Acoustic Modelling of Sport and Hunting Shooting Ranges in the Aspect of Shaping Noise Emissions Into the Environment

doi:10.2478/mape-2020-0027
Date of submission to the Editor: 03/2020
Date of acceptance by the Editor: 06/2020
MAPE 2020, volume 3, issue 1, pp. 308-319

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INTRODUCTION

Over the past few years, very dynamic development of shooting sports has been observed. This is due to the greater accessibility of citizens to weapons and the specificity of permits issued (e.g. weapons for sporting purposes), which forces weapon owners to actively implement shooting sport through participation in shooting competitions and tournaments. Recreational shooting has also recently become very fashionable and, above all, available to citizens (sport, hunting, black powder, long distance shooting, etc.). Following the growing popularity of shooting, the number of new shooting ranges is also growing, where the above-mentioned passions can be realized. Due to the necessary space, however, most of the shooting takes place in open shooting ranges, which makes the roar of shots heard in the immediate vicinity. Therefore, an important problem is the negative acoustic impact of the shooting range on the environment, especially where residential buildings are located nearby. Limiting the acoustic nuisance of shooting ranges is possible by appropriate location and orientation of the shooting axes, limiting the intensity of firing on individual axes, or using appropriate shielding elements. Conscious shaping of the acoustic climate around the shooting range requires modelling of existing noise sources and calculations of noise propagation into the environment using available acoustic software, such as: CadnaA, SoundPlan, LimaA, etc.

PRESENT STATE ANALYSIS

Excessive noise in the environment has been a significant problem for many years and we are trying to fight it. However, we are talking here about traffic and industrial noise. The acoustic impact of shooting ranges is, however, a relatively new phenomenon, associated with the emergence of an increasing number of shooting ranges, reactivation of old shooting ranges and an increasing number of people practicing recreational and sport shooting. Regular trainings takes place in their area, and the practisers are: police, prison services, security guards, etc. Therefore, intensification of shooting and bringing residential buildings closer to the existing shooting ranges causes the increase of local

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conflicts with residents. At the moment, the modelling of shooting ranges in terms of noise emissions in Poland is not dealt with by any scientific centre, there are no official guidelines for the modelling of impulse noise associated with the operation of shooting ranges and their acoustic assessment. Although there is an ISO 17201-3 (ISO 17201-3:2010, 2010) standard describing the general principles of calculating the sound level in the shooting range environment based on measurements and calculations of exposure levels of impulse sounds, it does not contain guidelines for the acoustic modelling of noise sources taking into account the type and specificity of shooting competition.

In the light of Polish legislation, pursuant to the Regulation of the Minister of the Environment of 14 June 2007 on permissible noise levels in the environment (Dz. U. 2014, poz. 112, 2014), the shooting range facility can be treated in accordance with Table 1 of the abovementioned of the Regulation as "Other objects and activities as a source of noise", for which noise limit values are expressed as L_{AeqD} and L_{AeqN} indicators, depending on the type and purpose of the area where the buildings are exposed to noise. As a rule, shooting ranges do not work at night, although night shooting becomes more and more fashionable. Measurements of noise emitted to the environment from the shooting range facility are carried out on the basis of the Regulation of the Environment Minister on the requirements for measuring emissions and measuring the amount of water drawn (Dz. U. 2014, poz. 1542, 2014). These measurements are carried out in the area subject to noise protection in accordance with Annex 7 or 8 depending on the noise qualification and PN-ISO 10843 (PN-ISO 10843, 2002). As mentioned earlier, Polish legislation lacks detailed guidelines regarding modelling of shooting range noise. Emission models described in PN-EN ISO 9613-1 (PN-ISO 9613-1, 2000) and PN-EN ISO 9613-2 (PN-ISO 9613-2, 2002) can be used to assess noise propagation in the environment. The available software can be also used for acoustic calculations having the abovementioned implemented calculation algorithms. Examples of their applications are widely described in (Boczkowski, 2012, 2015). However, there are no guidelines and studies describing how to take the acoustic power of noise sources and their directivity, how to model individual shooting axes and what to take the frequency of pulses (shots) depending on the type of competition. Each of the axes and the competition played on them has different characteristics.

Therefore, there is a need to develop guidelines for modelling noise emitted by individual shooting axes, depending on the type of competition, the number of shooters and the intensity of shooting (e.g. training, competition, learning how to shoot, etc.). On this basis, it will be possible to carry out an analysis of sound propagation from a selected shooting axis to the external environment, analyse cumulative noise from several shooting axes simultaneously, or model the location of selected shooting axes in such a way as to minimize the negative impact on the acoustic climate. Using the cumulative models described in (Wall et al., 2019), it will be possible to determine the exposure of individual shooters or instructors or referees to excessive noise. The simplest cumulative models are based on typical energy summation from different sources, taking into account the number of elementary events or the time of exposure.

TYPICAL SHOOTING COMPETITIONS PLAYED AT SHOOTING RANGES

Typical shooting competitions played in open ground, depending on the type of weapon, can be divided into bullet and shot competition. Among sporting bullet competitions, mainly target shooting at distances of 25 and 50 m (for short weapons) and 50 and 100 m (for long weapons) are played. Some shooting ranges have shooting axes with greater distances, e.g. 200, 300, 600 m or axes for dynamic shooting. Hunting bullet competitions are *deer* and *boar*. The *deer* competition is shot at a scaled roe deer goat and fox at a distance of 100m using a shooting post, while *the boar* competition consists of hitting the scored shield with a drawing of a boar from a distance of 50 m while moving the scale left and right.

Among the shot competition one can mention typical sport competitions such as *trap, double trap* or *skeet* and hunting competitions: *hunting trap, hunting skeet, pheasant, hare*. Most of these competitions involve shooting at moving targets (clay pigeons), which are thrown using special machines along a fixed trajectory. In each competition, shooting takes place at different distances and to other targets trajectories.

In recent years parcour shooting has been developing dynamically in the world and in Poland. This is shooting at moving targets with a shotgun. The targets are thrown from the machines on the shooting axis in various ways, at different angles, directions, etc. On each axis you shoot from five shooting stands to 25 targets. Depending on the distance to the targets and shooting rules, two main competitions are distinguished, namely: Compak Sporting and Sporting.

The article will not discuss in detail the rules of shooting individual competitions, because this is not the purpose of this study. A multitude of the above competition, different types of weapons used, different calibres, shot weights, machine settings, etc. cause that the emission of noise into the environment when firing each of them is completely different. Each of these competitions also has a number of common features that can be used in acoustic modelling. The rest of the article will present a description of *the hunting trap* competition and an example of acoustic noise emission modelling during its play.

DESCRIPTION OF *THE HUNTING TRAP* COMPETITION

Hunting trap is a shot competition played in open space. It takes around 15 minutes to play in it. A group of six shooters takes part in it simultaneously, who shoot up to 20 targets from five shooting positions (one pending position). Shooting takes place in the following order: first all shooters from all positions shoot at a single target, then from all positions to the doublet of targets (2 targets flying one after the other) and at the very end all shoot at 5 targets from the stalk. Shooting takes place with bock shotguns (vertical shotgun, over-the-barrel) in calibre 12/70 or 12/76. A maximum diameter of 2.5 mm, the maximum weight of shot is 24 or 28 grams, children and women sometimes use a weight of 21 grams. The range of the shot is a maximum of 250 m with shots fired at targets about 20-60 m away. Targets are given on command from a floating machine, at a variable vertical and horizontal angle, but within certain strictly defined frames. *The hunting trap* competition axis is shown in Fig. 1.

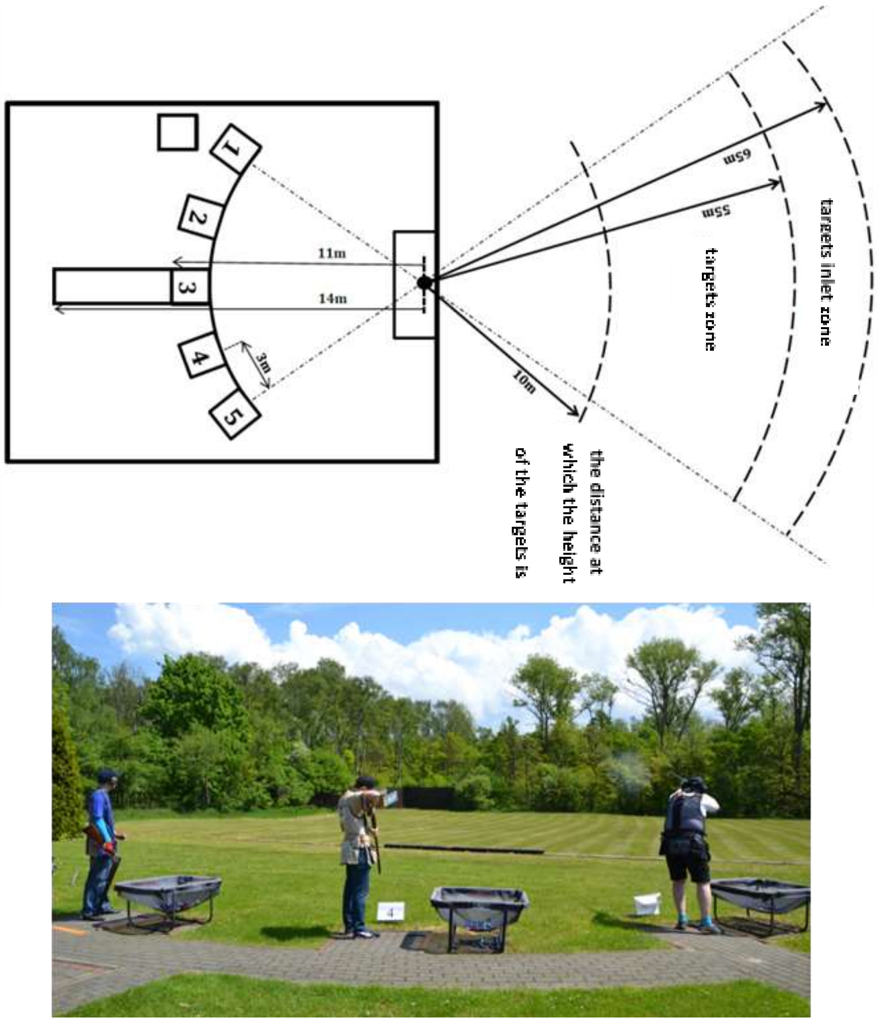

Fig. 1 Diagram and axis view for the *hunting trap* competition

NOISE MEASUREMENTS DURING SHOOTING WITH SHOTGUNS

In order to model the shooting axis described above, it is necessary to know the acoustic characteristics of a single shooting position. Therefore, the author carried out measurements of the sound level during test shots from a shotgun. The measurements were carried out at a hunting shooting range in Siemianowice Śląskie, placing the shooter in such a way that there were no elements reflecting the acoustic wave in the immediate vicinity. During the shooting, the L_{pA} sound pressure level was measured and the changes in the instantaneous SPL sound pressure level were recorded with a sampling time of 2 ms. The location of the measuring points around the shooting position is shown in Fig. 2.

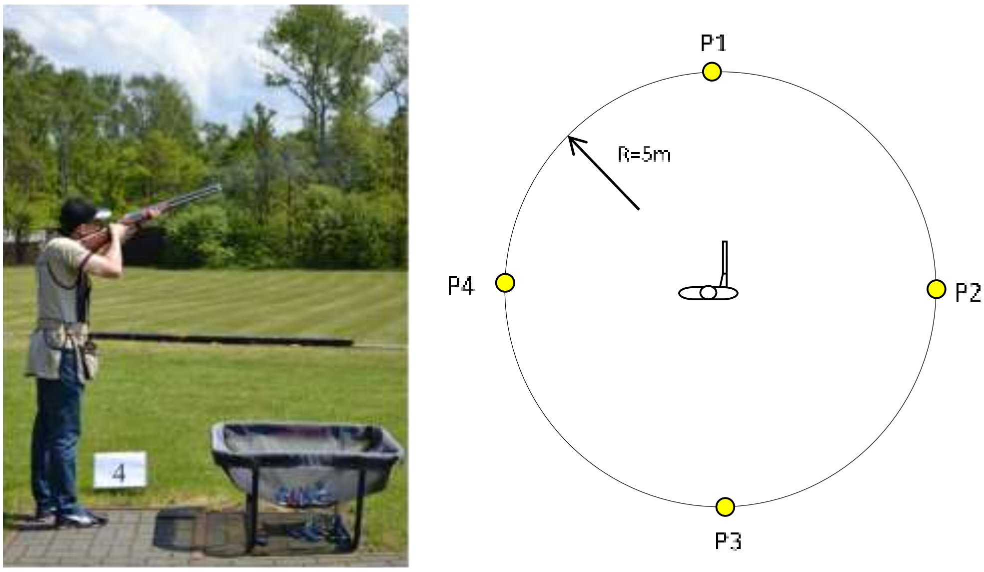

Fig. 2 Location of sound level measurement points

The obtained results of sound level measurements during the shooting are presented in Table 1. The total measurement time at each point was 30 seconds. During this time, the shooter fired two series of two shots in each series – a total of 4 shots, and the results were averaged at individual points. During real-time shootings, the shooter fires a maximum of two targets to shoot during single targets, and exactly two shots to shoot at doublets.

Table 1 The results of sound level measurements during shooting. Shotgun Krieghoff K80, ammunition FAM Pionki Trap, weight 24 grams, measuring distance 5.0 m

Measurement point	Average sound level in dBA	Maximum sound level in dBA	Peak sound level in dBC	Measurement time in sec.
P1	104.3	129.8	142.8	30
P2	93.3	116.5	139.5	30
P3	89.2	111.2	132.1	30
P4	93.8	117.1	139.8	30

Source: own study

The carried out measurements were preliminary measurements, therefore the level difference with one shot or two successive direct shots was not tested. It was assumed that the shooter fires two successive shots at each position. It is a variant presenting the maximum noise emission during shooting. This type of thorough analysis will be performed in the course of further work. It is also planned to precisely determine the directivity of the sound wave propagation with a resolution of up to 30 degrees and synchronous averaging of individual shots (pulses). The noise measurements described above allowed the modelling of directivity and the determination of the acoustic parameters of the sound source.

ACOUSTIC MODELLING OF NOISE EMISSION FROM A POINT SOURCE DURING SHOOTING

The sound power level of the noise source which is the shooter at the station during the shot for engineering needs can be calculated using the approximate method in accordance with EN ISO 3746 (PN-EN ISO 3746, 2011). This level is determined according to the formula (1):

$$L_{WA} = L_{pAśr} + 10log\frac{S}{So}, dB \quad (1)$$

where:

$L_{pAśr}$ – average sound level on the measuring surface in dB,

S – measuring surface area in m^2,

S_o – reference surface area: S_o = 1 m^2.

Because the measurements were carried out in a free field with a negligible impact of the background noise, the environmental corrections K_{1A} and K_{2A} are zero. The average sound level on the $L_{pAśr}$ measuring surface is 99.1 dB, the surface S of the hemisphere for a 5 m radius is 157 m^2, the 10logS correction is 21.9 dB, and therefore the sound power level L_{WA} = 121.0 dB.

The analysed noise source is not omnidirectional, however, because it has clearly defined directionality. According to (Puzyna, 1981, Zakrzewski and Zuchowski, 2019), the source directivity is determined by means of the directivity factor G, i.e. the ratio of the square of the sound pressure in the free field on the main axis of the source to the square of the mean pressure determined on the surface of the hemisphere with a radius r in the centre of which the source is located. The difference in sound level at a point relative to the average level is R = 10logG. The calculated source directivity coefficients are presented in Table 2, and the directivity characteristics in Fig. 3.

Table 2 Results of calculations of the source directivity coefficient

Measuring point	Sound level at the measuring point in dBA	Average sound level A on the measuring surface in dBA	Directivity factor G	Level difference R, dBA
P1	104.3	99.1	3.33	5.2
P2	93.3		0.26	-5.8
P3	89.2		0.10	-9.9
P4	93.8		0.29	-5.3

Source: own study

Based on the obtained measurement data and calculation results, the point directional source was modelled using the CadnaA software from the German company DataKustik GmbH in version 4.0. Calculations of noise emission in the environment are made based on the propagation model described in PN-ISO 9613-1 (PN-ISO 9613-1, 2000) and PN-ISO 9613-2 (PN-ISO 9613-2, 2002). This software will also be used later in the work related to acoustic modelling of the entire shooting axis.

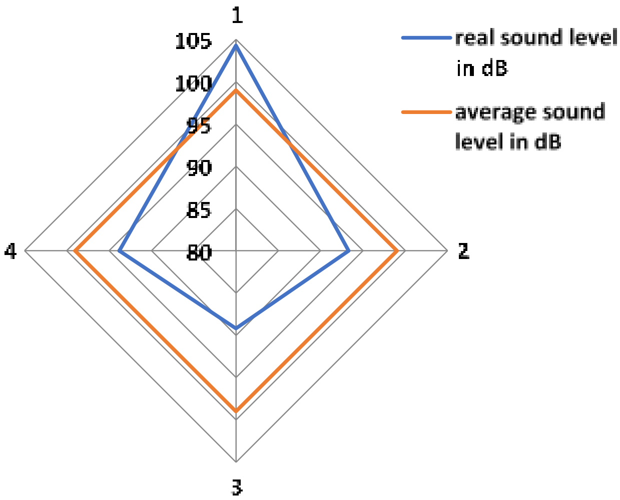

Fig. 3 Characteristic of the calculated source directivity

The CadnaA program offers the possibility of modelling the source directivity by specifying the main direction of noise emission (here it is consistent with the positive direction of the y axis) and by choosing one of the predefined directional type options.

Available options are: *building element, opening* and *chimney*. The last two distributions are best suited to model directionality of noise emissions at the shooting position, the effect of which is presented in Fig. 4 and Fig. 5.

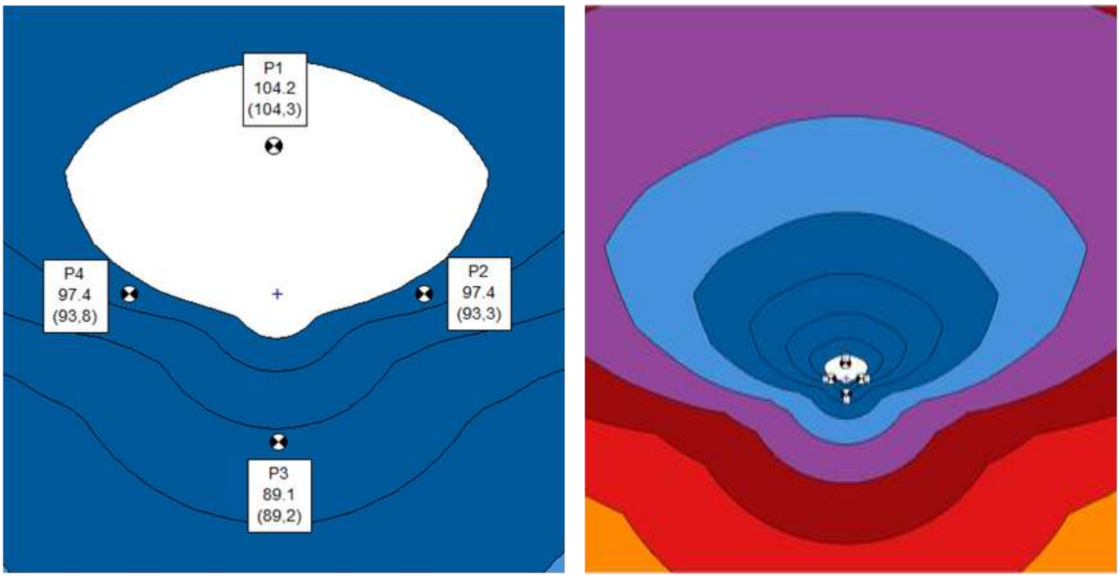

Fig. 4 Directional sound emission map for the shooting stand obtained as a result of modelling using the chimney option

Analysing the directionality characteristics presented in Figs. 4 and 5, it can be concluded that at the initial stage, the characteristics obtained using *the chimney* option seems more similar to the real one. This model perfectly reflects noise emission in the vertical direction and slightly increases in the horizontal direction. However, this is acceptable at the stage of preliminary considerations and analysis.

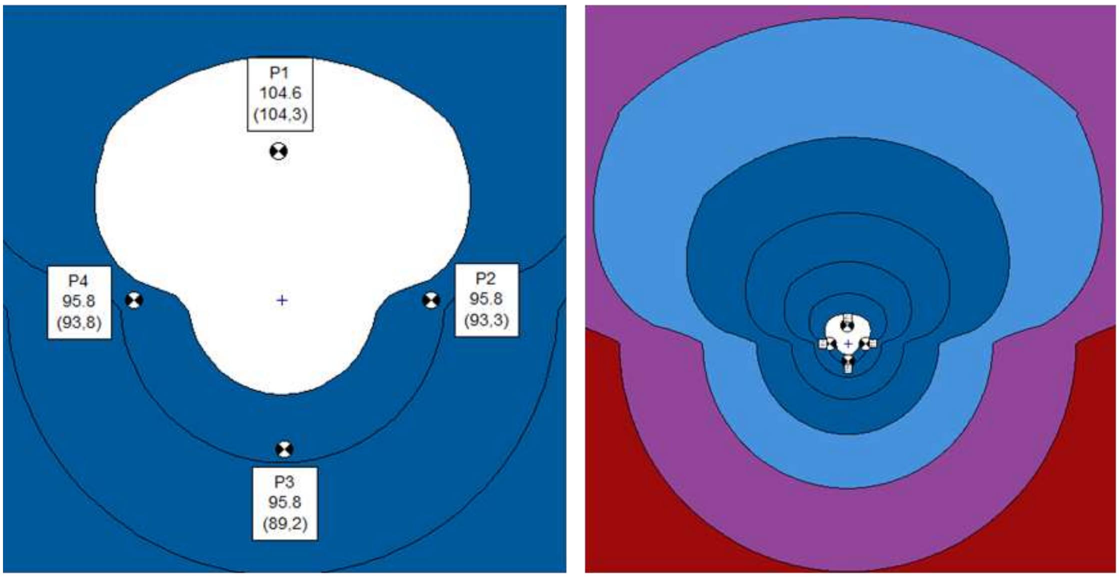

Fig. 5 Direction of sound emission at the shooting position obtained as a result of modelling using the *opening* option

At the stage of further research, it is necessary to more accurately determine the directional characteristics of the shooting position, i.e. with greater angular resolution.

EXAMPLE OF ACOUSTIC MODELLING OF NOISE EMISSIONS FROM THE SHOOTING AXIS – HUNTING TRAP

Using the model of a directional source, which is a single shooting position, you can model the acoustic impact of the entire shooting axis for the hunting trap shooting competition. Technical details and shooting arrangements are described in chapter 4 of this article. By starting modelling a typical shooting system was assumed, in which six competitors in the group start simultaneously. It was also assumed that each shooter spends 15 seconds at the station, during which he takes a position, prepares himself for a shot, loads a weapon, puts himself into a shot, gives a voice command, gives two successive shots and unloads the weapon. In the whole competition it takes a total of 1350 seconds, which gives 22 minutes and 30 seconds. Subsequent groups start firing at intervals of 30 minutes, and this is also how the total reference time to assess sound emissions during one competition was adopted. Such a model made using CadnaA software is shown in Fig. 6.

The calculated average distribution of sound level in the environment related to the duration of the entire competition, so up to 30 minutes, is shown in Fig. 7a, while related to the time of day (8 hours) in Fig. 7b.

Fig. 6 Location of noise sources (shooters) on the trap shooting axis

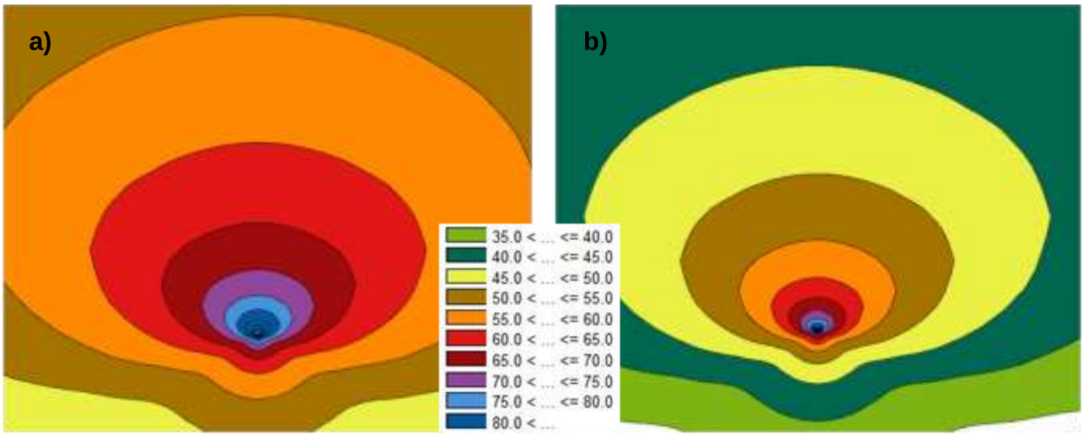

Fig. 7 Distribution of the equivalent sound level in the environment emitted by the trap shooting axis referred to the duration of the competition (a) and the time of day (b)

The sound level distributions calculated using propagation models and presented in Fig. 7 allow to create a mathematical model of the examined shooting axis. The constant value in such a model should be the axial direction characteristics, while the variable values: direction of the shooting axis as well as time and intensity of shooting. Creating an accurate acoustic model for the trap shooting axis will be the subject of further research. At the moment, the results obtained can be used to calculate noise propagation from the shooting range during the shooting competition on the trap's axis.

AN EXAMPLE OF USING THE DEVELOPED MODEL TO ANALYSE THE ACOUSTIC IMPACT OF THE SHOOTING RANGE ON THE ENVIRONMENT

The developed shooting axis model can easily be implemented in any computational environment, allowing the introduction of point sources described by the sound power level and source directivity coefficient. It will allow to calculate noise emissions from the shooting axis, taking into account the impact of the environment, i.e. shielding elements such as buildings, slopes, backstops, trees, etc. In addition, it will be possible to carry out, e.g. optimization of shooting time, taking into account the criterion of not exceeding the permissible noise levels at the nearest housing development. Fig. 8 shows examples of isoline waveforms of the same sound level of 55 dB in the event of one hunting trap competition in relation to its actual duration, i.e. 30 minutes (a) and in relation to 8 hours of daytime (b). Fig. 8c shows a 55 dB isoline waveforms in the event of 10 trap shooting competition in relation to 8 hours of the day. The calculations were carried out on the example of the real trap axis located at the PZŁ shooting range in Siemianowice Śląskie. The conducted analyses show that in none of the analysed cases shooting on the trap does not cause the danger of excessive noise for the environment.

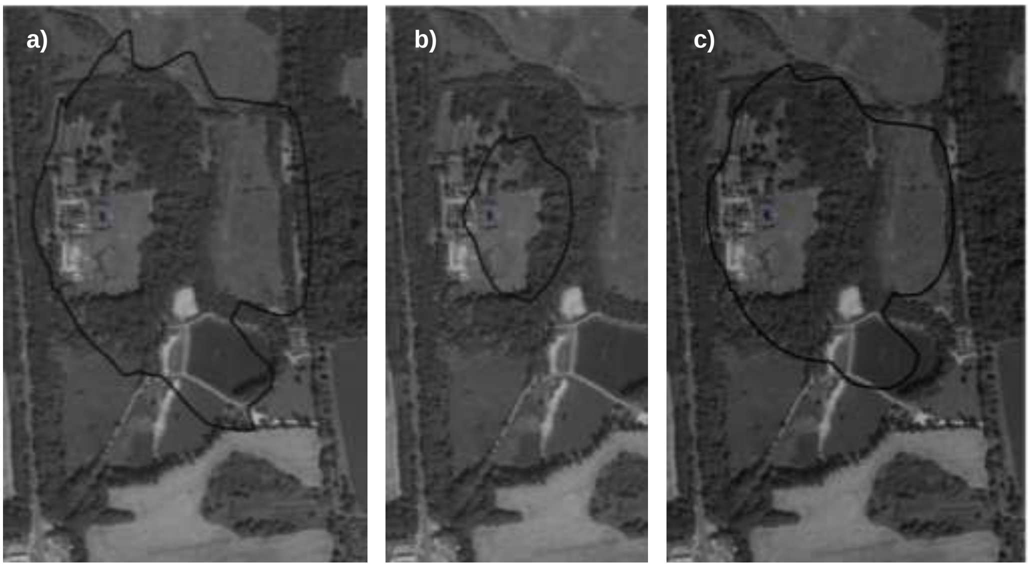

Fig. 8 Isoline waveforms 55 dB for "hunting trap" competition shootings:
a) one competition and a reference time of 30 minutes,
b) one competition and a reference time of 8 hours,
c) 10 competition and a reference time of 8 hours

CONCLUSION

The article presents the method of acoustic modelling of the shooting axis on the example of the *hunting trap shooting* competition and the possibility of using the developed model to implement assessments of the acoustic impact of sport and hunting shooting ranges on the environment. The developed model, despite the simplified measurement procedure used, is perfectly suited for use in calculations of noise propagation during firing on *the hunting trap shooting* axis. A slight modification of the directionality of point sources and shooting times will also allow its use in modelling competitions like *sports trap* and *double trap*. The measurement and calculation procedure presented in the article may be reproduced on the other axes intended for shot blasting (e.g. skeet, pheasant, parcour) and bullets shooting.

ACKNOWLEDGEMENT

The research was conducted with the support of the statutory work titled "The use of modern methods and tools for developing the priority research areas of the Faculty of Organization and Management at Silesian University of Technology", project number 13/030/BK-20/0059.

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Abstract: The article deals with the problem of acoustic modelling of sport and hunting shooting ranges for the purposes of carrying out acoustic impact assessments on the environment. The fashion for recreational shooting and the dynamic development of shooting ranges resulted in conflict situations between the shooting range and the residents. Increasingly, the condition for allowing the shooting range to be used is to carry out an acoustic analysis to confirm the lack of noise nuisance. Therefore, it is necessary to develop guidelines for acoustic modelling of shooting ranges, taking into account their purpose and types of shooting axes. Each of the shooting axes is designed for a different type of shooting and thus has different acoustic characteristics. In the article, the author presents a method of modelling noise emissions from the shooting range on the example of one of the popular shooting competitions which is the hunting trap. First, acoustic measurements of the unit noise source related to the firing of shots by a firearms shooter were made. Then the directional characteristics of this source were determined, the shooting axis of the "hunting trap" type was modelled during a typical shooting competition and its directionality was determined. Then, on the example of a specific shooting range, the possibility of using the results to analyse the propagation of noise into the environment during typical shootings on the trap axis was presented.

Keywords: noise, shooting range, sound propagation, acoustic modelling, clay pigeons shooting