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MODELLING THE NOISE GENERATED BY RAILWAY TRANSPORT: STATISTICAL ANALYSIS OF MODELLING RESULTS APPLYING *CADNAA* AND *IMMI* PROGRAMS

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Abstract. To avoid a negative impact on human health, Lithuania, alike other countries, pays full attention to reducing noise in the environment. One of the implemented actions against noise sources and the way to reduce it is a composition of strategic maps. Research focuses on the performance of modelling noise dispersion employing *CadnaA* and *IMMI* software and proposes the analysis of the actuarial reliability of the above-mentioned programs. The dispersion of the noise generated by railway transport has been modelled in the dwelling area of Klaipeda railway station. The chosen zone covers a sector of 500 m in length and is situated at the distance of 150–200 m from this sector. Modelling noise dispersion maps applying both programs displayed that the maximum level of noise caused by day and night railway transport was registered near railway during both periods of time and varied from 75 to 80 dBA, whereas at the locations of 150–200 m that are more distant from the railway line, the level of noise gradually reduces and reaches the level of 35–50 dBA in cases *CadnaA* or *IMMI* programs are introduced. Program *STATISTICA* along with *Mann Whitney U* and *Kolmogorov–Smirnov D* non-parametric statistical tests were used for assessing the actuarial reliability of modelling programs used for noise dispersion. The obtained data indicate that the level of significance *p* was not exceeding the value of 0.05 in all cases.

Keywords: railway noise, noise level, *CadnaA*, *IMMI*.

1. Introduction

Although noise is related to various activities of people, the noise of the roadway, railway and air freight generates the most significant impact on human being (Lercher *et al.* 1996).

Cumulative noise pollution depends on a cumulative number of vehicles in the environment (Gražulevičienė, Bendokienė 2009). A transport system, including rail freight is one of the major noise sources causing a negative influence on the environment. Therefore, no sufficient attention to the above introduced problem has been given (Bazaras, Rutka 2002).

The noise generated by rolling-stock has remained an important ecological problem. Railway transport, especially freight trains create noise up to 100 dBA moving even at low speed. Such noise exceeds allowable limits in residential and industrial buildings. Thus, the problem of this kind of railway noise is a significant issue in villages or cities (Sakalauskas 1997).

Noise influence on the human organism depends on noise character (intensity, range of frequency, etc.), the period and the duration of effect likewise individual characteristics of the organism: age, health and noise sensitivity (Ašmenskas *et al.* 1997).

Constant noise affects the nervous system and evokes stress. Therefore, World Health Organization (WHO) classified noise as a physical factor inducing the emersion and amplification of the industrial disease (Butkus, Grubliauskas 2008).

WHO emphasizes the following problems caused by noise: auricular injury, speech incomprehension, disorders of sleep and physical functions, letup of science achievement, social and behaviour alteration (irritability, aggression, etc.) (Lietuvos sveikata … 2010).

A noisy environment may irritate you at work or while having a rest, causes fatigue, reduces attention and reflexes, negatively affects the nervous system (Jaskelevičius, Užpelkienė 2008).

It is hard to communicate, hear sound signals, memorize information and concentrate in the noisy environment (Stansfeld *et al.* 2000). Scientific research indicates that noise at working place raises arterial blood pressure which increases the risk of ischemic heart disease (Babisch 1998; Van Kempen *et al.* 2002).

Environmental noise disturbs sleep, and therefore blood pressure increases and rapid pulse emerges (Passchier-Vermeer, W.; Passchier, W. F. 2000). The latest scientific investigations state that noise causes serious risk for people's health if the level of noise exceeds 65 dBA during the day and 55 dBA during the night period (Butkus *et al.* 2004).

In terms of railways, the countries of the European Union perceive the concept of environmental safety as protection from harmful impact upon people, as a reduction in risk factor while moving and sorting dangerous cargo, as noise and vibration compression and as the way to save energy resources (Pilipavičiūtė, Bakas 1998).

A number of countries, including those of Western Europe assess technical conditions of transport (various sorts of rolling-stock, road, water and air transport) and pay careful attention to the noise generated by railway transport. Therefore, more focus is given for research on noise formation processes and noise source detection, reduction, isolation, etc. (Klibavičius 2008).

Noise is a relevant problem faced worldwide (Baltrėnas *et al*. 2010). Lithuania, likewise other countries, properly concentrates on reducing environmental noise and on avoiding a negative impact on health and environment quality (Ustinavičienė *et al*. 2004).

One of the ways to implement actions against noise is creating strategic maps. (Baltrėnas, Ščupakas 2007).

Noise control in Europe is maintained in accordance with directive 2002/49/EB Environmental noise management approved on 25 June 2002.

According to the results of noise mapping, the EU Member States 1) confirm action plans; 2) determine how to prevent environmental noise reducing it in any required area, particularly where influence levels could harm people health; 3) maintain a suitable environmental noise level (2002/49/EB).

The strategic maps of noise are designed for a general assessment of noise impact generated by various sources in a particular area or for general prediction (Mačiūnas *et al*. 2007).

Computer program *CadnaA* is used for modelling and forecasting noise dispersion.

CadnaA is a computer program designed for calculating, rendering, assessing and forecasting induced noise and air pollution (Environmental condition...2003).

Program *IMMI* produced by German company Wolfel could also be used for mapping railway noise.

The level and spread of railway noise are computed according to the number of wagons per hour relative to the type of the train. Data is divided into three time intervals: day, afternoon and night.

The calculation of the level and spread of railway noise is a subject to the number of particular type wagons per hour (separating data into 3 time intervals: day, afternoon and night), train speed, braking sector and rail type (Drewes *et al.* 2003).

The performed research is targeted at performing the simulation of noise spread applying *CadnaA* and *IMMI* programs and proposing the analysis of statistical reliability.

2. Method and object of research

Research demonstrates the noise generated by railway transport at the residential area of Klaipeda railway station covering a railway section of 500 m at the distance of 150–200 m from rails.

The goal of research is the performance of a numerical simulation using *CadnaA* and *IMMI* programs and reliability evaluation of prognosis for the spread of noise.

The conducted research employed the above introduced two programs used for modelling noise pollution in a number of organizations and universities, so that to show interest in finding difference between them.

Both programs are using similar input data.

CadnaA is a program for simulating the spread of noise and is an effective tool for modelling environmental noise. The program was designed for the experts in the fields of acoustics and software. The assessment of noise emission using *CadnaA* program is performed under specifications of national and international legislation (Computer Aided… 2006). The discussed software has many advantages, especially in comparison with other programmable noise forecasting equipment used in Lithuania (Vaišis, Januševičius 2009).

The dimensions of buildings are the main parameters for creating a building model (Computer Aided… 2006).

Noise maps are created by excluding noise levels and points placed in the territory in *CadnaA* program. The points can be in particular of absolute height. Noise maps can be drawn taking the required step (Computer Aided… 2006).

The performed research has also referred to *IMMI* software designed by German company *Wolfel* operating computing module SRM II – 1996 used for the spread of railway noise. The module comprises Dutch methodology RMVR 1996, *Reken – en Meetvoorschrift Railverkeerslawaai "96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer", 20 November 1996 (RMR),* including detailed calculation scheme SRM II recommended by Noise Control Directive 2002/49/EB (Drewes *et al.* 2003).

IMMI contains a number of packages and can be configured according to user demands. Software support starts with the input of information and covers all levels of calculation, documentation and data up the output of the colourful maps of noise.

The calculation of the level and spread of railway noise is a subject to the number of wagons of a particular type per hour (separating data into 3 time intervals: day, afternoon and night), train speed, braking sector and rail type.

Software also includes the assessment of environment relief, the influence of noise barriers and screens, building height and construction materials (Drewes *et al.* 2003).

The input data required for modelling is the number of passing trains per hour at different times depending on the type of the train selected on the basis of annual activity report delivered by *AB Lietuvos geležinkeliai*. The heights of buildings and roads, the length and width of rail lines, the position coordinates of specific objects (in our case, a railway track) have been selected using a topographical map of the area. For modelling purposes, input data on surface roughness, wind strength and direction have been applied.

Output data contain the maps of the spread of chromatic noise considering different intervals of days and are received after entering the required input data. The study analyzes the modelling results of the day and night period.

For statistical analysis, 50 examples of results indicating the noise level scattered throughout the examined site were chosen (Fig. 2–5).

The noise levels are random chosen. The points the noise level is measured has to match in all four maps, i.e. the value of the first level of noise from the first map of the spread of noise has to be chosen considering the same position as the rest of the three maps. This way, the rest of 49 noise levels have been chosen.

Statistical sets of information on day and the night periods have been created using data obtained from both types of software.

Primarily, hypothesis that data are fairly distributed is checked. *Shapiro–Wilk* test is used for verifying regularity. Data on analysis is genuine if significance level $p < 0.05$. In case of irregular data distribution, the *Spearman* correlation coefficient is used for describing a correlation link between two samples.

3. Results of research

The spread of the noise generated by railway transport in Klaipėda railway station residential area (Fig. 1) covering 500 m of the railway section at the distance of 150–200 m away from rails has been simulated applying *CadnaA* and *IMMI* programs.

Fig. 1. The researched residential area at the railway station in Klaipėda

The modelling programs include the heights of buildings, terrain relief, types of trains, the number of trains per hour and the quantity of braking and accelerating trains in general transport flow.

Road transport is not involved in simulating the noise level of the residential area situated near Klaipėda railway station.

A two day period, including daytime and nighttime is analyzed. The nighttime noise level is important for the residential area and has to be controlled not to exceed limits and not to cause discomfort for resting people.

The spread of the noise generated by railway transport in the residential area during daytime is shown in Figures 2 and 3 (2 – the results obtained using *CadnaA* modelling; 3 – the results obtained using *IMMI* modelling).

Both models are generated for assessing the noise level of trains passing the residential territory.

The given maps of noise distribution can predict the level of the noise affecting the residents at a particular distance from the railway track. The provided prediction offers a possibility of choosing measures for reducing noise in the required areas.

Figure 2 shows that the maximum noise level, i.e. > 75 dBA is beside railway tracks and gradually declines while spreading in all directions. Moving away approximately150–200 m from the railway track, the noise level is reduced to 35 dBA. There are no noise reduction implements in this territory. Therefore, only buildings may function as noise barrier.

Figure 3 displays the spread of noise simulated by *IMMI* program, which slightly differs from Figure 2 showing the *CadnaA* model. The noise level in the *IMMI* model does not change that gradually while moving away from the railway track compared to the *CadnaA* model. The models differently evaluate some of the factors such as relief and the level of background noise, and therefore visual and numerical expressions of the results are diverse.

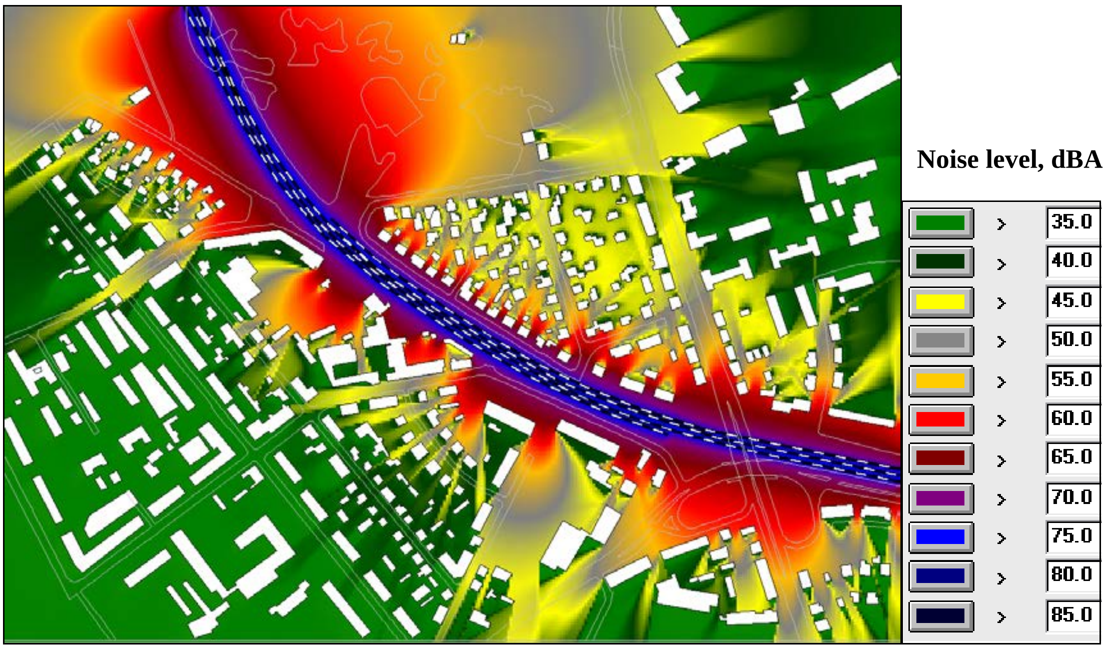

Fig. 2. The dispersion of railway noise over the residential area during daytime applying program *CadnaA*

Fig. 3. The dispersion of railway noise over the residential area during daytime applying program *IMMI*

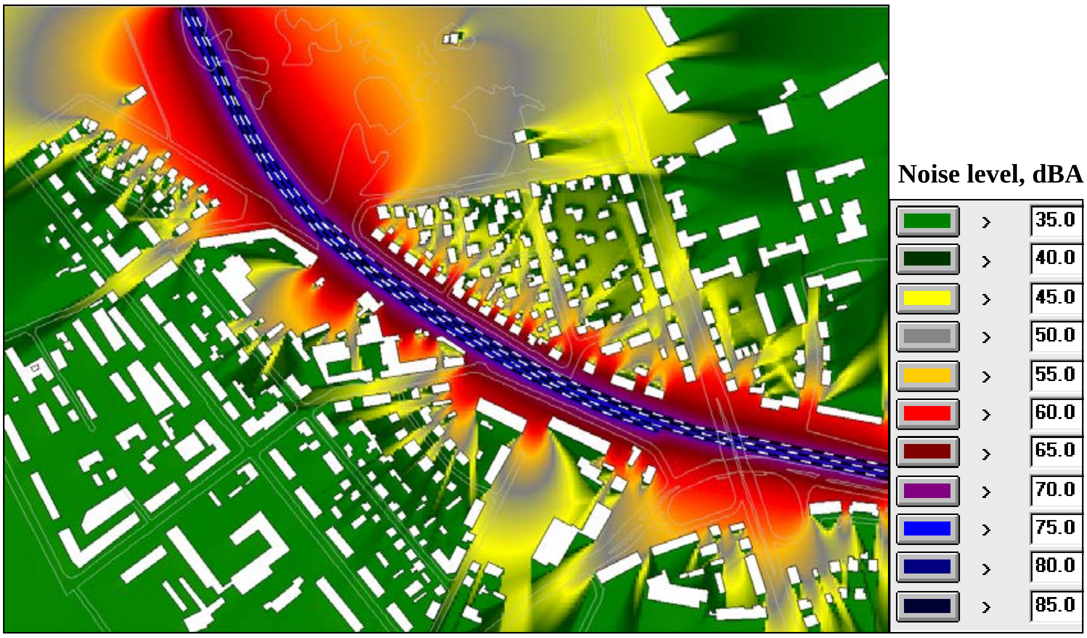

Fig. 4. The dispersion of railway noise over the residential area during nighttime applying program *CadnaA*

The maximum noise level in the *IMMI* model as well as in *CadnaA`s* dominates closely to the railway track; however, in the *IMMI* model, the noise level exceeds 80 dBA. The difference is 5 dBA between two programs.

This difference remains almost in the whole territory, though in some places it increases up to 10–15 dB, and elsewhere, for example, near the residential houses situated 20 m from the railway track, the noise level reaches 70–75 dBA in both *CadnaA* and *IMMI* models.

Next, the models showing the spread of nighttime noise in both programs are presented (Figs 4 and 5, *CadnaA* and *IMMI* models respectively).

The spread of daytime noise basically has no difference comparing to that generated at nighttime, but the major difference is that the noise of passenger trains is not taken into account during the night. There are no passenger trains running at night in the residential area of Klaipeda railway station.

The maps showing the spread of nose during nighttime (Fig. 4) and daytime confirm that the maximum noise level dominates nearby railway track and beside the residential houses situated at the distance of 20 m from the railway track. The noise level at this location dominates in the range of 65–75 dBA.

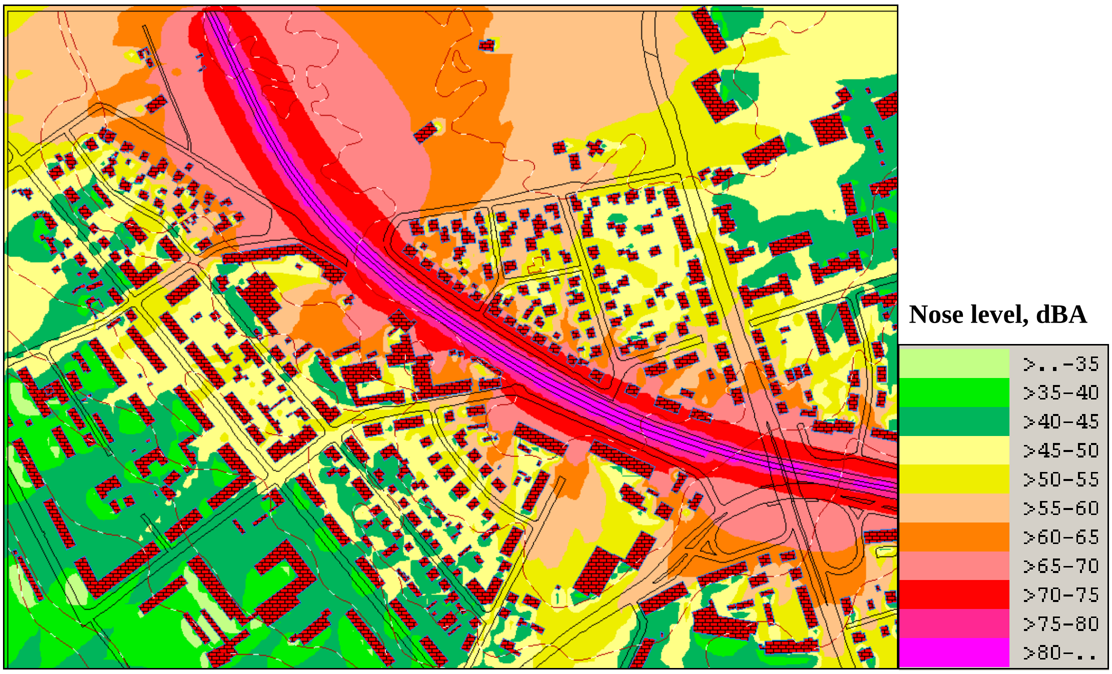

Fig. 5. The dispersion of railway noise over the residential area during nighttime applying program *IMM*

A comparison of such level of noise to the *IMMI* model (Fig. 5) shows that the noise level at the same location varies in the range of 70–80 dBA. As for daytime, the difference of 5 dBA between the results of modelling programs can be noticed. All results of the *IMMI* program are higher than those achieved applying *CadnaA* in the whole territory.

When moving 150–200 m away from the railway track, the noise level is reduced to 35–50 dBA regarding both *CadnaA* and *IMMI* programs for the models showing the spread of noise at night (Figs 4 and 5).

With reference to the modelling results of the spread of noise, statistical checking is performed to ascertain which of the two programs *CadnaA* or *IMMI* is providing more reliable results and which one is more appropriate for making prognosis.

Software *STATISTICA* is used for statistical analysis.

Testing the normality of distribution analysis has revealed that the analyzed data of both programs is abnormally distributed, and therefore tools and tests of nonparametric statistics are used.

The difference between modelling programs is examined using two nonparametric statistics tests – *Mann Whitney U* and *Kolmogorov–Smirnov D*.

The accomplished statistical analysis indicates that the results of both programs for noise emission at all locations during daytime have difference, i.e. reliable discrepancy (*U test* $p = 0.0123$; *D test* $p = 0.025$).

The analysis also demonstrates that the results provided by the programs for modelling the noise generated by railway transport are different. Similar tendencies emerged after performing similar tests on noise emissions during nighttime (*U test* $p = 0.003$; *D test* $p = 0.001$), and only reliable discrepancy between modelling results is greater.

Data on daytime and nighttime modelling has a reliable difference. The difference between the obtained results is insignificant; on average, daytime results differ by 3.18±0.26 dBA, whereas those of nighttime make 4.08±0.33 dBA.

In both cases, *IMMI* program has displayed higher noise levels.

There was a link between the results identified during the process of assessing both modelling programs. A clear connection between the results of both programs was defined for every modelling period. The *Spearman* correlation coefficient made $R = 0.93$ ($p < 0.05$) during daytime and $R = 0.89$ ($p < 0.05$) during nighttime.

The results of analysis on data link indicate that the calculation outcome of both programs has a close contact and differs in numerical expression.

The calculation of different correlation coefficients can be caused by the shortcoming of task methodology (selection and assessment of analyzed spots), mathematical algorithm difference of modelling programs.

The results of statistical analysis clearly demonstrate that both *CadnaA* modelling program and *IMMI* software reliably perform modelling the spread of noise. However, the existing difference of 3–4.5 dBA could have an impact on further prognosis for the spread of noise.

Similarly, hygiene standards provide that under strict allowable noise values, the difference of 3–4.5 dBA could have a significant impact on implementing measures for noise reduction and on restriction of pursued activity. Therefore, the necessity of more explicit analysis between modelling and the real results of the spread of noise occurs. Thus, a possibility of evaluating a certain program for the purpose of using it for further research arises.

4. Conclusions

1. The paper has considered the issues of modelling the spread of the noise generated by railway transport during daytime and nighttime applying *CadnaA* programs and *IMMI*. The maximum level of noise dominates near the railway track in both analyzed periods of time. Noise ranges in the diapason of 75–80 dBA and is provided in the maps of the spread of noise indicated by both programs.

2. While moving away 150–200 m from the railway track, the noise level is gradually reduced to 35–50 dBA in both *CadnaA* and *IMMI* programs during nighttime and daytime.

3. The difference between the records of the programs is 5 dBA and may increase up to 10–15 dBA. Near the residential houses situated 20 m from the railway track, the noise level reaches 70–75 dBA in both *CadnaA* and *IMMI* models, difference gets even to 0 decibel.

4. After accomplishing *Mann Whitney U* test on modelling data on the daytime period, the level of significance $p = 0.0123$. The same test on nighttime results showed $p > 0.05$, i.e. $p = 0.003$. A test of *Kolmogorov–Smirnov D* indicated that $p = 0.001$. The results of modelling the spread of noise during the daytime and nighttime periods show a reliable difference.

5. The difference between the obtained results is insignificant: on average, it makes 3.18±0.26 dBA in the daytime period and 4.08±0.33 dBA in the nighttime period.

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GELEŽINKELIO TRANSPORTO KELIAMO TRIUKŠMO MODELIAVIMAS IR STATISTINĖ REZULTATŲ ANALIZĖ

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Santrauka

Lietuvoje, kaip ir kitose šalyse, daug dėmesio skiriama triukšmui aplinkoje mažinti siekiant išvengti jo neigiamo poveikio sveikatai, aplinkos kokybei. Viena iš triukšmo ir jo poveikio mažinimo priemonių yra strateginių žemėlapių sudarymas. Tyrimo tikslas – atlikti triukšmo sklaidos modeliavimą programomis *CadnaA* ir *IMMI* bei pateikti šių programų statistinio patikimumo analizę. Modeliuojama geležinkelio transporto triukšmo sklaida Klaipėdos geležinkelio stoties gyvenamojoje teritorijoje 500 m ilgio geležinkelio ruože ir per 150–200 m nuo jo. Modeliuojant geležinkelio transporto dieną ir naktį sukeliamo triukšmo sklaidą nustatyta, jog abiem nagrinėtais laikotarpiais abiejų programų pateiktuose triukšmo sklaidos žemėlapiuose didžiausias triukšmo lygis – nuo 75 iki 80 dBA fiksuojamas šalia geležinkelio bėgių. Tolstant nuo bėgių, triukšmo lygis tolygiai mažėja, 150–200 m atstumu siekia 35–50 dBA ir *CadnaA*, ir *IMMI* triukšmo sklaidos modeliuose – ir dieną, ir naktį. Triukšmo sklaidos modeliavimo programų patikimumas vertintas programa *STATISTICA* bei *Mann Whitney U* ir *Kolmogorov–Smirnov D* neparametrinės statistikos testais. Šie rodė, jog reikšmingumo lygmuo p visais atvejais neviršijo 0,05 reikšmės. Todėl teigiama, kad abiejų modeliavimo programų pateikti rezultatai patikimi.

Reikšminiai žodžiai: geležinkelio triukšmas, triukšmo lygis, *CadnaA*, *IMMI*.

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