Assessment of occupational noise exposure in tyre manufacturing

I Roşca (Ciocan)¹, L C Dascălu² and G Solomon²
¹The National Research and Development Institute of Occupational Safety (INCDPM) - "Alexandru Darabont", Blvd. Ghencea, No. 35A, Bucharest, Romania
²University Politehnica of Bucharest, Faculty of Industrial Engineering and Robotics, Department of Quality Engineering and Industrial Technologies, Blvd. Splaiul Independentei, No. 202, 060021, Bucharest, Romania

E-mail: ioneliaciocan10@gmail.com

Abstract. According to the legislation in force the employer has a responsibility to evaluate and to measure the noise levels to which workers are exposed, paying special attention: level, type and duration of noise. Noise risk assessment is critical to protecting workers from the risks that threaten their health and safety from noise exposure. The noise risk assessment identifies the workers exposed to the risk generated by the noise and determines their level of noise exposure to ensure that the maximum noise exposure limit is not exceeded. When the worker exposure is exceeded, the noise becomes a risk for safety and health, because high noise levels cause hearing loss and this is irreversible. Also, stress from time spent at a high noise level was associated with increased workplace accident rates. This paper presents a technical method for measuring noise exposure in working environment using homogeneous noise exposure groups. The measuring process requires observation and analysis of all noise exposure conditions so that the quality of the measurements can be controlled. The uncertainty of the results is also taken into account. More than half of the workers were investigated during the research (over 900 workers), covering all the production workplaces. The results of the measurements obtained according to this method provided useful informations in order to define the main priorities regarding noise control measures.

1. Introduction
One of the most delicate of the five senses of the human body and one of the easiest to be damaged at working place is hearing of a person. Noise is a general problem present in the work environment.

Noise at the working place is one of the biggest contributors to the loss of professional hearing, especially if there are no effective measures to reduce exposure to it. The purpose of noise assessment is to help the employer identify workplaces where there are noise problems, employees who may be affected and where measures should be taken to reduce noise.

Performing a noise risk assessment is essential as it is the most important part of conservation program of hearing and noise control at the working place. The employer must take all necessary measures to ensure safe and healthy jobs for the employees.

This article presents a technical method by which the daily noise exposure assessment is applied in a tyre manufacturing. All the production places and over 900 workers were investigated. This process may require a longer period due to the time required for measurements, but it produces less uncertainty about the result obtained.
2. Research methodology
The selection of an appropriate measurement strategy is influenced by several factors such as the purpose of the measurements, the complexity of the work situation, the number of workers involved, effective duration of the working day, the time available for measurement and analysis and the required amount of detailed information. [1]

In order to be able to choose the most suitable method of measurement, work analysis must be done. The work analysis is necessary in all situations and it must provide the information necessary to: describe the activities of the enterprise and the jobs of the workers under consideration; define homogeneous exposure noise groups (HENGs); determine a nominal day or days for each worker or group; identify tasks which make up the jobs, if relevant; identify possible significant noise events. Then the measurement process is chosen and the measurement plan is established. The work must be analyzed with emphasis put on production, process, organization, workers and activities. [1,2]

The method chosen for noise exposure assessment, presented in this study, is the function-based method. The principle of this measurement strategy is to take random samples of noise exposure, by measuring $A$-weighted equivalent continuous sound pressure levels for $T = \text{the effective duration, in hours, of the working day}$ ($L_{p,A,eq}$) while performing the functions identified in the job analysis. [1]

Defining homogeneous exposure noise groups (HENGs) can reduce measurement efforts. These are groups of workers that are performing the same job (as sum of the same tasks) and are expected to have similar noise exposures levels during the working day. The homogeneous noise exposure group may be composed of one or many workers. [1-3] In this case, the HENGs were defined by the representatives of the factory.

2.1. Measurement plan
The measurement plan was established as follows. From the identified functions were established the homogeneous exposure noise groups. For each HENG:

a) is determined from table 1, the minimum cumulative duration of measurement, for the number of workers, $n_G$, from the HENG;

b) is selected a sample duration and the number of samples (at least five), such that the cumulative duration corresponds meets or exceeds the minimum duration, determined in the step above;

c) is planned to take samples which are distributed randomly among the members of the group and across the duration of the working day. [1,2,4]

**Table 1.** Specifications for the minimum duration of measurements to be applied to a HENG of size $n_G$.

| Number of workers in the homogeneous exposure group $n_G$ | Minimum cumulative duration of measurement to be distributed to the homogeneous exposure group |
|----------------------------------------------------------|---------------------------------------------------------------------------------------------|
| $n_G \leq 5$                                            | 5 h                                                                                         |
| $5 < n_G \leq 15$                                       | $5 + (n_G - 5) \times 0.5$ h                                                                |
| $15 < n_G \leq 40$                                      | $10 + (n_G - 15) \times 0.25$ h                                                             |
| $n_G > 40$                                              | 17 h or split the group                                                                     |

2.2. Noise measurements
The measurements for determining the noise exposure in the working environment are made using the following types of equipment:

a) dosimeter worn by the worker whose noise exposure is being determined;

b) integrator-mediator sound level meter placed in discrete positions or held in the hand when tracking a mobile worker.

In this case were used dosimeters Brüel & Kjaer type 4442 and 4448; sound level meter Brüel & Kjaer type 2250. The dosimeters can be used for measurements in all types of work situations. This is
the preferred method when making long-term measurements for a mobile worker, engaged in complex or unpredictable tasks or performing a large number of discrete tasks.

The microphone should be mounted on the top of the shoulder at a distance of at least 0.1 m from the entrance of the external ear canal, at the side of the most exposed ear and it is recommended to be approximately 0.04 m above the shoulder. It is recommended that the microphone and the cable shall be fasted such a way that mechanical influence or covering by clothing do not lead to false results. It must also be ensured that the performance of the worker is not disturbed and especially not to introduce safety risks. The advantage of using dosimeters is that the monitored workers do not have to be closely monitored and that multiple measurements can be made simultaneously.

Before each series of measurement and at the beginning of each daily series of measurements, a field calibration with the appropriate adjustment must be performed. At the end of each series of measurements and at the end of each daily series of measurements, a field calibration without adjustment must be performed. Field calibration is performed in a quiet area. In this case, the equipment used was calibrated with the Bruel & Kjaer acoustic calibrator type 4231. [1-3]

3. Case study - assessment of occupational noise exposure in a tyre manufacturing

The calculation of daily exposure level using measurements based on homogeneous exposure noise groups (HENGs) involved the following steps [1,2,5]

- **Step 1: Work analysis**
  Workers at the production line do the same job: they operate and control a production line and intervene in the event of a production incident. Their work encompasses many tasks (eg, material supply, production control, product removal, adjustments). However, during the analysis of the work, no possible distinctions could be made between tasks, for the following reasons: the conditions of noise exposure of the workers are similar from one task to another and the daily duration of each task cannot be determined from the job descriptions. The workers form an homogeneous exposure noise group, consisting of 16 people. The effective duration of the working day, for this HENG, is 7.5 h.

- **Step 2: Choice of procedure**
  From the analysis of work for this HENG, consisting of 18 workers, it appears that it is neither practical nor desirable to carry out a detailed analysis of the tasks. As a result, was chosen function-based measurements.

- **Step 3: Measurements**
  The choice of measurement plan was guided by the following specifications:
  - the total minimum duration of the measurements is given in table 1: for a group of 16 persons, this is 10.25 h (625 minutes);
  - a minimum of five noise level samples of the same duration is required.
  Starting from these, it has been decided to make 8 measurements and to set the measurements duration to 80 minutes each. The distribution of the 8 measurements among the workers in this HENG and over the working duration is made knowing that:
  - two dosimeters are available;
  - working periods for the group are: 07:00 - 15:00; 15:00 - 23:00 and 23:00 - 07:00.

Eight workers are randomly selected from the 16 members of the HENG.

The chosen distribution of the measurements is as follows:

- **Day 1:** The morning team, 2 different workers; measurement periods: 8:00 - 9:20 and 8:40 - 10:00
- **Day 2:** The morning team, 2 different workers; measurement periods: 10:00 - 11:20 and 10:30 - 11:50
- **Day 1:** The afternoon team, 2 different workers; measurement periods: 15:30- 16:50 and 17:00 - 18:20
- **Day 2:** The afternoon team, 2 different workers; measurement periods: 15:10- 16:30 and 18:00 - 19:20

The eight measurements result in the following values of A-weighted equivalent continuous sound pressure of the sample for HENG (Lp, A, eqT, n) is presented in table 2.
Table 2. The values of measurements of A-weighted equivalent continuous sound pressure of the sample n.

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|----|-----|-----|-----|-----|-----|-----|-----|-----|
| L_p,A,eqT,n (dB) | 90.2 | 85.9 | 89.7 | 87.3 | 86.1 | 85.0 | 86.6 | 87.8 |

- **Step 4: Handling errors**
  No potential sources of error have been identified.

- **Step 5: Calculation of the A-weighted noise exposure level, presentation of results and uncertainty**

  The determination of the daily noise exposure levels for workers belonging to a specific HENG has to be made by means of the following next steps:

  ✓ **Evaluation of the A-weighted equivalent continuous sound pressure:**

  \[
  L_{p,A,eqT,n} = 10 \log \left( \frac{1}{N} \sum_{n=1}^{N} 10^{0.1 \times L_{p,A,eqT,n}} \right) \text{ dB} \tag{1}
  \]

  where:
  - \(L_{p,A,eqT,n}\) is the A-weighted equivalent continuous sound pressure of the sample \(n\);
  - \(n\) is the job sample number;
  - \(N\) is the total number of job samples.

  ✓ **Calculation of the A-weighted noise exposure level**

  Calculation of the A-weighted noise exposure level of the workers belonging to a specific HENG is given by the following equation:

  \[
  L_{EX,8h} = L_{p,A,eqT_e} + 10 \log \left( \frac{T_e}{T_0} \right) \text{ dB(A)} \tag{2}
  \]

  where:
  - \(L_{p,A,eqT_e}\) is the A-weighted equivalent continuous sound pressure for the effective duration of the working day;
  - \(T_e\) is the effective duration of the working day;
  - \(T_0\) is the reference duration of the working day, \(T_0 = 8\) h.

  ✓ **Calculation of standard uncertainty, \(u\), and expanded standard uncertainty, \(U\)**

  The standard uncertainty, \(u(L_{EX,8h})\), for the A-weighted noise exposure level, \(L_{EX,8h}\), is calculated with relation (3):

  \[
  u^2(L_{EX,8h}) = c_1^2 u_1^2 + c_2^2 (u_2^2 + u_3^2) \tag{3}
  \]

  where:
  - \(c_1 u_1\) the contribution to uncertainty;
  - \(c_2\) the coefficients of sensitivity associated with measuring equipment;
  - \(u_2\) the standard uncertainty due to the equipment;
  - \(u_3\) the standard uncertainty due to the microphone position;

  The expanded standard uncertainty, \(U\), is given by relation (4):

  \[
  U = 1.65 \times u. \tag{4}
  \]

  Uncertainty contribution, \(c_1 u_1\), of job noise level sampling, can be found in table 3 and depending on the number, \(N\).

  The coefficient of sensitivity, \(c_2\), for the uncertainty due to the equipment, is:

  \[
  c_2 = 1 \tag{5}
  \]
The standard uncertainty, $u_2$, due to the equipment (the device used was a dosimeter):

$$u_2 = 1.5 \text{ dB} \quad (6)$$

The uncertainty contribution due to the microphone position is conventionally equal to:

$$u_3 = 1.0 \text{ dB} \quad (7)$$

Table 3. Uncertainty contribution of job noise level sampling ($u_s$, expressed in dB) applicable to a set of $N$ measured values $L_{p,A,eq,Tn}$ with a standard uncertainty $u_1$.

| N | 0.5 | 1  | 1.5 | 2  | 2.5 | 3  | 3.5 | 4  | 4.5 | 5  | 5.5 | 6  |
|---|-----|----|-----|----|-----|----|-----|----|-----|----|-----|----|
| c | 0.1 | 0.2| 0.3 | 0.4| 0.5 | 0.6| 0.7 | 0.8| 0.9 | 1.0| 1.1 | 1.2|

The standard uncertainty of the measured values is: $u_1 = 2.0 \text{ dB}$

Contribution to uncertainty due to the sampling of the function noise level (value taken from the Table 2 for $N = 8$ and $u_1 = 2.0 \text{ dB}$): $c_1 u_1 = 1.1 \text{ dB}$

The coefficients of sensitivity: $c_2 = c_3 = 1$

The standard uncertainty, $u_2$, due to the equipment (the device used was a dosimeter): $u_2 = 1.5 \text{ dB}$

The standard uncertainty due to the microphone position is: $u_3 = 1.0 \text{ dB}$

The expanded standard uncertainty: $U(L_{EX,8h}) = 1.65 \times u = 3.5 \text{ dB}$

Final result of the calculation was as follows:

For an effective duration $T_e$ of the working day equal to 7.5 h and for an average noise level $L_{p,A,eq}$, the daily A-weighted noise exposure of this 16 members HENG, is 87.3 dB. Associated expanded uncertainty, $U(L_{EX,8h}) = 3.5 \text{ dB}$

Results are presented in figure 1.

**Figure 1.** Calculation of daily noise exposure level.
4. Results and discussions
Similarly, 73 homogeneous exposure noise groups have been evaluated. The minimum cumulative
duration of the measurements, for the number of workers in each homogeneous exposure noise group,
varies between 350 and 5280 minutes. The number of workers in a HENG varies from 1 to 88 persons.
The total number of noise samples measured depends on the number of workers in a HENG and the
minimum cumulative duration. A larger number of samples reduces measurement uncertainty, which
means increased accuracy of measurements. In this case, the noise level was evaluated for 947
samples distributed over the 73 groups. [5]
Table 4 shows the results obtained for all HENGs subject to evaluation.

Table 4. Results obtained for all HENGs in tyre manufacturing [5].

| Crt. No. | Depart ment         | Homogenous exposure noise groups (HENGs) | Workers number from HENG / Noise samples number | Daily noise exposure value calculated for HENG, L_Ex,8h dB(A) | Uncertainty dB(A) |
|---------|---------------------|----------------------------------------|-----------------------------------------------|-------------------------------------------------------------|-------------------|
| 1.      | 101                 | BY 1, BY 2, BY 3, Self-sealing 1        | 36/18                                         | 90.4                                                        | 3.4               |
| 2.      | Height 0            | BY 4, BY 5, BY 6, BY 7                 | 16/8                                          | 85.8                                                        | 3.5               |
| 3.      | 111                 | BY 8, BY 9, BY 10                      | 12/6                                          | 85.1                                                        | 3.1               |
| 4.      | BY 15, BY 16        | 24/12                                   |                                               | 87.2                                                        | 3.1               |
| 5.      | 101                 | BY 1, BY 2, BY 3                       | 12/6                                          | 82.7                                                        | 3.7               |
| 6.      | Height 7            | BY 4, BY 5, BY 6, BY 7                 | 16/8                                          | 84.5                                                        | 3.2               |
| 7.      | 111                 | BY 8, BY 9, BY 10, BY 15, BY 16        | 20/10                                         | 86.1                                                        | 3.6               |
| 8.      |                   | Laboratory Quick Control               | 16/8                                          | 76.5                                                        | 3.7               |
| 9.      |                   | Laboratory Reinforcement               | 9/5                                           | 73.9                                                        | 3.6               |
| 10.     | 101                 | Laboratory Physical                    | 11/6                                          | 74.0                                                        | 3.3               |
| 11.     |                   | Laboratory Chemical                    | 4/5                                           | 72.6                                                        | 4.0               |
| 12.     |                   | Laboratory Office                      | 6/5                                           | 70.0                                                        | 6.2               |
| 13.     | 111                 | PTSM 1, PTSM 2, Self-sealing 2         | 13/7                                          | 88.4                                                        | 3.2               |
| 14.     | 400                 | Maintenance Department                 | 9/5                                           | 72.4                                                        | 4.9               |
| 15.     |                   | Warehouse Office                       | 4/5                                           | 81.5                                                        | 7.8               |
| 16.     | 101, 111, 400, 401 | Transport Operators                    | 17/9                                          | 85.4                                                        | 4.0               |
| 17.     | 400                 | Carbon Black Operators                 | 6/5                                           | 84.3                                                        | 3.6               |
| 18.     |                   | Mechanical Atelier                     | 30/15                                         | 84.7                                                        | 3.5               |
| 19.     | 111                 | R&D Office                             | 10/5                                          | 77.7                                                        | 4.9               |
| 20.     |                   | Production Office                      | 10/5                                          | 85.7                                                        | 4.1               |
| 21.     | 101                 | Maintenance + Quality Office           | 12/6                                          | 76.3                                                        | 5.2               |
| 22.     | 101, 111            | Transport Operators                    | 9/5                                           | 86.1                                                        | 4.0               |
| 23.     |                   | Bochetonist Department                 | 9/5                                           | 80.0                                                        | 4.0               |
| 24.     |                   | TTM, TTS, TTO Operators                | 28/14                                         | 82.5                                                        | 3.3               |
| 25.     |                   | Bandina 1, Bandina 2 Operators         | 8/5                                           | 79.4                                                        | 4.0               |
| 26.     |                   | Filler, Capiatrice Operators           | 64/32                                         | 82.5                                                        | 3.2               |
| 27.     |                   | Bartell, Calemand Operators           | 16/8                                          | 83.2                                                        | 3.5               |
| 28.     | 102                 | Calandra Operators                     | 20/10                                         | 86.6                                                        | 4.3               |
| 29.     |                   | Q-plex 1, O-plex 2 Operators           | 32/16                                         | 85.1                                                        | 3.2               |
| 30.     |                   | Duplex 1 Operators                     | 12/6                                          | 85.8                                                        | 3.7               |
| 31.     |                   | Comerio 1 Operators                    | 12/6                                          | 84.8                                                        | 3.3               |
| 32.     |                   | Filler, Capiatrice, Bartell Operators  | 60/30                                         | 81.7                                                        | 3.2               |
| 33.     |                   | Bandina 3 Operators                    | 4/5                                           | 82.0                                                        | 3.6               |
| 34.     | 112                 | Triplex, Duplex, Comerio, SRH          | 60/30                                         | 83.2                                                        | 3.0               |
| 35.     |                   | TTM 3, TTS 3, TTM 3, TTS 4             | 16/10                                         | 83.8                                                        | 3.1               |
| 36.     |                   | VMI                                   | 8/5                                           | 81.9                                                        | 3.2               |
To know if the obtained values are a danger to the health of the workers, we must know the minimum requirements regarding the exposure of the workers to the noise. The results obtained are compared with the values established by the Government Decision no. 493/2006 [6] (amended and supplemented by the GD 601/2017), a decision that took over the provisions of European Directive 10/2003/EC. [7]

Framing within the maximum permissible limits was achieved in accordance with the maximum noise exposure value of 87 dB (A). It is noted that there are jobs with exceeding the maximum allowed limit, like: BY 1, BY 2, BY 3, Self-sealing 1, BY 15, BY 16, PTSM 1, PTSM 2, Self-sealing 2, Samples Atelier, Grinder Operators. Employers have a legal obligation to protect the safety and health of workers against all workplace noise risks and must take immediate measures to reduce noise.

| No. | Department/Atelier                  | Code   | Efficiency (% ±) |
|-----|-------------------------------------|--------|-----------------|
| 37. | Confection Efficiency Atelier       | 34/17  | 84.3 ± 3.1      |
| 38. | Maintenance Atelier                | 12/6   | 83.2 ± 3.7      |
| 39. | 103 Vulcanization Efficiency Atelier| 20/10  | 85.4 ± 3.3      |
| 40. | Tyre Vulcanization                  | 32/16  | 87.0 ± 3.1      |
| 41. | Samples Atelier                     | 44/22  | 87.1 ± 3.5      |
| 42. | 103-104 Boiacca Transport          | 17/9   | 85.9 ± 3.2      |
| 43. | 103-113 Boiacca Fix                | 8/5    | 79.5 ± 3.2      |
| 44. | 103 Confection Office              | 7/6    | 85.3 ± 3.9      |
| 45. | 112 Tailoring Operators            | 7/5    | 81.5 ± 3.6      |
| 46. | Modulo Plus Operators              | 96/48  | 80.7 ± 3.0      |
| 47. | 103 Flexi Operators                | 176/88 | 80.0 ± 3.0      |
| 48. | Tradizionale Operators             | 16/8   | 81.3 ± 3.2      |
| 49. | 113 Flexi Faza 1 Operators         | 52/26  | 81.7 ± 3.3      |
| 50. | 113 Flexi Faza 2 Operators         | 52/26  | 79.1 ± 3.0      |
| 51. | EVO Operators                      | 96/48  | 81.5 ± 3.0      |
| 52. | 115 Tyres Recover                  | 8/5    | 81.8 ± 3.6      |
| 53. | 122 Mechanical Atelier             | 9/5    | 81.3 ± 5.2      |
| 54. | 113-114 Boiacca Transport          | 17/9   | 84.0 ± 3.2      |
| 55. | Vulcanization A Operators          | 8/5    | 86.8 ± 3.2      |
| 56. | 104 Vulcanization B, C Operators   | 16/8   | 86.9 ± 3.2      |
| 57. | Vulcanization D Operators          | 8/5    | 86.4 ± 3.6      |
| 58. | 114 Vulcanization E Operators      | 8/5    | 87.0 ± 3.2      |
| 59. | Vulcanization F, G, K Operators   | 24/12  | 85.5 ± 3.1      |
| 60. | Tyres Uniformity Operators         | 48/24  | 86.8 ± 3.0      |
| 61. | Tyres Classification +Online Control Operators | 52/26 | 86.2 ± 3.0 |
| 62. | Trimming                           | 8/7    | 86.3 ± 3.3      |
| 63. | 105 First and Second Control       | 88/44  | 83.0 ± 3.0      |
| 64. | Scerografie                         | 4/5    | 84.6 ± 3.2      |
| 65. | X-Ray                               | 8/5    | 85.5 ± 3.2      |
| 66. | Transport Operators                 | 16/8   | 86.8 ± 3.5      |
| 67. | Tyres Repairing Operators          | 8/5    | 83.6 ± 4.0      |
| 68. | Tyres Uniformity Operators         | 88/44  | 85.6 ± 3.0      |
| 69. | 115 Grinder Operators              | 20/10  | **89.5** ± 2.5  |
| 70. | ZF                                  | 24/12  | 85.3 ± 3.4      |
| 71. | Therme Power Plant & Compresor Station Operators & GSM Operators | 18/9 | 85.4 ± 3.2 |
| 72. | Fire Department Fire Safety Operators | 10/5 | **81.0** ± 4.9 |
| 73. | Market Quality Operators            | 1/5    | 67.0 ± 5.8      |
Article 5(1) of the directive 10/2003/CE requires that, taking into account technical progress and the measures available to control the risk at source, ‘the risks arising from exposure to noise shall be eliminated at their source or reduced to a minimum’. [7,8]

The research will continue with the design of technical and organizational solutions to reduce noise at the workplace and may be a support for companies regarding the risk of hearing loss.

5. Conclusions
This paper presents the necessary steps to evaluate the exposure to noise in the workplace using the function-based strategy. The principle of this measurement strategy is to take samples of the noise exposure, for the identified functions in the work analysis and implicitly to define the homogeneous exposure noise groups (HENGs) to reduce the measurement efforts.

Function-based measurements are most useful when it is difficult to describe typical work patterns or when it is not desirable or impractical to perform a detailed work analysis.

In this paper, the noise exposure was evaluated for 947 samples distributed on 73 HENGs covering all the jobs in the production workplaces. The number of workers in a group varies from 1 to 88 persons. The minimum cumulative duration of the measurements, for the number of workers in each HENG, varies between 350 and 5280 minutes. This method may require a longer period due to the time required for measurements, but it produces less uncertainty about the obtained result. A larger number of samples reduces measurement uncertainty, which means increased accuracy of measurements.

The method presented in this paper is very useful for detailed studies of noise exposure, for epidemiological studies of hearing loss and for observing other negative effects regarding noise exposure.

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