that the average traffic intensity (ATI), based on 24-hour series is rather stable during the whole year. The analysis of street traffic flows in respect to driving speed shows that typical speed ranges between 40-60 km/h. The data was registered using Marksman 660 (Golden River Traffic, United Kingdom) counters-classifiers.

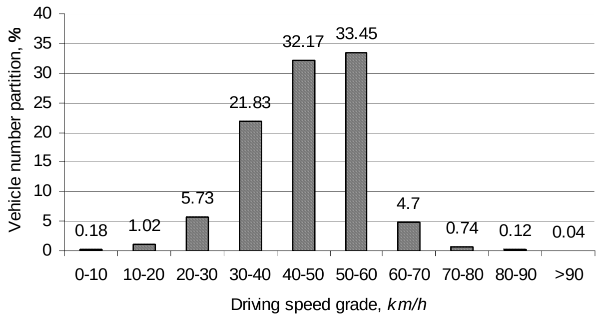

Fig. 1 The partition of street traffic flow based on the driving speed (K. Donelaičio str.)

The integration of the data was performed over 15 minute periods. The stationary counter-classifier in the segment 009-012 (Donelaičio str.) was used to identify the average of 24-hour yearly flow for different vehicle classification groups. Fig. 1 represents the episode distribution of the driving speed in the street segment 009-012.

The network of streets [10] in the study area is divided into 37 segments, reflecting conditions (the width of street, average speed) typical of the particular segment of the street (see Fig. 2). The specification of flows in each segment is based on the measurement data from 2001. Since data of traffic flows for all street segments within the same year were not available, authors made a decision to approximate retrospective data sets. In order to determine the corrective factor, for estimating the increase of traffic flows from retrospective time series, the authors used comparative data [11]. As a result, the factor 1.2 has been applied to correct data. Traffic flow analysis for the street segments 033-034, 020-022, 010-011, 030-033, 020-030, 035-038, 034-035, 030-031, 030-029 was performed using the approximated data.

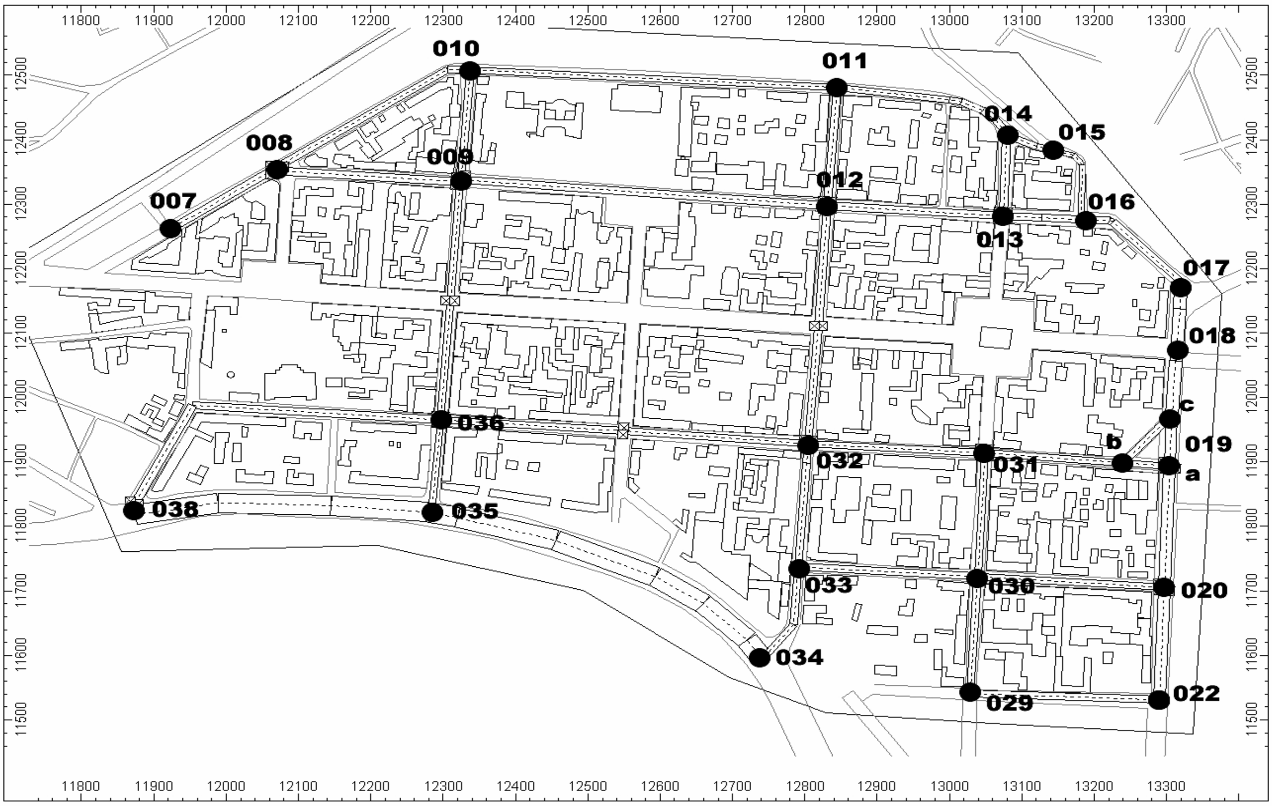

Fig. 2 The segmentation of the street grid in the study area

Periodical week-long measurements were carried out once each month from June to November, 2001. The measurements estimated: a) the annual averages of traffic intensity during 24 hours, b) the variation of traffic intensity averages during 6 month, c) 24 hour traffic intensity for each day of the week, d) features of traffic intensity fluctuations during 24 hours, e) the average speed of traffic flow.

Table 1 presents the average of monthly and yearly 24 hour traffic intensity and the ratios between monthly and yearly averages. The averages of weekly measurements served as monthly averages of appropriate month. The authors have noticed that the 'commuting circle' reflects temporal variations of traffic flows fairly well and is rather stable all over the year. It was taken into consideration that meteorological conditions in winter and early spring have essential influence on urban traffic flows and have strong correlation with the intensity of flows on out of town roads. As a result, the averages of monthly urban traffic flows from January to April were estimated in proportion to the intensity of flows on out of town roads.

Table 2 presents the average intensity of traffic flows on weekdays respectively for two periods: July-August and September–November. The maximal values of traffic flows were recorded on Fridays. The differences in the intensities of traffic flows from Monday to Thursday periods ranged within the limits of 1.2%. The minimal values of traffic flows were recorded on Sundays and comprised 60.7% of week averages. The values of traffic intensity values on working days exceeded the values of weekends by the factor 1.44-1.67. This ratio was even more extensive from July to August.

Table 1

The average of monthly and yearly 24-hour traffic intensity in Donelaičio str.(street segment 009-012)

Yearly 24hours average	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
	24 hours monthly average (vehicles / 24hours) and ratios between monthly and yearly averages (%)											
12800	9900	10600	11600	12900	13700	13700	12600	12200	13900	14100	14200	14200
	0.77	0.83	0.91	1.01	1.07	1.07	0.98	0.95	1.09	1.10	1.11	1.11

Table 2

The average of traffic intensity on week days in Donelaičio str. (street segment 009-012)

Measurement period	Average 24 hours intensity			Week days						
	Total	Working days	Weekend days	1	2	3	4	5	6	7
				24 hours yearly averages (vehicles / 24hours) and their ratios with weekly averages (%)						
July-August	12400	14300	7700	14200	14400	14100	14200	14400	9200	6200
				1.149	1.167	1.139	1.144	1.162	0.740	0.500
September-November	14100	15700	10000	15300	15400	15600	15600	16500	12100	7900
				1.093	1.094	1.110	1.110	1.173	0.859	0.561

4. Estimation of street traffic noise

Field measurements were performed on working days in the warm period (April-May, 2005) using a tripod mounted Larson Davis (USA), type 4426 equipped with a condenser microphone adapted for free-field conditions and configured for A-weighted frequency response and fast sampling rate [12].

The equivalent continuous sound level L_{eq} was integrated over the periods of 5 minutes, which was considered sufficient to average the fluctuating noise from street traffic. The results of the measurement from 10 immission points were used to verify the noise dispersion model for the central part of Kaunas. Majority of the measurements conducted on working days in the close proximity of the streets, indicated L_{eq} exceeding 60 dB(A) threshold. The analysis of fluctuations on weekdays shows high correlation (r=0.89) between noise levels and intensity of traffic flows. Instantaneous values of 71.3 dB(A) were reached and were repeatedly registered on Fridays.

The noise dispersion modeling was carried out using CadnaA (DataCustik, Germany) software [13] and following the guidelines of the German Standard RLS 90 [14]. In semiempirical models a road is divided into point sources, which are both stationary and continuous. The noise emissions level at each point is relative to the length of the line segment it represents. The number of point noise sources required to properly represent a line source is determined by the distance criterion [15]

$$l \leq \beta s \tag{2}$$

with l the maximum length of each line segment, β is a constant < 1, s the distance from the centre of the segment to the receiving point.

According to the standard RLS 90 guidelines β value was accepted as 0.5. The road traffic source simulates a street with multiple tracks by assuming one-line sources at 0.5 m above the middle of each of the two outer tracks. The equivalent sound level is then computed as the energetic sum of the sources. The model calculates emission levels from relevant traffic flows and associated portion of trucks, vehicle speed, and road surface. In accordance with the software requirements motor vehicles were classified into light vehicles (less than 3.5 tones) and heavy-duty vehicles (more than 3.5 tones). The following data sets are used as inputs to the noise dispersion model: roads, topography, buildings, reference points for noise level data verification, and grid for data presentation.

The data sets on topography and height of constructions were composed from existing GIS maps 1: 5000 (municipality enterprise "Kauno planas") and visualized using CadnaA software. The longitudinal profile was defined as a horizontal carriageway whose gradient in direction of traffic flow is less than 2%. The single storey houses were attributed 3.4 m heights; respectively every additional storey was given extra 3.4 m height. Due to the fact that majority of the 3-5 storey buildings in close proximity to the streets make up urban structures exposed to the traffic noise, the modelling included one reflection from the buildings. At the same time acoustical permeability was equated 0. The 5 m resolution square grid was adopted to present the results of the modelling. The output results were modelled at 4 m above the ground level.

5. Mapping noise effects

The estimation of composition of traffic flows was based on manual counts. For the modelling purposes motor vehicles were grouped into the five classes: motorcycles, light duty vehicles, microbuses, lorries and buses/ trolleys. The initial noise level mapping (scenario 0) was based on the analysis of recent traffic flows with respect to the speed limit of 50 km/h. Only in the street segment 038-035-034 (King Mindaugas av.) the speed limit was 60km/h. The regressive data analysis was used to verify the model, respectively the linear regression equation $y = 0.8319x + 11.436$ was used to correct the output data. The validation of the map data shows high correlation ($r = 0.94$) between the measured and modelled data sets.

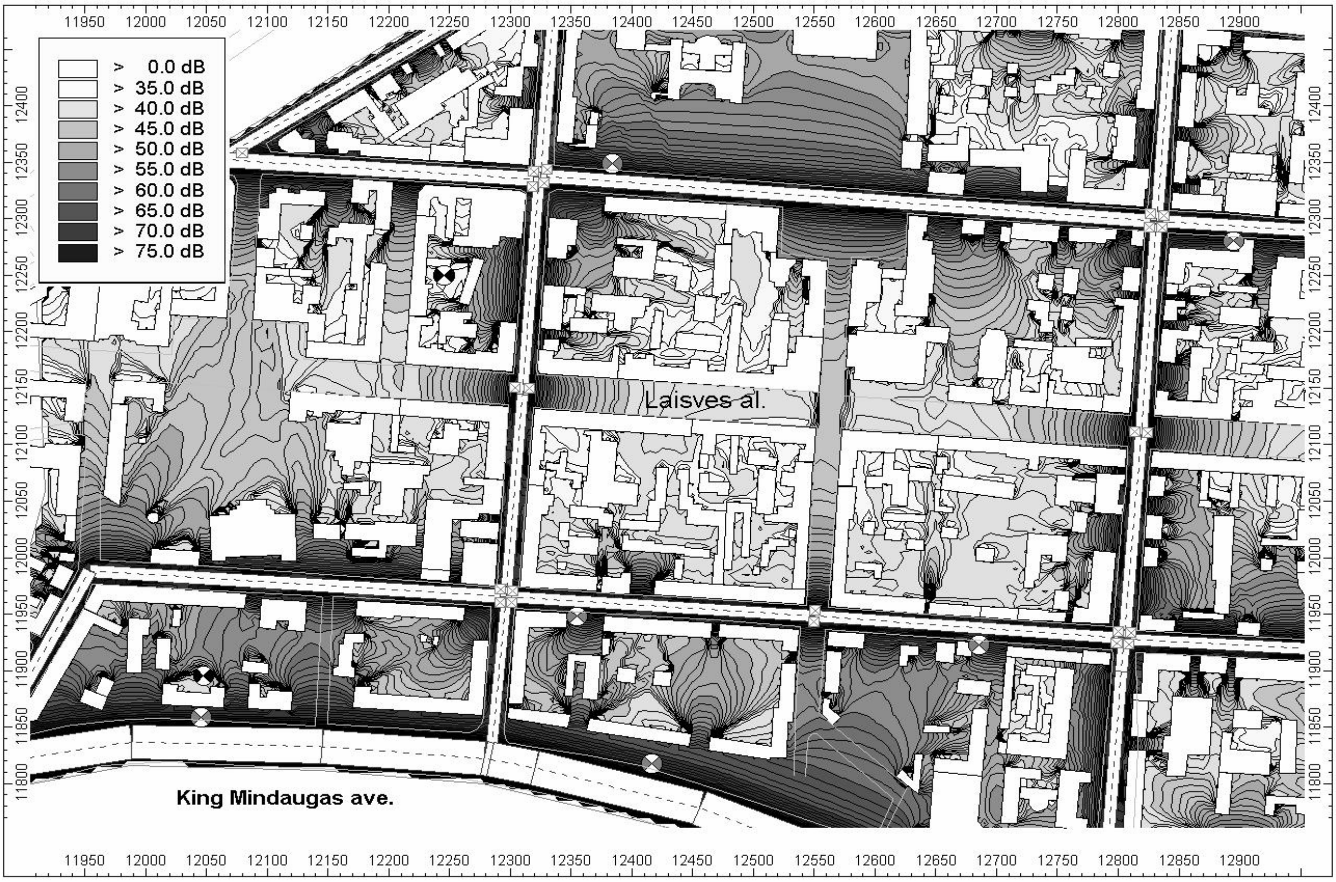

Fig. 3 The fragment of the street traffic noise map (predictive mapping, speed limit 60km/h)

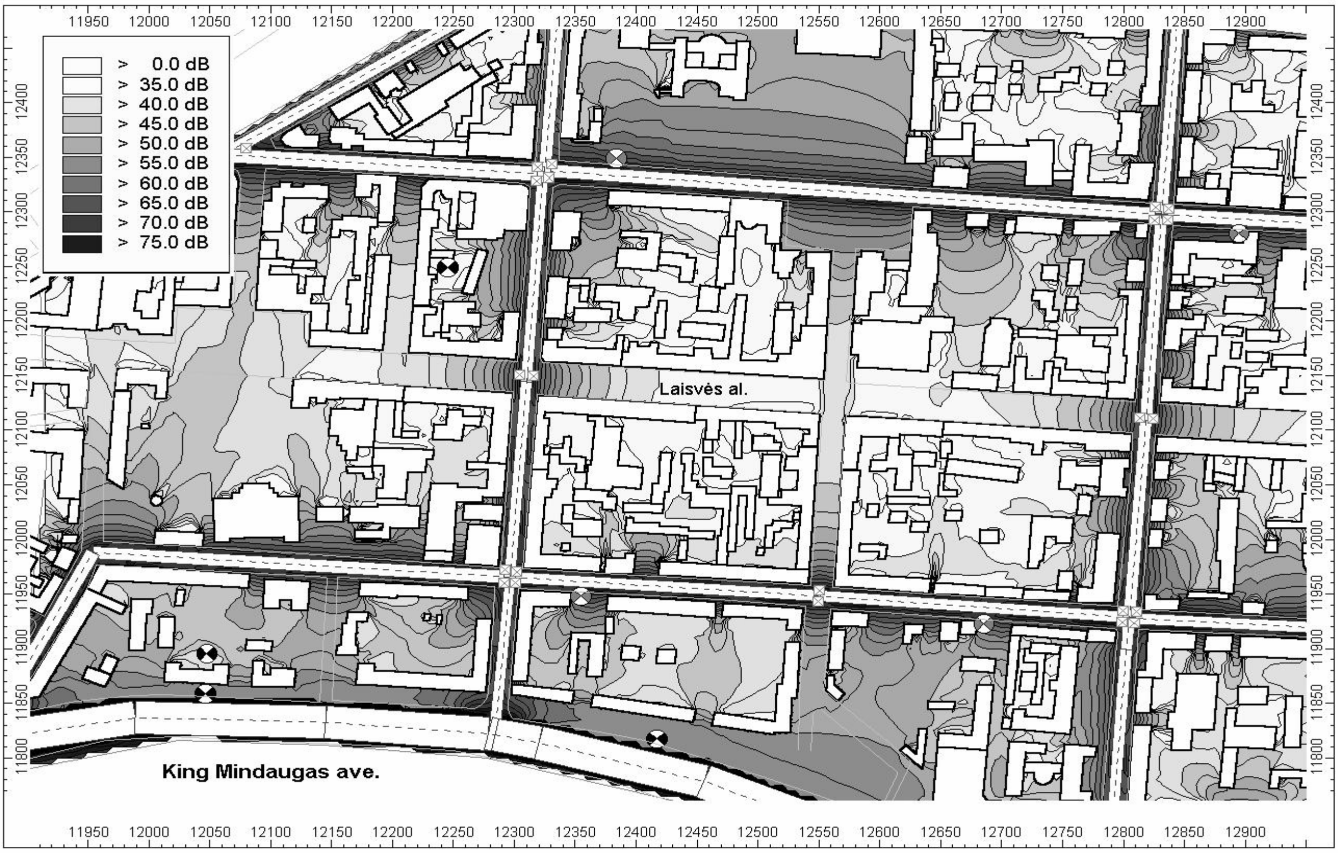

Fig. 4 The fragment of the street traffic noise map (predictive mapping, redistributed traffic flows)

The average equivalent noise level values at the distance of 3 m from the outside track varied from 65.6 dB(A) (the street segment 032-033-034) to 79.1 dB(A) on King Mindaugas av.

The predictive mapping involved (scenario I) the same composition of traffic flows, however the speed limit was raised to 60km/h (see Fig. 3). Generally speaking, the immission points (scenario I) exposed to traffic noise were effected by 1.1 dB(A) higher equivalent noise level, respectively L_{eq} from opposite facades increased by 1.2 dB(A) in comparison to the initial noise map (scenario 0).

The predictive modeling with redistributed traffic flows (scenario II) was performed in the context of Strategic Traffic System Plan of Kaunas city (municipality enterprise "Kauno planas*")*. At the planning level it was considered that integrated networks of public transport would be dominant in the central part of the city [16, 17]. The modeled scenario eliminated 90% of light vehicles (sized up within scenario 0) replacing them with up-to-date buses, as the alternative mode of transport. The authors came to the conclusion that the type of the traffic flow described in the method "XPS 31-133" corresponds to fluid continuous flow. The speed limit in the central part of the city was considered to be 50 km/h, except the King Mindaugas ave. with speed limit v_{max} = 60 km/h. Fig. 4 presents fragment of noise mapping (scenario II) for the central part of Kaunas. Comparing scenario I, the modeled equivalent noise levels at immission points exposed to direct street traffic in average decreased by 6.8dB(A), respectively L_{eq} values from opposite facades of buildings were by 1.0 dB(A) lower.

6. Conclusions

An analysis of alternative noise maps (scenarios), based on the results of noise level measurement-modelling results, should be considered an important component of urban traffic planning procedure. Special care should be taken to elaborate precise datasets for both light and heavy-duty vehicles. Predictive modelling with redistributed traffic flows requires further elaboration of acoustical equivalent for different modes of transport, which has a direct influence on validation of the model.

This study shows that the description of the traffic flow type gives uncertainty when applying to speed correction. Therefore, the quantitative evaluation of various types of traffic flows is essential for practical applications.

Acknowledgement

The authors would like to express their sincere gratitude to Elena Taločkaitė from Environmental Centre for Administration and Technology (ECAT), Lithuania, for her help in noise maps modelling.

References

1. **Coelho, B. J. L**. Noise maps and noise action plans for urban noise management.- Proc. of the 10th Int. congress on Sound and Vibration.- Stockholm, 2003, v.5, p.2655-2663.
2. Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment and management of environmental noise.- Official J. of the European Communities, 2002, L189, p.12-25.
3. **Pasch, V., Mosconi, P., Yanitelli, M., Cabanellas, S., Vazquez, J., Rall, J.C.** Spectral information in noise-mapping: An exploratory study.- Proc. of the 1st Pan-American/Iberian Meeting on Acoustics.- Cancun, 2002, p.1213-1220.
4. **Kluijver, H., Stoter, J.** Noise mapping and GIS: optimizing quality and efficiency of noise effect studies. Computers, Environment and Urban Systems, 2003, v.27, p.85-102.
5. **Heinonen-Guzejev, M., Vourinen, H. S., Kaprio, J., Heikkila, K., Mussalo-Rauhamaa, H.** Self-report of transportation noise exposure, annoyance and noise sensitivity in relation to noise map information.- J. of Sound and Vibration, 2000, v.234, issue 2, p.191-206.
6. Commission recommendation C(2003)2807 concerning the guidelines on the revised interim computation methods for industrial noise, aircraft noise, road traffic noise and railway noise, and related emission data.- Official J. of the European Union, 2003, L212/49, p.49-64.
7. Europe's Environment, **eds D. Stanners, P. Bourdeau** European Environment Agency.- Copenhagen, 1995, p. 359-364.
8. Traffic intensity counting by means of automated traffic counters-classifiers. Transport and Road Research Institute Report.- Kaunas, 2001, p.93. [in Lithuanian].
9. **Nooralahigan, A. Y., Kirby, H. R., McKeown, D.** Vehicle classification by acoustic signature.- J. of Mathematical Computational Modeling, 1995, v. 27, p. 205-214.
10. **Daganzo, C. F.** A simple traffic analysis procedure.- Networks and Spatial Economics, 1997, v.1, p.77-101.
11. Investigation of traffic intensity in crossroads of Kaunas. Transport and Road Research Institute Report.- Kaunas, 2004, p.53 [in Lithuanian].
12. **Larson Davis**. Reference Manual. System 824 TM. Precision Sound Level Meter and Real Time Analyzer, 2000.
13. **Cadna A.** Datacustic GmbH Technical Documentation and Training for Immission Protection.-Munich, 1998.
14. RLS-90 Richtlinien fur den Larmschutz an Strasen. Bonn: Der Bundesminister fur Verkehr, Abteilung Strasenbau, 1990.
15. **Wetzel, E., Nicolas, J., Andre, Ph., Boreux, J. J.** Modeling the propagation pathway of street-traffic noise: practical comparison of German guidelines and real-world measurements.- J. of Applied Acoustics, 1999, v.57, p.97-107.
16. **Kliučininkas, L.** Modeling noise effects of urban traffic flows management. Proc. of the 10th Int. Congress on Sound and Vibration.- Stockholm, 2003, v.5, p.2765 – 2773.
17. UK Department for Environment, Food and Rural Affairs. Tackling Background Noise from Transport and Industry. DEFRA Report 2002, p.204.

L. Kliučininkas, D. Šaliūnas

TRIUKŠMO ŽEMĖLAPIŲ TAIKYMAS MIESTO TRANSPORTO SRAUTŲ VALDYMUI

R e z i u m ė

Straipsnyje aptariama ES politika, susijusi su urbanizuotų teritorijų transporto triukšmo vertinimu ir valdymu. Pritaikius kompiuterinę modeliavimo programą *Cadna A* buvo sudaryti transporto triukšmo žemėlapiai Kauno miesto centrinei daliai. Duomenys apie transporto srautus, pastatų aukštį, greičio apribojimus, bei *in situ* transporto triukšmo lygių matavimų duomenys buvo naudojami triukšmo sklaidos modeliavimui. Triukšmo lygių vertinimas buvo atliekamas vadovaujantis „XPS 31-133“ metodu, apibrėžtu Europos Komisijos rekomendacijoje C(2003)2807. Triukšmo žemėlapių formavimo metu iškilo būtinybė kiekybiškai apibrėžti transporto srauto tipą ir išplėtoti skirtingų transporto priemonių akustinio ekvivalento koncepciją. Alternatyvių triukšmo žemėlapių (scenarijų) analizė parodė, kad tyrimų rezultatai gali būti taikomi valdant miestų transporto srautus.

L. Kliučininkas, D. Šaliūnas

NOISE MAPPING FOR THE MANAGEMENT OF URBAN TRAFFIC FLOWS

S u m m a r y

This study analyses the EU policies related to the assessment and management of traffic noise in urban areas. The analysis is based on the application of noise maps using *Cadna A* software for the central part of Kaunas city, Lithuania. Data on the traffic flows, height of buildings, speed limits combined with actual noise measurements are used as an input to the dispersion model. The assessment of noise is based on the guidelines of the method 'XPS 31-133' defined in the European Commission Recommendation C(2003)2807. The formation of noise maps has raised the need for qualitative determination of traffic flow type and the elaboration of acoustical equivalent concept for different modes of transport. An analysis of alternative noise maps (scenarios) should be considered as an important component of urban traffic flows management.

Л. Ключининкас, Д. Шалюнас

ПРИМЕНЕНИЕ ШУМОВЫХ КАРТ ДЛЯ УПРАВЛЕНИЯ ГОРОДСКИМИ ТРАНСПОРТНЫМИ ПОТОКАМИ

Р е з ю м е

В настоящей статье обсуждается политика ЕС по оценке и управлению городским транспортным шумом. При помощи компютерной программы *Cadna A* авторы разработали шумовые карты для центральной части города Каунас, Литва. Данные о транспортных потоках, высотности строений, ограничениях скорости, а также данные измерений уровня шума, были использованы для моделирования рассеивания шумовых волн. Оценка уровней шума производилась на основе метода „XPS 31-133“ представленного Европейской Комиссией в рекомендации C(2003) 2807. Во время разработки шумовых карт авторы столкнулись с необходимостью количественной оценки типа транспортного потока и совершенствованием концепции эквивалента транспортного шума для разных транспортных средств. Анализ альтернативных шумовых карт (сценариев) создаёт возможность применения результатов исследования при управлении городскими транспортными потоками.

Received December 21, 2005

DOI: 10.5755/j02.mech.14671