Diagnosis and Prognosis of the Hearing Impairment Risk

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Abstract: This paper describes a methodological approach on the analysis and on the statistical and probabilistic assessment of the hearing impairment risk, based on the hazards quantified as risk predictors, in order to establish the modalities for assessing the caution limits related to the acceptability ranges. The research has been achieved within the PN 45 07 01 15 project in the framework of the NUCLEU/2009-2010 program.

The statistical approach is based on the rational quantification of what exists and can be observed, the probabilistic part of this fact representing the extrapolation to what it can be reasonably deduced from these statistics of hearing impairment occurrence probability. This project has a national and international interest, entailing the increase of occupational health and safety level and ensuring sustainable environmental quality and comfort at workplaces.

Keywords: Noise, auditory handicap, diagnosis, prognosis, distribution, algorithm.

1. GENERALITIES REGARDING THE HEARING IMPAIRMENT DUE TO NOISE

For establishing the potential causes of injuries and/or occupational disease, the term of the hearing impairment risk is increasingly used in specialized analyses. The interest of the specialist for studying the risk factors (including the risk generated by exposure to noise) is perfectly justified by the possibility to establish prevention methods, starting from the potential risks of injury or occupational disease due to the exposure to this type of noxious (Covello V.T. and Merkhofer M.W. 1993).

Individuals regularly exposed to noise may suffer from hearing loss with variable severity. Due to hearing loss, there may be damaged both the speech understanding as well as the perception of acoustic signals generated during the work process or daily life. Excluding the exposure to explosions, to high impulse noise and extremely high levels of stationary noise, the permanent damage of the organ of hearing may be achieved progressively in time, depending on the exposure time (Valentin Petrescu, Sorin Borza, 2013).

The term regarding the “permanent displacement of the threshold caused by noise” is discussed in the paper as a component independent of other elements of the audibility threshold levels, which is usually equal to zero, and for a given noise exposure has a range of positive values representing the variation of individual susceptibility of hearing impairment to noise. The permanent displacement of the threshold caused by noise is generally preceded by a temporary reversible effect on the hearing named temporary modification of the threshold cause by noise, whose severity and recovery mode depend on the exposure level and time.

Since the precise determination related to the clearly differentiation of the changes of the hearing threshold levels caused by noise or other factors is difficult in case of punctual approach for each individual, there has been chosen to determine the statistical distribution changes of the hearing threshold levels for a population exposed to a specific kind of noise. In this regard, in order to highlight the differences between the hearing threshold levels of two groups of persons which are similar in all important aspects, excepting the fact that one group is exposed to occupational noise, there may be successfully used the average or median parameters related to the permanent displacement of the hearing threshold caused by noised (SR ISO, 2010).

At the European level the hearing handicap caused by noise exposure may have legal consequences regarding the responsibility and compensation. Levels of the hearing threshold at different frequencies at which it is considered that there is a hearing handicap (limit level) depends not only on the damage itself, but also on the legal aspects based on social and economic considerations. In addition, defining the hearing handicap depends on the required speech understanding quality, on the average background noise level and, in relation to the relative importance of different frequencies, perhaps even on the spoken language.

Because the hearing impairment caused by noise isn’t only the results of exposure to occupational noise, but also the result of the entire exposure to noise of the population, there is necessary to take in to account the

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non-occupational exposure of individuals (during their travelling to or from their jobs, home and during recreational activities etc.).

The prognosis of hearing impairment due to occupational noise exposure is possible when the non-occupational exposure is negligible compared to the occupational one, case in which it is required to calculate the hearing impairment due to total daily and combined exposures (occupational and non-occupational) to noise, and, if required, there may be also estimated the contribution to the total hearing impairment due to occupational noise exposure.

Thereby, the major objectives of any research is to perform an exploratory and prospective research of the activities unfolded in presence of generating sources of noise, in order to establish the forecast of the risk of exposure to noise. Once provided, the results can be used for modelling various risk scenarios and also to establish different areas of acceptability, specific to the development of work processes in sustainable conditions of safety and health (Cruz, 2004; Haimes, 2004).

From theory to practice, the research in the area of risk to whole-body vibrations generated by industrial activities with environmental impact addresses ways to conceptualize the structural components that allow the determination of a relative share of hazards identified through the harmful values of the vibration parameters. In order to achieve all of the above, the paper is relying on researches based on modern mathematical models, in the field of exposing to professional vibration. Also, this document provides viable solutions and alternatives for ensuring the sustainability of the safety operation of all work systems which are equipped with sources generating vibrations.

2. GENERALIZED MATHEMATICAL MODEL FOR ASSESSING THE RISK OF HEARING IMPAIRMENT CAUSED BY NOISE

2.1. Theoretical and Practical Considerations on the Prognosis of the Effects of Noise on the Hearing Threshold

The hearing quality depending on the age of a population which is to exposed to noise depends on the extent to which there are accidentally included other factors besides natural ageing. Also, some diseases, ototoxic drugs problems and unknown exposure to occupational noise may influence the hearing threshold level related to age.

In order to substantiate the hearing threshold level related to age, there are used two databases, A and B, where one is fully specified (A), and the other one being at the latitude of the user (B) (SR ISO, 2010).

So, the A database is provided from normal people, with normal health condition, who do not present signs or symptoms or ear diseases and wax plugs in the auditory channels and which have not been excessively exposed to noise. The statistical distribution of the thresholds of a population of this kind "very protected" have been standardized for male populations, as well as for female populations.

For the B database there is recommended a dataset collected from a control population which has not been exposed to occupational noise.

Also, choosing the proper database depends on the problem supposed to be solved.

The determination of the permanent displacement of the hearing threshold caused by noise

a) The calculation of $N_{0,50}$

Values of the permanent displacement of the threshold caused by noise depend on the audiometric frequency, on the exposure time, on the θ/θ_0 ratio and on the exposure level for a 8h working day, $L_{EX,8h}$ mediated on the θ exposure time. So, for exposure times between 10 and 40 years, values of permanent displacements of the threshold caused by noise (potential medians), are given for both sexes by the following relation: (Desroches A., 1995;SR ISO, 2010).

$$N_{0,50} = \left\{ \begin{bmatrix} -0,033^{(500\mathrm{Hz})} \\ -0,020^{(1000\mathrm{Hz})} \\ -0,045^{(2000\mathrm{Hz})} \\ 0,012^{(3000\mathrm{Hz})} \\ 0,025^{(4000\mathrm{Hz})} \\ 0,019^{(6000\mathrm{Hz})} \end{bmatrix} + \begin{bmatrix} 0,110^{(500\mathrm{Hz})} \\ 0,070^{(1000\mathrm{Hz})} \\ 0,066^{(2000\mathrm{Hz})} \\ 0,037^{(3000\mathrm{Hz})} \\ 0,025^{(4000\mathrm{Hz})} \\ 0,024^{(6000\mathrm{Hz})} \end{bmatrix} \lg(\frac{\theta}{\theta_0}) \right\}$$

$$\mathrm{x} \left\{ L_{EX,8h} - \begin{bmatrix} 93^{(500\mathrm{Hz})} \\ 89^{(1000\mathrm{Hz})} \\ 80^{(2000\mathrm{Hz})} \\ 77^{(3000\mathrm{Hz})} \\ 75^{(4000\mathrm{Hz})} \\ 77^{(6000\mathrm{Hz})} \end{bmatrix} \right\}^2$$

where,

[$93^{(500\ \mathrm{Hz})}$, $89^{(1000\mathrm{Hz})}$, $80^{(2000\mathrm{Hz})}$, $77^{(3000\mathrm{Hz})}$, $75^{(4000\mathrm{Hz})}$, $77^{(6000\mathrm{Hz})}$] - range of values of the limit acoustical pressure level defined depending on the frequency, L_0 (dB) ;

θ(years) – exposure time, θ_0=1 year;

$L_{EX,8h}$ – represents the level of exposure to noise for an 8h working day;

[500, 1000, 2000, 3000, 4000, 6000] - audiometric frequency values; (Hz).

Equation (1) is applied in case in which $L_{EX,8h}$ is higher than L_0, otherwise the level of exposure to noise for an 8h working day ($L_{EX,8h}$) being equal to L_0, so that $N_{0,50}$ is equal to 0.

Also, for periods of time smaller than 10 years, N will be extrapolated from the value of $N_{0,50}$ corresponding to a 10 year period, according to the following relation [1, 5]:

$$N_{0,50;\theta<10ani} = \frac{\lg(\theta+1)}{\lg 11} N_{0,50;\theta=10ani} \tag{2}$$

b) Statistical distribution of N

The distribution of N is approximated by two different halves of normal distributions (Gaussian), respectively: upper half for the quintile with the hearing weaker than the median found over the $N_{0,50}$ median value and the lower half which is found below the $N_{0,50}$ median value (Desroches A., 1995;SR ISO, 2010).

So, there are two situations:

1. If 0,05≤Q≤0,50 then the permanent displacement of the threshold caused by noise, N_Q, is given by the following relation (3):

$$\begin{bmatrix} N_{0,05;0,95} \\ N_{0,10;0,90} \\ N_{0,15;0,85} \\ N_{0,20;0,80} \\ N_{0,25;0,75} \\ N_{0,30;0,70} \\ N_{0,35;0,65} \\ N_{0,40;0,60} \\ N_{0,45;0,55} \\ N_{0,50} \end{bmatrix} = N_{0,50} + \begin{bmatrix} 1,645 \\ 1,282 \\ 1,036 \\ 0,842 \\ 0,675 \\ 0,524 \\ 0,385 \\ 0,253 \\ 0,126 \\ 0 \end{bmatrix} x \left\{ \left[\left[\begin{pmatrix} 0,044^{(500Hz)} \\ 0,022^{(1000Hz)} \\ 0,031^{(2000Hz)} \\ 0,007^{(3000Hz)} \\ 0,005^{(4000Hz)} \\ 0,013^{(6000Hz)} \end{pmatrix} + \begin{pmatrix} 0,016^{(500Hz)} \\ 0,016^{(1000Hz)} \\ -0,002^{(2000Hz)} \\ 0,016^{(3000Hz)} \\ 0,009^{(4000Hz)} \\ 0,008^{(6000Hz)} \end{pmatrix} \right. \right. \right.$$

$$\left. \left. \left. \lg \frac{\theta}{\theta_0} \right] x \left[L_{EX,8h} - \begin{pmatrix} 93^{(500Hz)} \\ 89^{(1000Hz)} \\ 80^{(2000Hz)} \\ 77^{(3000Hz)} \\ 75^{(4000Hz)} \\ 77^{(6000HZ)} \end{pmatrix} \right] \right] \right\}$$

2. If 0,50<Q≤0,95 then the permanent displacement of the threshold caused by noise is given by the following relation (4).

$$\begin{bmatrix} N_{0,05;0,95} \\ N_{0,10;0,90} \\ N_{0,15;0,85} \\ N_{0,20;0,80} \\ N_{0,25;0,75} \\ N_{0,30;0,70} \\ N_{0,35;0,65} \\ N_{0,40;0,60} \\ N_{0,45;0,55} \\ N_{0,50} \end{bmatrix} = N_{0,50} - \begin{bmatrix} 1,645 \\ 1,282 \\ 1,036 \\ 0,842 \\ 0,675 \\ 0,524 \\ 0,385 \\ 0,253 \\ 0,126 \\ 0 \end{bmatrix} x \left\{ \left[\left[\begin{pmatrix} 0,033^{(500Hz)} \\ 0,020^{(1000Hz)} \\ 0,016^{(2000Hz)} \\ 0,029^{(3000Hz)} \\ 0,016^{(4000Hz)} \\ 0,028^{(6000Hz)} \end{pmatrix} + \right. \right. \right.$$

$$\left. \left. \left. \cdot \begin{pmatrix} 0,002^{(500Hz)} \\ 0,000^{(1000Hz)} \\ 0,000^{(2000Hz)} \\ -0,010^{(3000Hz)} \\ -0,002^{(4000Hz)} \\ -0,007^{(6000Hz)} \end{pmatrix} \lg \frac{\theta}{\theta_0} \right] x \left[L_{EX,8h} - \begin{pmatrix} 93^{(500Hz)} \\ 89^{(1000Hz)} \\ 80^{(2000Hz)} \\ 77^{(3000Hz)} \\ 75^{(4000Hz)} \\ 77^{(6000HZ)} \end{pmatrix} \right] \right] \right\}$$

where:

[1, 645; 1, 282; 1,036; 0, 842; 0, 675; 0, 524; 0, 385; 0, 253; 0, 126; 0] - is represents the values of the k multiplication factor in 0.05 intervals for the Q quantile;

[$93^{(500\ \mathrm{Hz})}$, $89^{(1000\mathrm{Hz})}$, $80^{(2000\mathrm{Hz})}$, $77^{(3000\mathrm{Hz})}$, $75^{(4000\mathrm{Hz})}$, $77^{(6000\mathrm{Hz})}$] - is the range of values of the limit acoustical pressure level defined depending on the frequency, L_0(dB) ;

θ(years) – is the exposure time, θ_0=1 year;

$L_{EX,8h}$ – represents the level of exposure to noise for an 8h working day;

[500, 1000, 2000, 3000, 4000, 6000]- audiometric frequency values (Hz).

The values which correspond to the statistical distribution queues for situations in which 0<Q<0.05 and 0.95<Q<1, aren't sure and therefore they aren't estimated following the difficulties to validate these domains.

2.2. The Determination if the Hearing Impairment and of the Hearing Handicap Caused by Noise

Potentially hearing impairment due to occupational exposure to noise is directly assessed through the permanent displacement of the threshold caused by noise, which may be (Babisch, W., 2002; NUCLEU, 2010):

Separately considered for each frequency of interest;

- Gathered for a certain number of frequencies having as result a total threshold displacement.
- Averaged over a number of selected frequencies which usually represent the main frequency domain for speech understanding.

In order to calculate the hearing handicap there may be used (for each ear; for the average of both ears; for weighted average of both ears) a combination of hearing threshold levels at mentioned frequencies, respectively: average hearing threshold level at 500 Hz, 1000Hz, 2000Hz; average hearing threshold level at 500 Hz, 1000Hz, 2000Hz and 3000Hz; average hearing threshold level at 1000Hz, 2000Hz and 4000Hz; average hearing threshold level at 1000Hz, 2000Hz and 3000Hz; average hearing threshold level at 1000Hz, 2000Hz, 3000Hz and 4000Hz; average hearing threshold level at 2000Hz and 4000Hz; average hearing threshold level at 2000Hz, 3000Hz and 4000Hz, etc.

The risk of hearing handicap due to noise exposure and age or only due to noise exposure frequently represents measures of the negative effects of noise exposure over the population (Macdonald, E.B., Baranski, B., Wilford, J., Ed., 2000; Vasilescu, 2008 a, b).

2.3. Calculating the A Database

Equations applied for the H hearing threshold level depending on the Y age (years) for different intervals of the Q quantile which has the value of the threshold higher than the H_Q are the following [1, 5]

1. If 0.05≤Q≤0,50 then le hearing threshold level related to the H_Q age is given by the equation (4.1) for a male population and by equation (4.2) for a female population.

2. If Q=0.50 then le hearing threshold level related to the H_Q age is given by the equation (5.1) for a male population and by equation (5.2) for a female population.

$$\begin{pmatrix} H_{0,05;0,95} \\ H_{0,10;0,90} \\ H_{0,15;0,85} \\ H_{0,20;0,80} \\ H_{0,25;0,75} \\ H_{0,30;0,70} \\ H_{0,35;0,65} \\ H_{0,40;0,60} \\ H_{0,45;0,55} \\ H_{0,50} \end{pmatrix} = H_{0,50} + \begin{pmatrix} 1,645 \\ 1,282 \\ 1,036 \\ 0,842 \\ 0,675 \\ 0,524 \\ 0,385 \\ 0,253 \\ 0,126 \\ 0 \end{pmatrix} \text{x} \left[\begin{pmatrix} 7,23^{(125\text{Hz})} \\ 6,67^{(250\text{Hz})} \\ 6,12^{(500\text{Hz})} \\ 6,12^{(1000\text{Hz})} \\ 6,67^{(1500\text{Hz})} \\ 7,23^{(2000\text{Hz})} \\ 7,78^{(3000\text{Hz})} \\ 8,34^{(4000\text{Hz})} \\ 9,45^{(6000\text{Hz})} \\ 10,56^{(8000\text{Hz})} \end{pmatrix} + 0,445 H_{0,50} \right]$$

Male population (4.1)

$$\begin{pmatrix} H_{0,05;0,95} \\ H_{0,10;0,90} \\ H_{0,15;0,85} \\ H_{0,20;0,80} \\ H_{0,25;0,75} \\ H_{0,30;0,70} \\ H_{0,35;0,65} \\ H_{0,40;0,60} \\ H_{0,45;0,55} \\ H_{0,50} \end{pmatrix} = H_{0,50} + \begin{pmatrix} 1,645 \\ 1,282 \\ 1,036 \\ 0,842 \\ 0,675 \\ 0,524 \\ 0,385 \\ 0,253 \\ 0,126 \\ 0 \end{pmatrix} \text{x} \left[\begin{pmatrix} 7,23^{(125\text{Hz})} \\ 6,67^{(250\text{Hz})} \\ 6,12^{(500\text{Hz})} \\ 6,12^{(1000\text{Hz})} \\ 6,67^{(1500\text{Hz})} \\ 7,23^{(2000\text{Hz})} \\ 7,78^{(3000\text{Hz})} \\ 8,34^{(4000\text{Hz})} \\ 9,45^{(6000\text{Hz})} \\ 10,56^{(8000\text{Hz})} \end{pmatrix} + 0,445 H_{0,50} \right]$$

Female population (4.2)

$$H_{0,50} = \begin{pmatrix} 0,0030^{(125Hz)} \\ 0,0030^{(250Hz)} \\ 0,0035^{(500Hz)} \\ 0,0040^{(1000Hz)} \\ 0,0055^{(1500Hz)} \\ 0,0070^{(2000Hz)} \\ 0,0115^{(3000Hz)} \\ 0,0160^{(4000Hz)} \\ 0,0180^{(6000Hz)} \\ 0,0220^{(8000Hz)} \end{pmatrix} x(Y-18)^2 + H_{0,50;18}$$

Male population (5.1)

$$H_{0,50} = \begin{pmatrix} 0{,}0030^{(125Hz)} \\ 0{,}0030^{(250Hz)} \\ 0{,}0035^{(500Hz)} \\ 0{,}0040^{(1000Hz)} \\ 0{,}0050^{(1500Hz)} \\ 0{,}0060^{(2000Hz)} \\ 0{,}0075^{(3000Hz)} \\ 0{,}0090^{(4000Hz)} \\ 0{,}0120^{(6000Hz)} \\ 0{,}0150^{(8000Hz)} \end{pmatrix} x(Y-18)^2 + H_{0,50;18}$$

Female population (5.2)

3. If 0.50≤Q≤0.95 then le hearing threshold level related to the H_Q age is given by the equation (6.1) for a male population and by equation (6.2) for a female population.

$$\begin{pmatrix} H_{0,05;0,95} \\ H_{0,10;0,90} \\ H_{0,15;0,85} \\ H_{0,20;0,80} \\ H_{0,25;0,75} \\ H_{0,30;0,70} \\ H_{0,35;0,65} \\ H_{0,40;0,60} \\ H_{0,45;0,55} \\ H_{0,50} \end{pmatrix} = H_{0,50} + \begin{pmatrix} 1{,}645 \\ 1{,}282 \\ 1{,}036 \\ 0{,}842 \\ 0{,}675 \\ 0{,}524 \\ 0{,}385 \\ 0{,}253 \\ 0{,}126 \\ 0 \end{pmatrix} x \left[\begin{pmatrix} 5{,}78^{(125Hz)} \\ 5{,}34^{(250Hz)} \\ 4{,}89^{(500Hz)} \\ 4{,}89^{(1000Hz)} \\ 5{,}34^{(1500Hz)} \\ 5{,}78^{(2000Hz)} \\ 6{,}23^{(3000Hz)} \\ 6{,}67^{(4000Hz)} \\ 7{,}56^{(6000Hz)} \\ 8{,}45^{(8000Hz)} \end{pmatrix} + 0{,}356\, H_{0,50} \right]$$

Male population (6.1)

$$\begin{pmatrix} H_{0,05;0,95} \\ H_{0,10;0,90} \\ H_{0,15;0,85} \\ H_{0,20;0,80} \\ H_{0,25;0,75} \\ H_{0,30;0,70} \\ H_{0,35;0,65} \\ H_{0,40;0,60} \\ H_{0,45;0,55} \\ H_{0,50} \end{pmatrix} = H_{0,50} + \begin{pmatrix} 1{,}645 \\ 1{,}282 \\ 1{,}036 \\ 0{,}842 \\ 0{,}675 \\ 0{,}524 \\ 0{,}385 \\ 0{,}253 \\ 0{,}126 \\ 0 \end{pmatrix} x \left[\begin{pmatrix} 5{,}34^{(125Hz)} \\ 4{,}89^{(250Hz)} \\ 4{,}89^{(500Hz)} \\ 4{,}89^{(1000Hz)} \\ 5{,}34^{(1500Hz)} \\ 5{,}34^{(2000Hz)} \\ 5{,}78^{(3000Hz)} \\ 6{,}23^{(4000Hz)} \\ 7{,}12^{(6000Hz)} \\ 8{,}45^{(8000Hz)} \end{pmatrix} + 0{,}356\, H_{0,50} \right]$$

Female population (6.2)

2.4. Algorithm of the Generalised Mathematical Model for Assessing the Hearing Impairment Risk

In order to substantiate a hearing impairment risk assessment system, there has been designed a graphical-analytical mathematical mode which confers the possibility to estimate and appreciate the risk of hearing handicap due to noise exposure, based on the difference between the hearing handicap risk due to age and noise and on the hearing handicap risk of the population (SR ISO, 2010; NUCLEU, 2010).

The application of the mathematical prognosis model of the hearing impairment risk, involves the following steps (Vasilescu, 2008 b; Waddell, G. & Burton, A.K., 2001):

(S1): Defining the problem to solve (establishing the type of population: male or female; age of the subjects from the analysed population; daily noise exposure for n years (8h/day, 5 days/week, 50 weeks/year);

(S2): Establishing the combination of frequencies for the mediation of the hearing threshold levels;

(S3): Calculating the hearing threshold level related to the H_Q age for a certain type population (male or female) unexposed to noise according to the A database; Also, verification of the equation related to the sum of values between permanent threshold displacement caused by noise and the level of the hearing threshold related to age, which if it is higher than 40dB, then it significantly modifies the result and therefore the value of the permanent displacement of the threshold caused by noise shall be corrected according to the equation: N-(HxN)/120;

(S4): Calculating the permanent displacement of the threshold caused by noise:

$$H' = H + N - \frac{HxN}{120} \tag{7}$$

(S5): Determining the hearing threshold level related to age and noise for the population exposed to noise;

(S6): Graphical representation in Gaussian coordinates (within a rectangular axis system in which, on the abscissa there are highlighted as percentage, at the lower part the values of people with weaker hearing (from right to left)/at the upper part the values of people with better hearing, and on the ordinate the values of the hearing threshold level in dB);

(S7): Determining the hearing impairment risk corresponding to a daily exposure to noise level in each day, over a period of time (expressed in years). With data specific for the hearing threshold level related to the age from the A database.

2.5. Case Study on the Hearing Impairment Risk Assessment

In order to apply the mathematical model for assessing the hearing impairment risk, there is taken into account a sample of workers in the exploration of

Table 1: Selected Values of the Hearing Threshold Level, in dB, from the A Database

HEARING THRESHOLD LEVEL, dB									
Frequency Hz	Age: 50 years								
	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1
Men									
500	-4	-2	0	2	4	6	8	10	13
1000	-4	-1	1	2	4	6	8	11	14
2000	-4	0	3	5	7	10	13	16	21
3000	-2	3	6	9	12	15	19	23	28
4000	0	6	10	13	16	20	25	30	36
6000	0	7	11	15	18	23	28	33	41

coal deposits in the Jiu Valley coalfield - Romania, resulted in a 50 years old male population, which has been exposed to a medium level of daily noise of $L_{EX,8h}$ = 90 dB, each day, during 30 years (NUCLEU, 2010; Smid, T., 2001).

Application of the mathematical prognosis model of the hearing impairment risk, involves the following steps:

(P1): Defining the problem to solve: population: male; age 50 years; daily exposure level each day during 30 years (8h/day, 5 days/weeks, 50 weeks/year): $L_{EX,8h}$ = 90 dB;

(P2): Establishing the combination of frequencies for the mediation of the hearing thresholds level: in order to determine the hearing handicap there is used the combination of frequencies 1000Hz, 2000Hz and 4000Hz;

(P3): Calculating the hearing threshold level related to H_Q age for a certain type population (male or female), unexposed to noise according to database A: The level of the hearing threshold level related to H_Q noise for the unexposed to noise population is calculated according to the A database (Table **1**) and it is mediated for 1000Hz, 2000Hz and 4000Hz frequencies, respectively:

$$\begin{pmatrix} H_{0,9;50} \\ H_{0,8;50} \\ H_{0,7;50} \\ H_{0,6;50} \\ H_{0,5;50} \\ H_{0,4;50} \\ H_{0,3;50} \\ H_{0,2;50} \\ H_{0,1;50} \end{pmatrix} = \begin{bmatrix} (-4-4+0)/3 \\ (-1+0+6)/3 \\ (1+3+10)/3 \\ (2+5+13)/3 \\ (4+7+16)/3 \\ (6+10+20)/3 \\ (8+13+25)/3 \\ (11+16+30)/3 \\ 14+21+36)/3 \end{bmatrix} = \begin{pmatrix} -2,7 \\ 1,7 \\ 4,7 \\ 6,7 \\ 9,0 \\ 12,0 \\ 15,3 \\ 19,0 \\ 23,7 \end{pmatrix}$$

Values of the hearing threshold level related to H_Q age for the unexposed to noise population.

(P4): Calculating the permanent displacement of the threshold caused by noise and the verification of the equation related to the sum of values between the permanent displacement of the threshold caused by noise and the threshold hearing level related to age: At a 4000 Hz frequency, the sum of the values related to the permanent displacement of the threshold caused by noise and the hearing threshold level related to age for the quantile 01. Is higher than 40dB (Table **2**). Therefore, the 19 dB value from Table 2 is reduced as following:

$$19 - \frac{36x19}{120} = 13{,}3dB$$

$$\begin{pmatrix} N_{0,9;30} \\ N_{0,8;30} \\ N_{0,7;30} \\ N_{0,6;30} \\ N_{0,5;30} \\ N_{0,4;30} \\ N_{0,3;30} \\ N_{0,2;30} \\ N_{0,1;30} \end{pmatrix} = \begin{bmatrix} (0+3+0)/3 \\ (0+4+11)/3 \\ (0+4+12)/3 \\ (0+5+13)/3 \\ (0+5+14)/3 \\ (0+6+15)/3 \\ (0+7+16)/3 \\ (0+8+17)/3 \\ 0+9+13{,}3)/3 \end{bmatrix} = \begin{pmatrix} 4{,}3 \\ 5{,}0 \\ 5{,}3 \\ 6{,}0 \\ 6{,}3 \\ 7{,}0 \\ 7{,}7 \\ 8{,}3 \\ 7{,}4 \end{pmatrix}$$

Values related to the permanent displacement of the threshold caused by noise

(P5): Determining the hearing threshold level related to age and noise for the population exposed to noise: Through the application of equation (7) referring to the hearing threshold level related to the H age and to the permanent displacement of the threshold caused by noise, real or potential N, there is obtained an approximation of the biological events,

Table 2: Permanent Displacement of the Hearing Threshold Level Caused by Noise, in dB

NIPTS, dB, Noise exposure level $L_{EX,8h}$ = 90 dB									
Frequency Hz	**Exposure time: 30 years**								
	0,9	0,8	0,7	0,6	0,5	0,4	0,3	0,2	0,1
500	0	0	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0	0	0
2000	3	4	4	5	5	6	7	8	9
3000	8	9	9	11	11	13	14	16	18
4000	10	11	12	13	14	15	16	17	19
6000	5	7	8	8	9	10	11	13	15

considered to be precise enough according to the specialized literature:

$$\begin{bmatrix} H'_{0,9} \\ H'_{0,8} \\ H'_{0,7} \\ H'_{0,6} \\ H'_{0,5} \\ H'_{0,4} \\ H'_{0,3} \\ H'_{0,2} \\ H'_{0,1} \end{bmatrix} = \begin{bmatrix} -2,7 \\ 1,7 \\ 4,7 \\ 6,7 \\ 9,0 \\ 12,0 \\ 15,3 \\ 19,0 \\ 23,7 \end{bmatrix} + \begin{bmatrix} 4,3 \\ 5,0 \\ 5,3 \\ 6,0 \\ 6,3 \\ 7,0 \\ 7,7 \\ 8,3 \\ 7,4 \end{bmatrix} - \frac{1}{120} \left\{ \begin{bmatrix} -2,7 \\ 1,7 \\ 4,7 \\ 6,7 \\ 9,0 \\ 12,0 \\ 15,3 \\ 19,0 \\ 23,7 \end{bmatrix} x \begin{bmatrix} 4,3 \\ 5,0 \\ 5,3 \\ 6,0 \\ 6,3 \\ 7,0 \\ 7,7 \\ 8,3 \\ 7,4 \end{bmatrix} \right\} = \begin{bmatrix} 1,7 \\ 6,6 \\ 9,8 \\ 12,4 \\ 14,8 \\ 18,3 \\ 22,0 \\ 26,0 \\ 30,0 \end{bmatrix}$$

(P6): Graphical representation in Gaussian coordinates:

The results obtained in (S5) are graphically represented in Gaussian coordinates with different handicap risks represented for an arbitrary limit of 27 dB, in order to study the dependency of the risks values with limits values (Figure **1**).

P7): Determining the hearing impairment risk corresponding to the daily noise exposure, for each day during a time period (in years), with specific data for the hearing threshold level related to age from database A: The graphical-analytical determination of the hearing impairment risk for a 50 year old male population exposed to average daily exposure to noise level of $L_{EX,8h}$=90 dB / day, during 30 years (8h/day, 5days/week, 50 weeks/year), has led to the following results:

- The auditory handicap risk due to age and noise is 18% (X point);
- The handicap risk of the population is 6.5% (Y point);
- The auditory handicap risk due to noise exposure is 11.5% (the horizontal difference between X and Y).

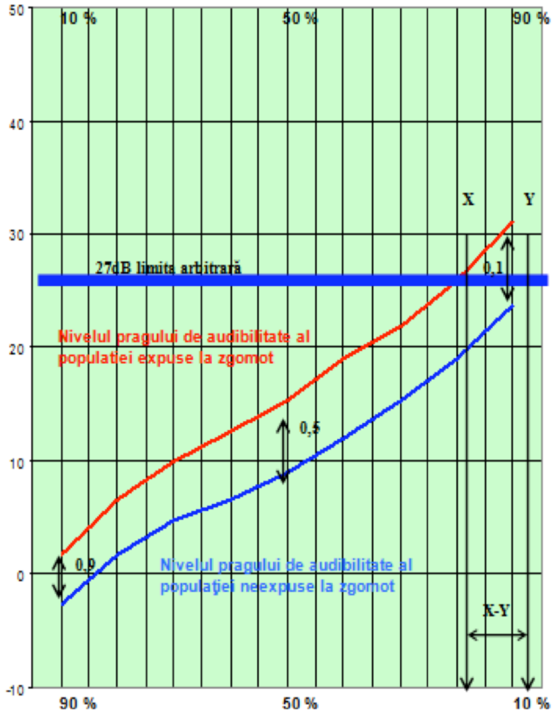

Figure 1: Graphical representation in Gaussian coordinates for the hearing impairment risk.

4. CONCLUSIONS

Starting from theory to practice, the paperwork highlights objectively through modern mathematical tools from the field of risk generated by noise in the occupational process, structural and process components which allow the proper determine a relative percentage of hazards identified as risk predictors, as well as the implications of these results on health and safety of the exposed population. Also, there is presented a method for estimating the hearing impairment due to noise exposure, in terms of conceptual and methodological defining for the auditory handicap assessment, taking into account both the legal consequences related to liability and compensation, as well as the legal definitions and interpretations based on economic and social considerations.

The graphical-analytical method determining the hearing impairment risk presented in the paperwork, provides the possibility to estimate this type of risk based on the auditory handicap risk of the population (determined in relation with the auditory threshold level of population un-exposed to noise) and on the auditory handicap due to age and noise (determined in accordance with the auditory threshold level of population exposed to noise). At the same time, the generalised mathematical model for assessing the hearing impairment risk, ensures, based on an algorithm, the method for estimating the auditory risk for a certain type population (male or female) which is exposed to daily noise over a certain period of time (years), representing calculation tool which is very useful for making decisions regarding the caution level required to be established for clarifying the acceptable/tolerable risk domain.

Results gained from the application of this mathematical model may contribute to the development of specialised databases for various fields of activities carried out at the level of the national economy, in order to develop the knowledge from the occupational risk prognosis and diagnosis field, having a preventive role for an occupational safety problem.

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