Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management
Istanbul, Turkey, July 3 – 6, 2012

Noise in the Workplace: Proposal for Decreasing Noise Pollution.

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Abstract

The noise pollution and its effects have been underestimated in the recent past because they have been considered as a local disturbing factor only concentrated in restricted fields and in particular areas of work. Nonetheless, today the noise appears as one of the major causes of life quality decrease. The aim of this article is to define and analyze this issue from a privileged point of view, considering the consequences of the noise pollution both within a working environment both within the urban environment in which is located a production system. In detail, this paper presents the results obtained from the analysis of a company operating in the field of environmental protection and that performs different activities of screening, sorting and recycling of waste produced in the urban context. For this company the authors have studied the operating conditions in which the workers perform their work activities, established the most adapted methodologies and tools indispensable to carry out the noise measurements and evaluated the existence of hazardous conditions. They present in the last part of the work different operational and structural solutions capable of contain the risk for the health of the workers and significantly reduce the noise emissions in the environment.

Keywords
Noise pollution, waste management, environmental protection

1. Introduction
The noise is one of the main factors which negatively characterize the usability of the workplace because of the physiological damage that it causes to humans and it is one of many occupational diseases from work (Alton, 2001). The determination of the hazard levels of noise is the result of complex statistical surveys carried out on representative groups of individuals. ISO/R 1999/1990 (International Organization for Standardization, 1990) describes the principle generally used to establish the limits of acceptability of noise in industrial environments. This rule establishes a relationship between the noise exposure in a working environment (in terms of equivalent sound level, relative to an exposure of 40 hours per week) and the estimate percentage of people exposed to this noise who have exhibited an increase in increase in hearing threshold greater than or equal to 25 dB. This percentage is determined as the arithmetic mean on the threshold elevations at frequencies of 500, 1000 and 2000 Hz (Kaliakatsos et al., 2011). Hearing loss resulting from exposure to noise can not be confused with total or partial deafness deriving from injury to the auditory nerve. In fact, the hearing loss is characterized by a progressive loss that develops over several years, generally from 5 to 10 years (Çelik et al., 1998). The audiometric loss is an index of auditory disability and it is measured as mean value at the frequencies of 500, 1000 and 2000 Hz. Table 1 shows the disability classification in function of the audiometric loss. Interventions to be implemented in workplaces to protect people exposed depend on the disability classification. From these configurations derives the formulation of rules, which aim to reduce the "noise risk" in work activities.

Table 1. Mean value of audiometric loss for frequencies of 500, 1000, and 2000 Hz and relative disability degree

Audiometric loss (dB)	Disability Degree
< 25	No
25 - 40	light
40 - 55	medium
> 55	serious

Two different types of hearing damage can be identified depending on the time interval at which the damage occurs: the "acute injury" that is realized in a short time after a particularly intense stimulation (160-180 dB) and the "chronic damage" that occurs after a few years as a result of prolonged exposure to high noise levels. In addition, beside to the hearing damage, the noises exposure causes other effects on humans that are not always directly connected to it, because: (i) they are not characterized by specific clinical symptoms; (ii) often they are transitional in nature; (iii) they are mediated by the central nervous system; (iv) they can occur even at low noise intensity; (v) the medical diagnosis is not readily feasible (Mattei, 1966; Cocchi et al., 1992). The physiological systems directly affected by the noise, in addition to the auditory system, are:

- Respiratory apparatus. In some subjects, the respiratory rate increases by 10-30% if noise levels exceed 85 dB. This results in an evident reduction in the amount of air that is inhaled and exhaled from the lungs.
- Endocrine system. Some glands such as pituitary, adrenal, thyroid and pancreas are most stimulated.
- Cardiovascular apparatus. When the noise achieves high sound levels, it involves peripheral vasoconstriction, decreased cardiac output, tachycardia and extrasystoles. In such a context, thresholds of 90 dB are dangerous for workers who already suffer from cardiovascular problems.
- Visual apparatus. Noise exceeding 75 dB reduces the perception of depth of vision and a reduction of the visual field is present if the noise level exceeds 120 dB.
- Gastrointestinal apparatus. Stomach upsets may occur accompanied by spasms and cramps. In these cases the stomach is urged to produce more acid secretion by increasing the risk of gastritis, colitis, and duodenal ulcers.
- Nervous system. The slowdown and alteration of the electrical activity of nerve cells affects both the ability to react (reducing glare) and the ability to fix the memory (reduction in memory).
- Psychological reactions. Noise may include from a psychological perspective poor concentration, mental fatigue, insomnia, irritability, intolerance, reduced alertness and, in severe cases, forms of depression.

The analysis carried out highlights the risks related to noise and shows that it is necessary to ensure that sound levels generated during work activities are contained within the safety limits set by the rules.

2. The Acoustic Quantities

The human ear is sensitive to a minimum sound pressure of 20 μPa (2×10^{-5} N/m^2) and the maximum sound pressure that a man can endure without feeling sensations of pain is of 63.2 Pa (1×10^{2} N/m^2). In acoustic are used both the acoustic sound pressure level and the sound power level. Numerically the level of pressure or power is measured in decibels (dB). G.T. Fletcher (1801-1887) has defined the following quantities:

Sound Intensity Level

$$L_I = 10 \cdot \log\left(\frac{I}{I_0}\right) \qquad [\mathrm{dB}] \tag{1}$$

Sound Power Level

$$L_W = 10 \cdot \log\left(\frac{W}{W_0}\right) \qquad [\mathrm{dB}] \tag{2}$$

Sound Pressure Level

$$L_p = 10 \cdot \log\left(\frac{p^2}{p_0^2}\right) \qquad [\mathrm{dB}] \tag{3}$$

where:

I	is the intensity of sound expressed in [W/m^2];
I_0	is the reference sound intensity conventionally assumed equal to 10^{-12} [W/m^2];
W	is the sound power expressed in [W];
W_0	is the sound power conventionally assumed equal to 10^{-12} [W];
p	is the sound pressure expressed in [Pa];
p_0	is the reference sound pressure conventionally assumed equal to 20 Pa.

The noise in nature is an "unpleasant sound" and it is represented by a mechanical disturbance that propagates in an elastic means by sound waves with frequencies between 20 and 20,000 Hz. The characteristics of the noise can be studied in the frequency domain through the relief of the oscillations induced on the molecules of the elastic means of conduction. The noise, in addition to the harmonic content, can be classified depending on the nature of the source (natural/artificial), intensity, changes over time (continuous, intermittent, fluctuating, and impulsive). The work environment along with the external environment, the living environment and the habitat environment is one of the four areas where environmental noise is generated. Each environment is characterized by three environmental elements: the source, the space of propagation of sound waves and the receptors. Standards define, for each sector and for each environmental element, the physical quantities related to the risk of pollution and noise, measurement mode, the emission limit value of the sources, the exposure time for the areas and receptors, acts and territorial actions of planning and specific skills. Specific weighting curves identified by the letters A, B, C and D is used in the frequency domain to adapt the noise measured by an instrument to that perceived by the human ear. The curve A is used for the work environments and it approximates the inverse of the isophonic curve of 40-phon; it attenuates the low frequencies than high. International standards issued by ISO, in order to establish criteria and methods to prevent and contain the "noise risk", have set specific dimensions to control and levels of acceptability. The most important factors to check are: (i) the daily exposure of a worker ($L_{EP,d}$) and the weekly exposure of a worker ($L_{EP,w}$)

The first factor, expressed in dB, refers at observation intervals of 8 hours per day and it represents the daily noise exposure to which a worker is exposed. The safety limit of this factor is set at 87 dB. The daily exposure of a worker is expressed as:

$$L_{EP,d} = L_{eqA,T_e} + 10 \cdot \log\left(\frac{T_e}{T_o}\right) \qquad [\mathrm{dB}] \tag{4}$$

where

$$L_{eqA,T_e} = 10 \cdot \log\left[\frac{1}{T}\int_0^{T_e}\left(\frac{p_A(t)}{p_0}\right)^2 dt\right] \qquad [\mathrm{dB}] \tag{5}$$

L_{eqA,T_e}	is the equivalent continuous A-weighted sound "A" [dB];
$p_A(t)$	is the instantaneous value of the weighted sound pressure A [Pa];
p_0	is the reference sound pressure equal to 20 [Pa];
T_e	is the daily duration of exposure of a worker to noise [h];
T_o	is the duration of the work shift of 8 hours.

The second factor is the weekly average of daily values $L_{EP,d}$, evaluated on the number of days per week. For it the safety limit is set at 87 dB.

$L_{EP,w}$ is determined by the following formula if the working day per week are five:

$$L_{EP,w} = 10 \cdot \log\left[\frac{1}{5}\sum_{k=1}^{m} 10^{0,1\cdot\left(L_{EP,d}\right)_k}\right] \qquad [\mathrm{dB}] \tag{6}$$

where $(L_{EP,d})_k$ represents the values of $L_{EP,d}$ for each of the n days per week.

In the international context the main rules governing the sector refer to that issued by ISO and IEC, while each national Organization for Standardization shall adopt such rules and makes them applicable in the territories under its jurisdiction. The individual sovereign states enact specific laws to attract and include the contents of international standards and make them binding on the national territory (Brown et al., 1991; Sutton, 1976).

3. Case Study

The company and the urban context under analysis is the Calabria Maceri, SpA, located in the south of Italy. The company was founded in 1990 and operates in the recovery, recycling and disposal of Municipal Solid Waste (MSW) and waste from commercial, craft, industrial and service. Within its manufacturing facilities Calabra Maceri makes the screening and selection of waste. The transformation cycle was designed to obtain homogeneous materials that can be used again in the industrial field. The company is extremely sensitive to both environmental and quality aspects and it has obtained the certifications ISO 14001 and ISO 9001.

The main activities within the production system of Contrada Cutura concern:

- receiving and storage of waste;
- selection;
- recovery, packaging and shipping;
- the disposal of the non-recoverable.

The materials selected and trade by the company are: paper, plastics, ferrous materials, glass and aluminium. Currently, Calabria Maceri implements the selection with semi-automatic mode or by making use of both processes that do not need the human component and processes that make direct use of skilled labour. In each work shift are involved about 30 workers. The current configuration of the processing cycle is showed in Figure 1.

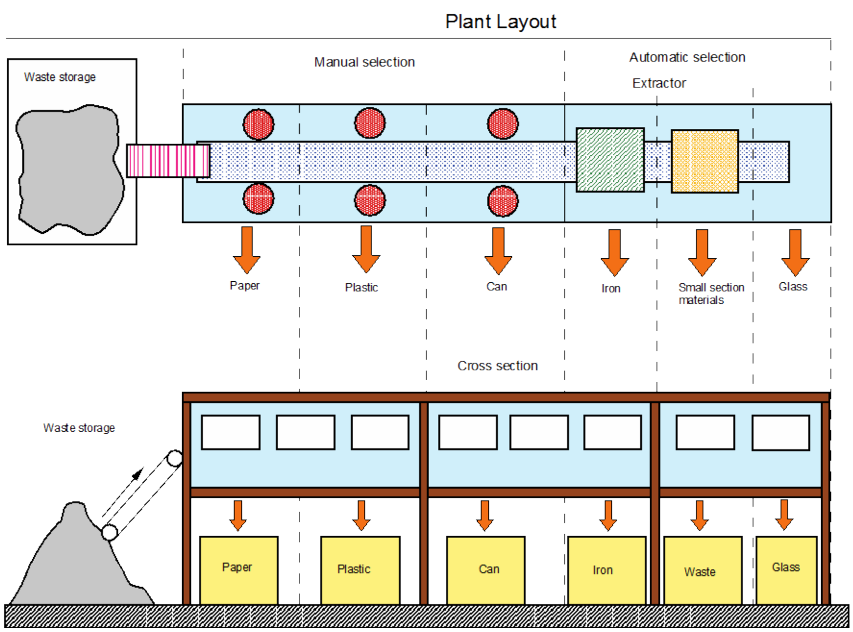

Figure 1: Current configuration of the selection process

The production line used for the selection involves the following steps:

1. the product obtained from the separate collection of rubbish is conveniently deposited in special storage areas.
2. using suitable mechanical means the waste is dispersed on the temporary parking areas.
3. an operator with suitable cutting tools manually "opens the bags" cutting the plastic bags containing the waste.
4. one or more workers operate the first selection whose objective is to remove the bulky materials of size greater than 25-30 cm.
5. the waste are conveyed, through the use of suitable mechanical means, in the vicinity of the conveyor belt that feeds the selection station.

At the end of these steps, it's operated the real process of screening and selecting. This process consists of two sections: in the first section is made a manual selection (Figure 2a), while in the second section the selection is automatic (Figure 2b).

Figure 2a: Multimaterial selection plant

Figure 2b: Mixed packaging selection plant

6. Downstream of the manual selection area, the final automatic activities are operated. The waste still present on the conveyor belt are subjected to the action of a magnetic deferrization. This apparatus, exploiting the magnetic properties of an electro-magnet, attracts the ferrous materials moving them away from the rest of the waste. Subsequently the residual materials are subjected to an intense stream of air, generated by an aspirator that captures the materials of lower weight and conveys them inside a duct to be eliminated. If the selection process is done correctly on the conveyor belt will be finally present only glass bottles and cans that will be discharged into the collecting box.

After the selection phase, the materials obtained are suitably moved within the plant to be shredded and packaged. The shredder and the compactor are showed respectively in Figure 3a and Figure 3b.

Figure 3a: Shredder

Figure 3b: Compacting

Other contributions which increase the noise pollution are provided both by the means of transport used for the collection of waste, both by the moving means employed to move the materials inside the plant. These noise sources take place occasionally because they are focused only in some time periods. Additional permanent contribution is made by selection activities and machineries. Therefore, the measurements to be performed must take into account these aspects and they should be performed not only at certain points in the system but also in well detailed moments.

4. Methodological Aspects

The dimensional characteristics of the plant in which the measurements were made are showed in Figure 4. Structurally the plant was built of reinforced concrete with brick infill appropriately plastered. In addition to vehicular and pedestrian accesses, in the exterior walls are present large windows to ensure a good flow of fresh air. The roof is of type sheed with a height about eight meters; the floor is industrial with superficial wear. The production machines are located in peripheral positions in order to allow ample manoeuvring space for the movement means and appropriate areas for the temporary storage of the materials being processed. Depending on

the type of work, the measuring points have been positioned as indicated in Figure 4. It should be noted that the points identified by the numbers 2 and 3 represent fixed work locations because workers perform their tasks without making significant shifts, while the positions indicated by the numbers 1 and 4 should be considered as mobile stations because operation dealing these positions only temporarily (Moreland et al. 1976; Cheremisinoff 1996; Cops 1985; Sutton 1968; Bettarello et al., 2010).
The noise recorded in Step 1 can be generated from the following causes:

- arrival of trucks and waste discharge;
- plant shredding on;
- compaction and active packaging system;
- cart for the handling of the materials in function;
- cardboard handling.

In particular, it was possible to perform measurements in the following conditions:

1. cart for the handling of the material active;
2. trucks arrival and waste discharge;
3. compacting plant active with handling of the carton by the cart;
4. compaction plant active.

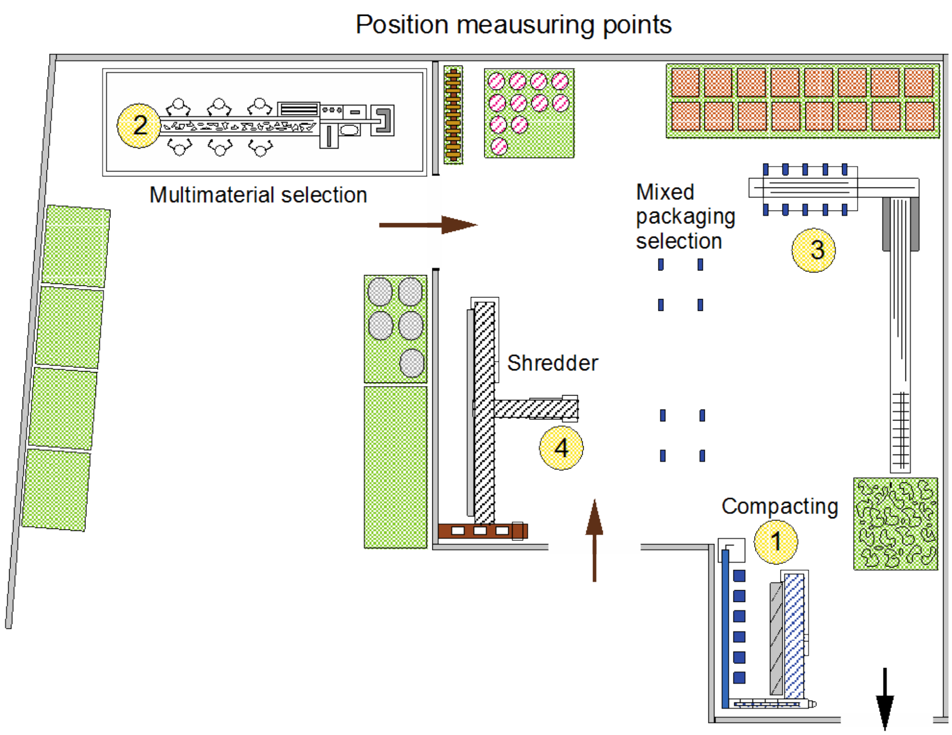

Figure 4: Plant layout with the points of measurement

The noise recorded in *Step 2* can be generated from the following causes:

- Handling waste conveyor belt inside the multi-material selection;
- Noise caused by the fall of various types of mixed materials in their containers.

The measurements were performed under the following conditions: (i) Pause working, in which the machine is stopped; (ii) normal working conditions, with the conveyor belt on.
The noise recorded in *Step 3* can be generated from the handling conveyor. In this case the measurements were carried out under the following conditions:

- Pause working, in which the plant selection mixed packaging is stationary;
- Under normal working conditions, with a conveyor belt on.

The noise recorded in *Step 4* can be generated from the following causes:

- Arrival of trucks and waste discharge;

- plant shredding on;
- Active packaging plant and compaction;
- Trolley for handling;
- Handling waste.

In this step measures take account:

1. Equipment off;
2. Shredding plant on;
3. Truck arrival and unloading waste, truck handling, packaging and compaction plant operating.

The measurements were made using a sound level meter SVAN 945th (BND309/310), suitable for statistical analysis and precision Class 1. The essential characteristics of this instrument are: integrating sound level meter with spectrum analyser sound in real time at 1/1 & 1/3 of octave, frequency band of 1 Hz - 20 kHz. The instrument has been set with the following parameters:

- Measurement functions = 1/3 octave;
- Measure setup:
  - Start delay = 2/2;
  - Integration Time = time of measurement (depending on the type and extent of events to log);
  - Buffer step = 1 second.
- Profile setup=3 profiles measured with A-weighting scale and functions slow, fast, and impulse.

In addition, in order to get accurate results, in the sound level meter were set the following parameters:

- Reference time T_r: Day Period;
- Observation time T_o: Period of time, within the reference time, during which has been I carry out the monitoring and verification of the conditions of noise.
- Measurement time T_m: Period of time, within the observation time during which were taken the noise measures.

To verify the correctness of the measures, the instrument has been calibrated before and after each measurement cycle in order to obtain deviations of measure included between ± 0.5 dB.
The sound level meter was positioned about 1.5 m above the ground, from a distance of more than one meter from the noise source and at about 0.5 m from the ear of the operator. The instrument was launched and left in position for the whole measurement time expected.
The most important parameter to be measured and analysed is the equivalent level of daily exposure of workers $L_{EP,d}$. For the precautions taken in the measurement and for the duration of the measure, the value of L_{eqA} measured by the sound level meter will correspond with the level of daily exposure of workers. Because the work period is formed by 8 hours, there is not need to add any correction factor.

5. Analysis, Results and Conclusions

In this section are showed the result of the measures. The authors focused particular attention to measurements made in Step 2, at the location occupied by the plant operators to multi material selection. As specified in Tables 2 and 3, the measurements were carried out at different times and in various operating conditions.

Table 2. Operating conditions for the measures in Step 2

Date	14/10/2011	T_r = Period daytime
Time	9:32:48	T_o = 7 hours (07:00 -14:00);
Under normal working conditions with belt latch		

Table 3. Operating conditions for the measures in Step 2

Date	14/10/2011	T_r = Period daytime
Time	10:28:40	T_o = 7 hours (07:00 -14:00);
Under normal working conditions with the active conveyor belt		

The first measurement was carried out during a work break when the conveyor belt was on, while the second measure refers to conditions of full operability, such as when the conveyor belt is active. Tables 4 and 5 show respectively the numerical values recorded by the instrument during the tests for the three profiles of measurement, while the graphs of Figure 5 and Figure 6 show the time course of these values.

Table 4. Values of the measured noise for the three profiles at the point n ° 2 (conveyor belt off**)**

Profile	Filter	Time Measure ment	Units	Peak	Min	Max	Spl	Leq	Ltm3	Ltm5	SEL	Lden
1	A	0.03.00	dB	78,7	50,7	61,6	52,4	53,8	55,2	55,9	76,4	53,8
2	A	0.03.00	dB	78,7	49,7	66,5	52,9	53,8	57,4	58,6	76,4	53,8
3	A	0.03.00	dB	78,7	50,6	67,6	53,6	53,8	59,2	60,5	76,4	53,8

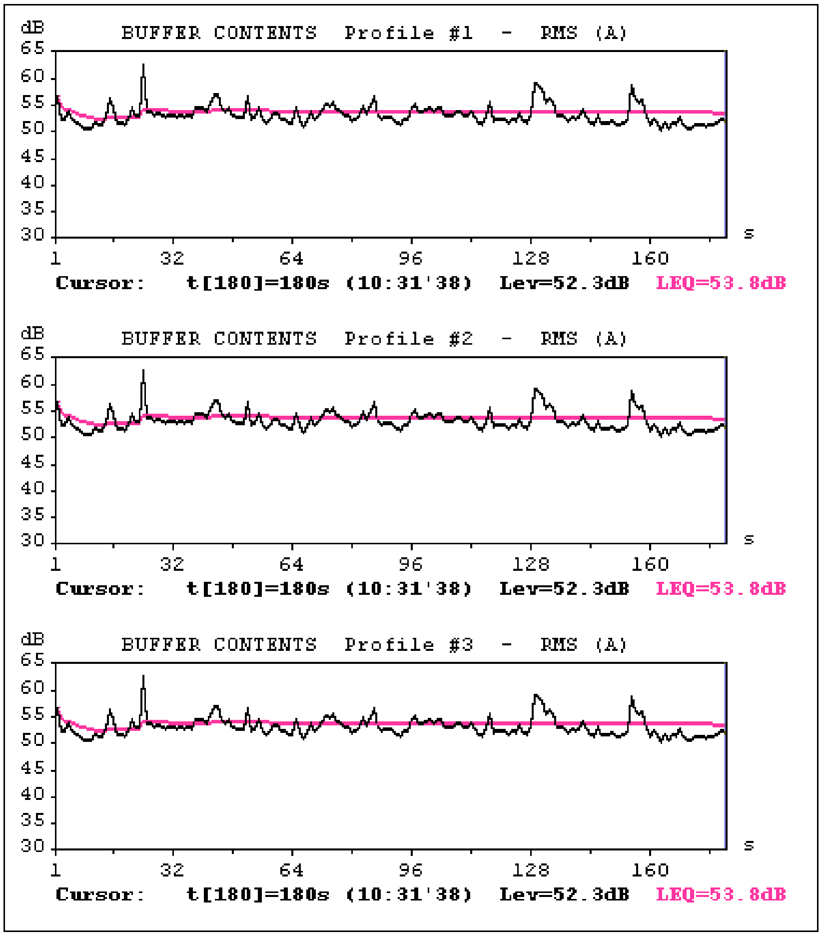

Figure 5: Temporal trend of the three profiles of measurement in the case of stopped conveyor belt

Table 5. Values of the measured noise for the three profiles in Step 2 (conveyor belt off)

Profile	Filter	Time measurement	Units	Peak	Min	Max	Spl	Leq	Ltm3	Ltm5	SEL	Lden
1	A	0.03.00	dB	117,8	71	91,9	82,7	83,3	86,8	87,8	105,9	83,3
2	A	0.03.00	dB	117,8	65,8	98,5	86,8	83,3	91,8	93,5	105,9	83,3
3	A	0.03.00	dB	117,8	73,9	101,9	90,8	83,3	95,8	96,9	105,9	83,3

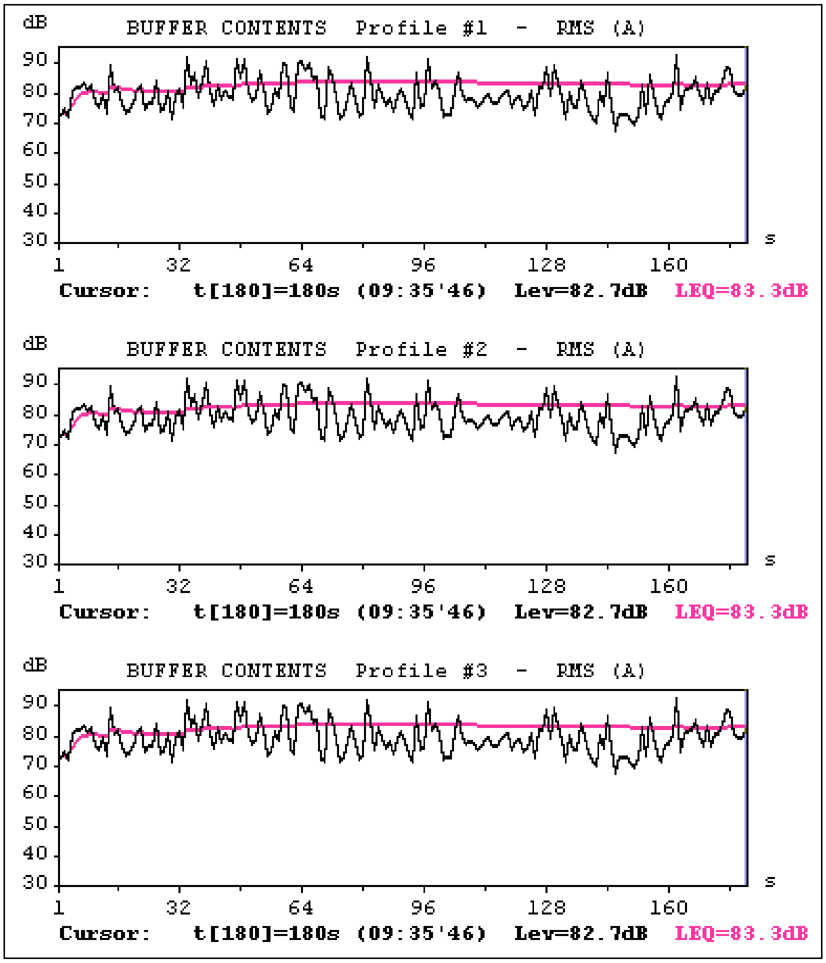

Figure 6: Temporal trend of the three profiles of measurement in the case of conveyor belt operating

The analysis of the results shows that for the first measure the equivalent noise level is equal to 53.8 dB, but there are both an impulsive and tonal components as highlighted by the spectral analysis performed by bands in 1/3 of octave. For the presence of these components, the results are corrected with an increment of 6 dB. The correction leads to achieve a total value of 59.8 dB. This value is located below the danger threshold.

For the second measure the equivalent noise level is equal to 83.3 dB. Because of tonal components and impulsive components the equivalent noise level is of 89.3 dB. This value exceeds the limits of dangerousness.

For each measurement point was performed four measurements in order to take account of the different operating conditions that may occur. The numerical synthesis of all the measurements carried out is shown in Table 6.

Table 6. Values of the measured noise at the observation point (dB)

	Measure 1	Measure 2	Measure 3	Measure 4
Point 1	71,1	83,3	78,2	81,8
Point 2	59,8	89,3	62,5	90,8
Point 3	72,1	78,6	75,2	82,7
Point 4	75,3	83,6	78,7	82,9

The data analysis shows that the safety limits are exceeded only at the measuring point 2 when all the equipment works at full capacity. To obtain more information the measurements were repeated by significantly increasing the observation interval from 3 to 30 minutes. The results to which it leads, unfortunately, do not differ from the initial ones and then confirm the presence of unacceptable working conditions.

The solutions proposed to bring the system within the limits imposed by the rules are twofold: organizational and structural. From the organizational point of view is necessary to avoid the simultaneous use of equipment and machinery therein, to make more frequent shifts of workers in order to reduce the exposure period, and finally giving the workers themselves the necessary devices personal protective equipment to reduce the sound vibrations. From the structural point of view it is necessary to install sound-absorbing panels along the side walls in sheet to absorb the sound waves generated by the machining. In addition, because the replacement of machines currently used is impossible, it is necessary to improve the efficiency of sound: through maintenance operations carried out frequently and the use of substances able to reduce the coefficients of friction of the moving parts, it is possible to limit the noise that is generated by mechanical contact and vibration.

In conclusion, it should be noted that the values of noise measured in the other measuring points are substantially below the regulatory limits and the operating conditions that have generated them are occasional and not repeatable with continuity over the entire work shift. This reduces significantly the time interval of exposure and therefore greatly limits the risk to workers.

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