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Excess noise reduction with ear protector applying mathematical algorithm: A case of medium density fiber industry

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Abstract

Consistent exposure to elevated sound levels results in noise health effects. The industrial environment represents a major source of such effects. There is significant variation in noise at different sections of such industries due to which most of the workers are exposed to these sounds at one or another level. In this study, a noise level measuring methodology is used for fixed and moving workers. This article introduces an algorithm for optimum selection of earmuff and earplug for different working places depending upon the exposure to noise. Medium density fiber industry is considered as a case for this study. It considers workers who are busy at a single point and face a consistent amount of noise as well as the workers who move and are exposed to a varying level of the noise. Noise level meters are used to measure the noise level at different points. At each point, the average value of the samples is taken. Based on the data collected, earmuff with high noise reduction rate is assigned to the workers closed to the machines. Implementation of the developed algorithm reduced the effect of noise on workers by 6.9%, 5%, and 16.3% for the chipper machine, pneumatic fan, and sanding machine, respectively, that were identified as the major source of noise at medium density fiber industry. This percentage reduction helped the workers to bring them to the optimum safe level of noise that is 85 dB and protect them from hearing loss severity due to frequency variations.

Keywords

Noise; noise reduction rate; noise health effects; earmuffs; medium density fiber

Introduction

Rapid industrialization is creating problems including noise, air, soil, and water pollution, increasing poor working condition and several health problems. Industrialization is becoming a major physical and psychological issue worldwide. Industry is the main component for converting raw material into finished goods. Noise issue is globally recognized that most of industries do not know standard safety limitation. Different types of machines are used in these industries, which create noise and affect workers. They are mostly affected mentally due to their more working time in that noisy environment. Proper noise standard is issued according to the human capacities and capabilities, exceeding those limits human health is affected. Many effects are attached to noise, for example, workers' performance and abilities are affected, reduce aggressiveness, annoying, and irritability comes into one's behaviors. "Physiological effect are produced in the presence loud noise, as loud noise the muscles are contracted. Due to continuous ear muscles contraction for longer time irritability, headache and aggression comes to effected person" (guidelines for Community Noise, WHO, 2000).[1] Noise is annoying in nature; there is no definite relationship between the degree of annoyance and the risk of adverse health effects due to noise. At times, even low noise can be irritating and frustrating. Speech intelligibility is the ability to understand spoken words. This ability of understanding of what people communicate in sayings disturbed when excessive noise occurs.

Many people contributed to techniques and algorithms in finding noise health effects. Most of these effects result in muscular disorders, for example, Miles (1953) assessed four subjects' ability to squeeze hand

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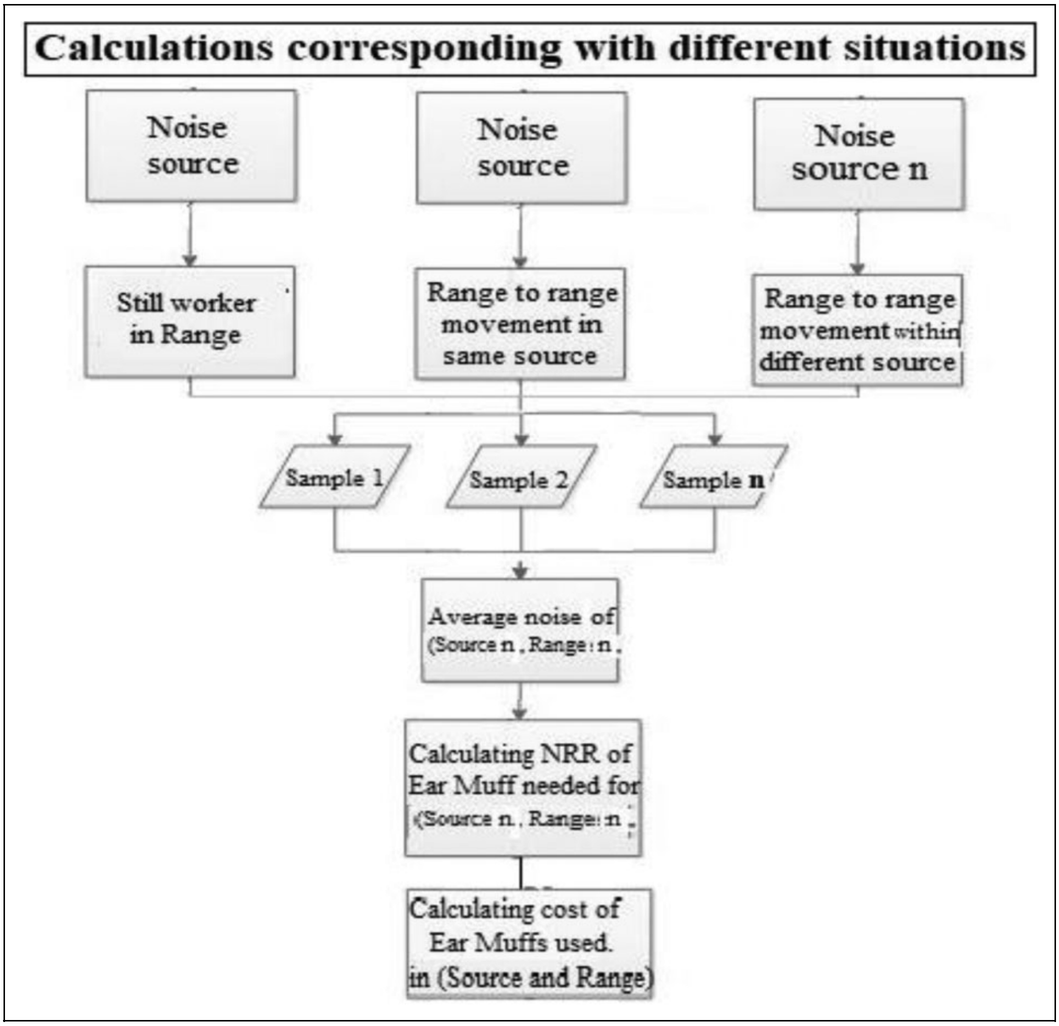

Figure 1. Noise level measuring methodology used for fixed and moving workers.

dynamometers in a background of jet engine noise at 128 to 135 dB (although subjects wore earplugs). He found that right-hand performance increased by 2%, left-hand performance decreased by 10%, and total output (both hands) decreased by 2%. Different people gave an algorithm to know about stress creation from a noisy environment and to handle that issue. Initially, active noise reduction technique is used to reduce the frequency of noise using earmuff equipment after which acoustics fixture technique is used. Azadeh gave an intelligent algorithm for performance evaluation of job stress and health, safety and environment (HSE) factors in petrochemical plants with noise and uncertainty. The flow chart in Figure 1 represents working methodology of this study. Sampling for each range are taken which lead to calculate average noise ranges, and help in earmuff handling to specific workers.

A case study

The study is performed on the chipboard industry, having excessive noise issues. Powerful machines like wood crushing and pneumatic and sanding machines were creating extensive noise in exactly the same location where a number of workers were performing their duties. The industrial working flow and effective noise area are shown in Figure 2. In this industry, most of the workers were in fixed position still while many of them were moving for performing material handling and for inspection purposes.

Protection of ear through "earmuffs and earplugs" from excessive noise vibrations is the optimal way, as it does not create hurdles for their hand and body movements of the worker. The novelty of this study is that it recommends ear protector to the worker of each scenario, either of location wise (near or away to noise source), their time spending wise (spending different times while moving from one noise source to other, in a shift time period), or their environmental noise effect (like traffic noise effect). The mathematical formulation allows all the defined situations to be measured stepwise. Workers closer to machines wearing noise reduction rate (NRR) earplugs overcome its noise effects up to high extent. It is unprofessional to recommend to each worker the earplug having same NRR, causing facilitator out of budget. Even there would have no idea

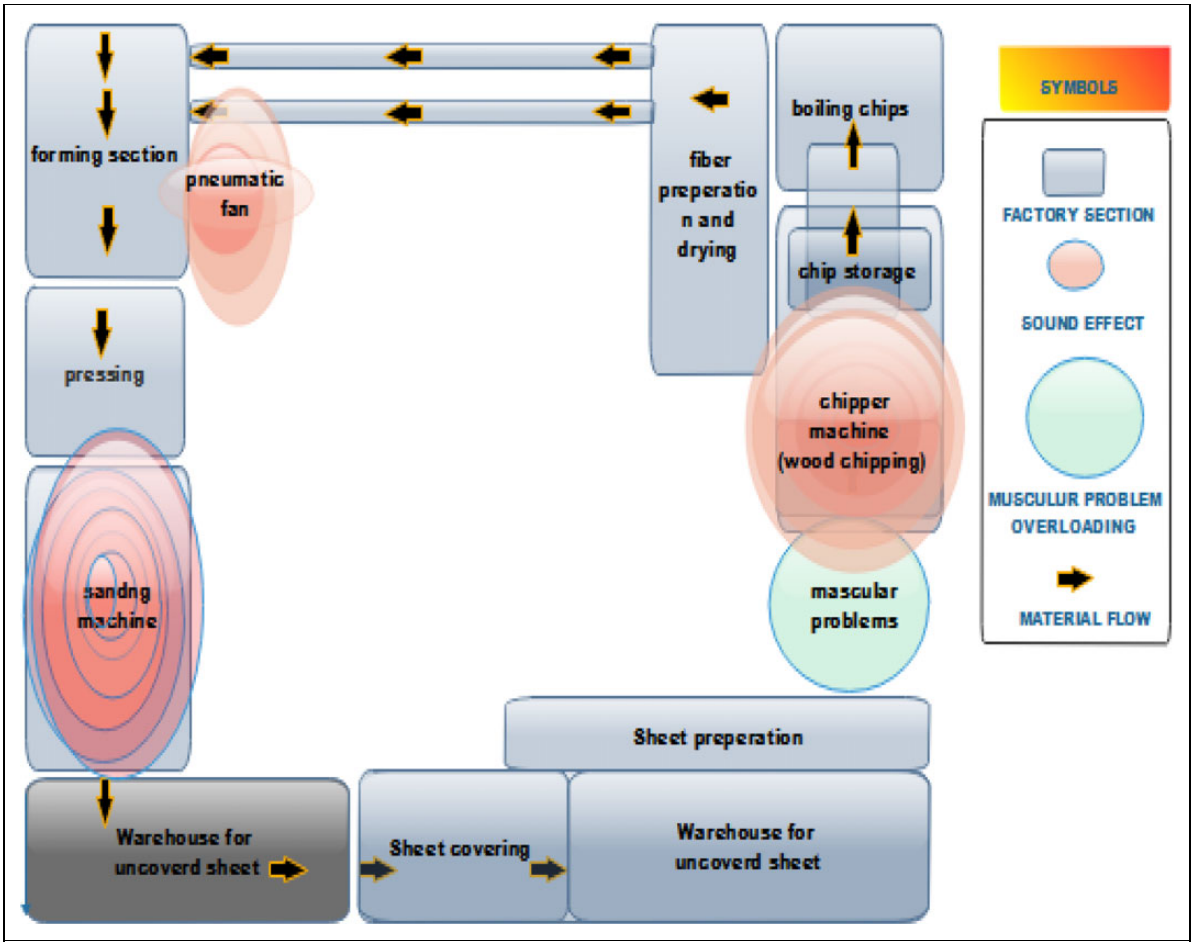

Figure 2. The critical noisy area in the MDF industry.

of noise effect of still and moving workers how much a worker is affecting, because their time spending durations and locations are unknown.

In this study, the noise produced by machines of medium density fiber (MDF) industries is observed, and their effect is reduced up to a safe level. For this, a number of workers are taken in account and their facing noise loudness and their frequencies are observed. NRR is a guideline that indicates the amount of potential protection a hearing protection device will give in a noisy environment. NRR was measured using the decibel, a standard unit of measurement used to describe how powerful or compressed a specific sound level is. An NRR, also sometimes referred to under the umbrella term of "hearing protection rating". Industrial machinery and processes are composed of various noise sources such as rotors, stators, gears, fans, vibrating panels, turbulent fluid flow, impact processes, electrical machines, and internal combustion engines. It happened very rare that labor was told or given earmuffs having unknown reduction power. So, there are no measures which could be decided to recommend earmuff to workers. The defined technique is comparatively simple for noise level to be known. M. Kube developed a system for noise reduction by modifying the audio feedback, which increases hearing efficiency.

Using noise level meter

Noise is measured by noise level meter; a digital sound level meter, model EXTECH 407732 was used to measure noise level to record the noise level of the selected site in the industry. It measures from 25 to 130 dB in two ranges, having the third option called "impulse" in which read noise is four times higher than, "fast option" in the measuring device. Noise has categorized into three main parts which are necessary to know for noise measuring prospective. They are A-B-C-weighting: in A-weighting option, the noise at the low frequency is measured to predict the risk to the human ear; B-weighting light metering is the option in which the noise is measured at the moderate level of the human ear; and C-weighting level metering is the option in which the level of sound is measured at a very high level. Mostly used for industrial purposes, high frequency is measured. Calibration of the noise meter is settled before taking reading. It includes checking the battery, amplifier calibration, and microphone test sound level meter calibration. While taking the reading, the microphone of the sound meter is directed toward noise source and measures noise in source ranges. This study is made to create an algorithm for the workers to wear specific and relevant earmuff equipment to keep safe from health effective noise working near to noisy machines. Noise affecting their health and work performance in the industry, as their working hours are greater than they need to spend in a noisy environment. Methodology introduces proper hearing safety equipment for each individual working in a noisy area. The objective is to minimize human and economic losses. Ear safety equipment—such as earmuffs and earplugs—is used for the reduction of the noise which the workers are facing. The worker wears it to stop the extra sound vibration and reduces harmful noise. It is used for individual comfort. The worker continues his own work for a greater amount of time. If he is wearing it, it keeps his ear safe. Each of ear safety instruments varies with various noisy environments. Each noise level required it own type of earplug or earmuff.

Literature review

Noise can cause the hearing losses and it is increasing day by day by even the social things, which cannot be stopped sometime. For example, the noise from the traffic, the noise which the industrial worker is facing from also has an adverse effect (e.g. through personal music players). The working in the noise environment causes physiological problems; it is measured.[2] Reduction of the noise is calculated and their protection is made ensured with safe alternative (earmuffs and earplugs), without medication which has a change of side effects. A high amount of hearing causes different losses which includes the balancing of the human body, also hearing losses occur due to excess of noise.[3][Cheryl Fairfield Estill, 2017 #43][Cheryl Fairfield Estill, 2017 #43] Different types of devices can be used for noise protection, for which a technique active noise reduction (ANR) is used to optimally use an earmuff for lower frequency noise energy without the use of expensive equipment. Later on, acoustic test fixture (ATF) technique is used to know about the performance of earmuff, which was a cost-effective technique to select a type of earmuff in excessive noise environment.[4] The Hazard and Operability Analysis (HAZOP) process is used to identify potential hazards and operational problems in terms of plant design and human error. Many studies of workers in noisy industries have just indicated health problems for those exposed to intense noise level; in this article, the methodology is introduced to make the workers safe from noise. The annoyance of the noise showed some relation with the noise level with the personal characteristics and with the housing. Panovich Katarina et al. conducted a study to know about the numerous factors on the annoyance of noise in a place where there were noise and the urban streets. They found that in 25,751 tested people, 4903 people had a headache problem and the eye strain. They also studied about the age of the people and found that the variation in the ages of those people, also the education level has a difference, the income of a household was also different, and the occupation level was different for most of those people. And occupational noise exposure between the two groups. Noise is created due to oscillation and vibrations of the different part of machines of people use them to find the mechanical issues, by tracing specific noise,[5] but for most of the machines, it is permanent which needs proper protection. Most of the work has done on the medication for psychological and mental effectors, which had faced excessive noise. They found a relationship between psychological medication usage with excessive noise. Individually and contextually perceptions are considered as an important factor with the use of hearing protection devices, it is considered as the safety behaviors. Samples of 434 are taken for analyzation under the constraint of 85 dB(A), and main individual risk factors were analyzed for which questionnaires helped them to observe risks.[6] Noise cancelation with the help of headphones is examined, six scenarios of aircraft where audio files were checked, with six different conditions. After performing experimentation, math is done in the secondary phase. It was concluded that using dual and single headphones, both were giving a good performance, and noise cancelation technology also benefited in the setting of aviation.[7] Modification of feedback of an audio, adaptive noise control (ANC) system is made for an open-fit hearing to reduce noise. This system increases power consumption and efficiency of hearing aids, and computer simulation and practical experiment both verify its results.[8] Unplanned remedies do not necessarily aim at higher risk locations and hence may impose significant and unjustified expense on the company. In most of the paper, technique of binary integer programming is used to investigate treatment along with the cost constraint.[9] Noise increases the risk of workplace injuries by various mechanisms consisting of communication and stress. Occupational noise might increase the risk of workplace injury through a variety of mechanisms, including interference with communication and increased stress. Effect of chronic noise exposure is studied for injuries of the workplace, and the time effect was considered. Effective methods can be developed to save workers from injuries. Noise is reduced by many of the coworkers with the help of different methods and analyzed. It is reduced due to awareness of a person, and a factor which occurs on worker due to organization and protection of hearing in which safety equipment come.[10] Noise-induced hearing loss (NIHL) occurred due to excessive noise, and also it is proven that it causes the highest number of diseases.[11] Criterion level (LC) is that noise level which is permitted for 8 h work shift. This is 90 dB(A) in most cases, in most cases, it is 85 dB(A). Most of papers have no such mythology or formulation to find out the noise level and to give specific earmuff and earplugs for workers. They just focus on importance of hearing protectors.[12][Enembe O. Okokona, 2018 #44][Abel, 1998 #34] The ISO 1996 is usually taken as reference to measure noise map, but its measurements are not so accurate as its measuring instrument location is not known, González et al.[13] carried out measurements of different noise measurements of various distances and heights. Job stress is evaluated for safety health environment. This is the first study that introduces an integrated intelligent algorithm. It is a first study which shows job stress assessment development of noisy environment.[14] Thirty-two millions people are exposed noise to observed to know about the hearing loss, 18% of them had resulted in hearing loss in the research, in which wood product making, mining, and construction industries are compared having higher risks.[15] Learning disability also occurs due to noise, which reduced the power of predicting something while working. Noisy data are necessary to be taken and are analyzed for the proper protective measure to be implemented to reducing harmful effects of learning during work.[16] Ali[17] worked on annoyance and accident in industries due to different noise levels, which increases from their own limits, and to protect its health from exceeding noise. Most of the work is done on workplace injuries on noise exposure and their timings, for which 26,000 workers worked in the era of 1950 to 1980, and cumulative and subchronic noise exposure was checked. The purpose of this study was to assess the effect of subchronic noise exposure on serious workplace injury and how the timing of exposure influenced risk. The authors examined a cohort of 26,000 workers, who worked between 1950 and 1989. Workers facing noise for long periods of times can develop a methodology of communication to prevent from injuries.[18] Active noise-canceling headphone's performance is observed in noise and shown in insertion loss curve form, which was not in regular pattern with practical noise. With the help of these curves, several ANC headphone's performance checked with various noise levels and conditions. Result was not prevalent under different noise levels, but noise controller and brand deviated the graphical curves significantly and extended up to 20.4 dB. With pink noise and actual noise deviations were larger, showing that actual noise in the future studies is important for more correct observations of ANC headphones.[19] For implementing protective measure about the noise, it is necessary to make organization focus on regulations because it has a great impact on noise protection because only awareness cannot keep workers much protective.[10] In a noisy environment, the age, sex, and marital status are also a factor. Statistical study of 3753 adults of age 48–92 years was checked for man and women, to know about the demographic characteristics and occupational histories were taken through questionnaires. The risk of hearing loss was higher in female than in the male, and this risk is observed exponentially higher, with the increase of age.[20] Williams et al.[21] conducted 1-h training for noise awareness in a workplace; the session was organized for two organizations at different locations, the participant was questioned, resulting in that with simple intervention hazard of workplace noise increases. Hearing loss risk is also controlled with the help of medical dose named AM-111; the control is proved to be sustained for a person facing noise from 1 to 4 h up to 155 dB, which is more time than the normal timing of noise limit, as for 4 h it is 90 dB.[22] Effect of noise communication effect was investigated in general aviation, by the cancelation of noise using the headphones.[23] Time and the level of the sound are also researched, which causes hyperacusis, for which 1418 samples are taken and the technique of Bayesian is used for probabilistic analysis. The research resulted that time on the job is an influential factors for its spreading.[24] These results are discussed from both an applied and theoretical perspective. Memoli et al.[25] worked on noise-related traffic, that is, noise related to railway, road traffic, and airplane noises and also with industries. They resulted their experimental data, and then compared with international standards which are theoretical models.

Methodology

The methodology of the article focuses on two types of scenarios, fixed position and moving workers. Each noise source has worker around; some are moving while others work at fix position. Categorization is performed in the ranges around each source. Their facing noise levels are collected by stratifying sampling in each range, and their average is calculated. These values are measured by the noise measuring meter taking samples of different spots. Data are arranged in a statistical way and ranges are made around the source, each having noise measuring samplings taken in a different area inside each range. Giving various readings range wise. At each range, the noise level of source was different, away from source the dB decreased until comfortability level reaches. Data are formulated and arranged taking averages, NRR, and cost for their equipment used by the workers. Collected data were tabulated having the ranges, samplings, and their average for each noise source. And for the data analysis, Excel is used, which helped in the evaluation of the result.

World Health Organization (WHO) has set a limit of 85 dB as allowable noise level, but Occupational Health and Safety Association (OSHA) has prescribed a limit of 90 dB for 8 h of duty in an industrial machining noise environment. Where the duty hours were 8. The regarding, different sections are presented in the following (source: Noise, Canadian Center for Occupational Health and Safety).[26]

The 85 dB for about 8 h is the minimum level, above which permanent loss causes and this hour decreases when the noise is increased every 5 dB above 85 dB and hearing loss is observed according to these time durations. Ambient room noise is about 40 dB, and average speech noise is about 50–60. Yelling up to 80 dB in industrial noise is 100–140 dB. The rules for hearing loss are 85 dB, noise greater than this limit causes hearing loss. Tinnitus is the most common in hearing loss. It is the perception of hearing sound when objective sound is present. It is caused by the

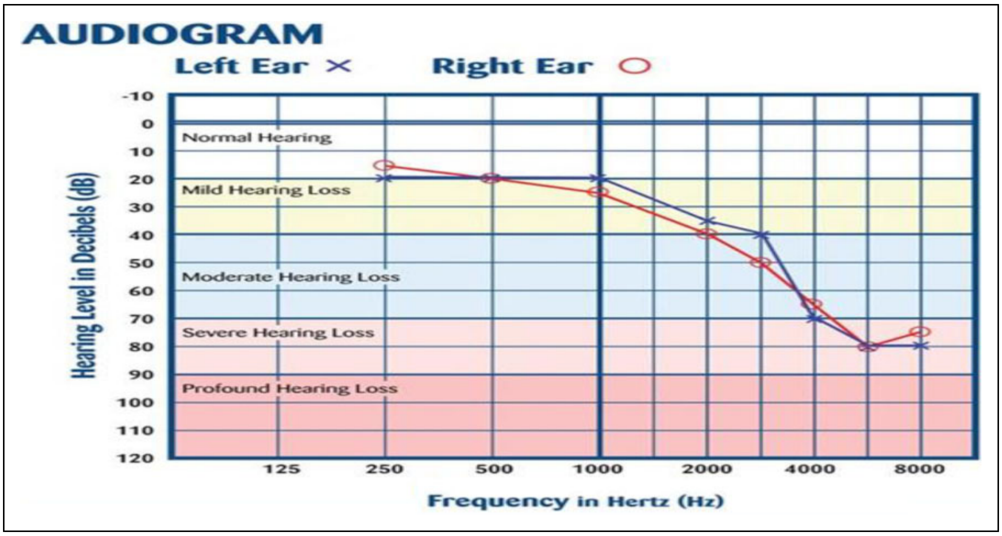

Figure 3. Hearing loss graph of the left and right ear with noise frequency.

Table 1. Increase in noise reduces the working time.

3 dB(A) exchange rate Allowable level dB(A)	Maximum daily permittable duration (h)	5 dB(A) exchange rate Allowable level dB(A)
85	8	85
88	4	90
91	2	95
94	1	100
97	0.5	105
100	0.25	110

hearing cells in the cochlea of the eardrum. In this effect, the sound is heard as ringing in the ear after a large and sudden noise of the hammering or gunshot, which disappeared after some time. If labor is lucky, then Tinnitus come back in a short time, but exposing their selves to lid noises for the time greater than the standard limit, they damage their cells permanently. Noise induced hearing loss in right and left ear due to louder sound is shown in the Figure 3. The test represents frequency on the horizontal axis and decibels on the vertical side, louder sound induces severe hearing loss as shown in the graph.

In Figure 2, pink color ranges show emitting noise from machines. There are three main noise spots (chipper, pneumatic fan, and sanding machine). Shown red areas are the noise affected areas, where the sound emitting is effective for workers. Noise in these areas is greater than 85 dB, as workers shift is 8 h as Table 1 shows. In this condition, facing noise must be lesser than 85 dB, or working time needs to be reduced, which is not affordable earmuffs reduce noise although working time is 8 h. Each of machines has variative noisy area covered, as sanding machine creates comparatively makes more noise than the other two machines, it has covered more of the area. Effecting more workers is shown in Figure 5.

Moving workers during transportation and handling spend time in various noise affected areas around machine source. There are three cases in which noise is effective for workers. First, for fixed position workers, as shown in Figure 4(a). Fixed position workers are still and work on same spot. Workers moving around single noise source are shown in Figure 4(b). Workers moving between different noise sources are shown in Figure 4(c). Workers moving from one location to another facing noises of different locations are shown in Figure 4.

Data collection involves noise level meter. The workers' number, type, and distances from source are shown in Figure 5. It also presents noise level of each machine, and the number and type of effected workers arround each individual machine. The space around each of the noise sources is divided into ranges as shown in Figure 5. Data are collected through stratified sampling. A type of sampling where the entire population is grouped and randomly sampled. Strata in the present have five samplings at different distances in the same range. Table 2 illustrates an arrangement for data collection as well calculates average ($\bar{X}$) noise level for the noisy area.

Variables used in the mathematical formulation for data analysis

To know about worker's facing noise, their distance from source and noise level in each range are measured. Most workers are still spending a specific amount of time, while some workers move randomly. It is difficult to observe each of workers without calculation measurements because some of the workers move randomly from one area to another, and their sending time is also known. For such kind, there are variables on the basis of which formulae are performed. Variable parameters for the noise measuring calculations are shown in Table 3.

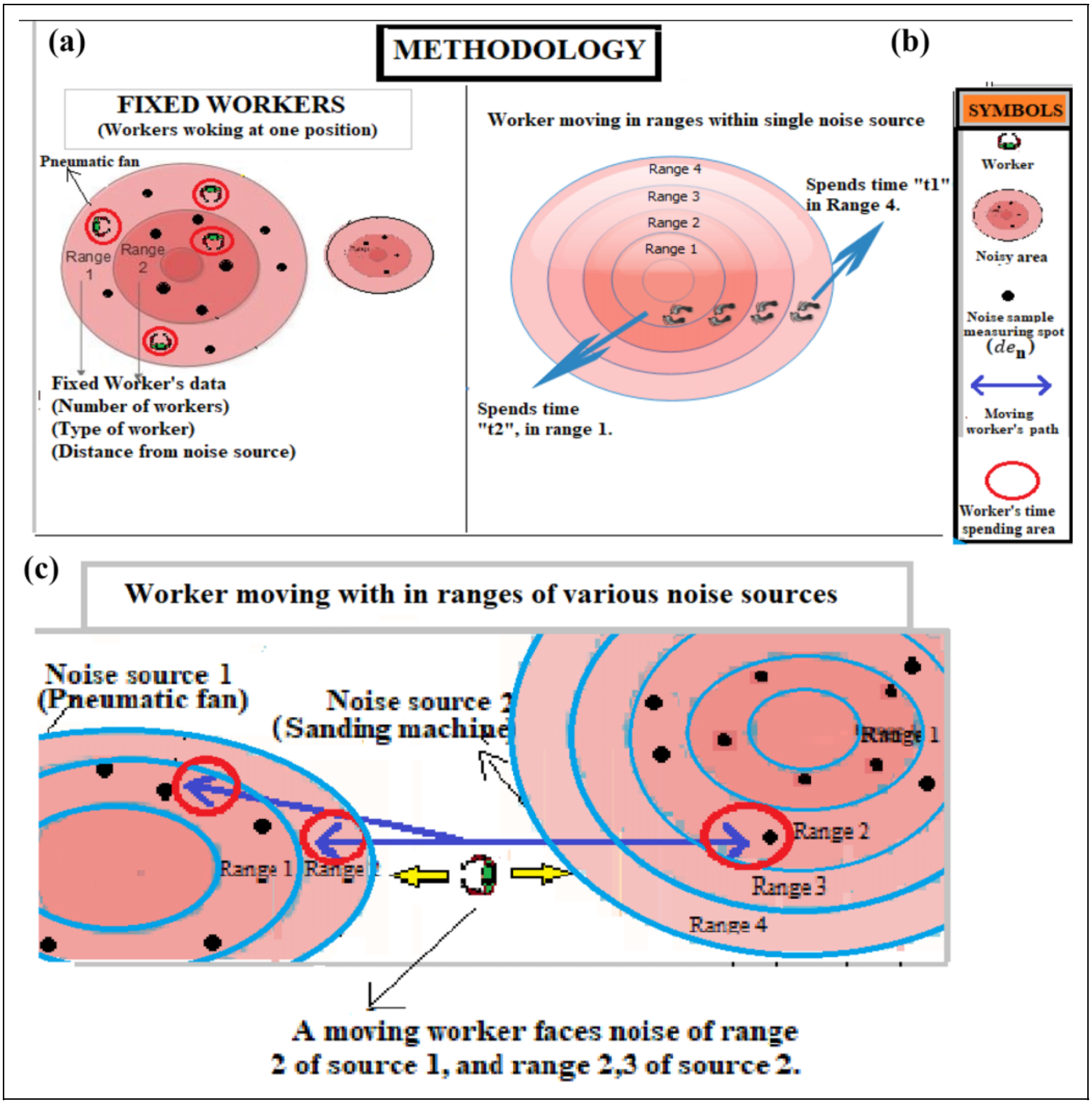

Figure 4. Workers spending time in different spots.

For this algorithm, it must satisfy the clustering algorithm for proper check that in which spot the noise is in an unsafe level. If there is no irregularity of noise or it is not risking workers, then use ranges in a regular manner. In the case study, the data initially were intended to be observed randomly having no ranges; during this, noise was irregularly observed with level. It was louder at some area, especially in those spots where the noise converged at the corners of the working hall. Vibrations moved turbulently due to walls and heavy machinery coming in the path of noise. Causing the average data clustered at a different location around the same source. The noise was observed to be exceeding from its safe level at the spots near to the wall shown in Figure 6, and the clustering technique is accepted in spite of range devolvement. However, when it came to the movement of workers, it is observed that there is no worker movement in noise turbulent areas. Bouncing back noise vibrations has a negligible effect on workers ultimately led use to ranges around the noise source in spite of using clustering technique.

First, the data collection is performed in the following manners, the samples are taken are grouped into ranges, which make calculations more appropriate. "$de_{m,n,s}$" represents the noise sample measured in "n" number of ranges of noise sources "m".

Noise source 1.

$$
\begin{array}{lll}
\text{Range } 1 = & r_{avg,1,1} = & de_{1,1,1st},\ de_{1,1,2nd},\ldots,\ de_{1,1,s} \\
\text{Range } 2 = & r_{avg,1,2} = & de_{1,2,1\,st},\ de_{1,2,2nd},\ldots,\ de_{1,2,s} \\
\vdots & \vdots & \vdots \\
\text{Range } n = & r_{avg,1,n} = & de_{1,n,1st},\ de_{1,n,2nd},\ldots,\ de_{1,n,s}
\end{array}
$$

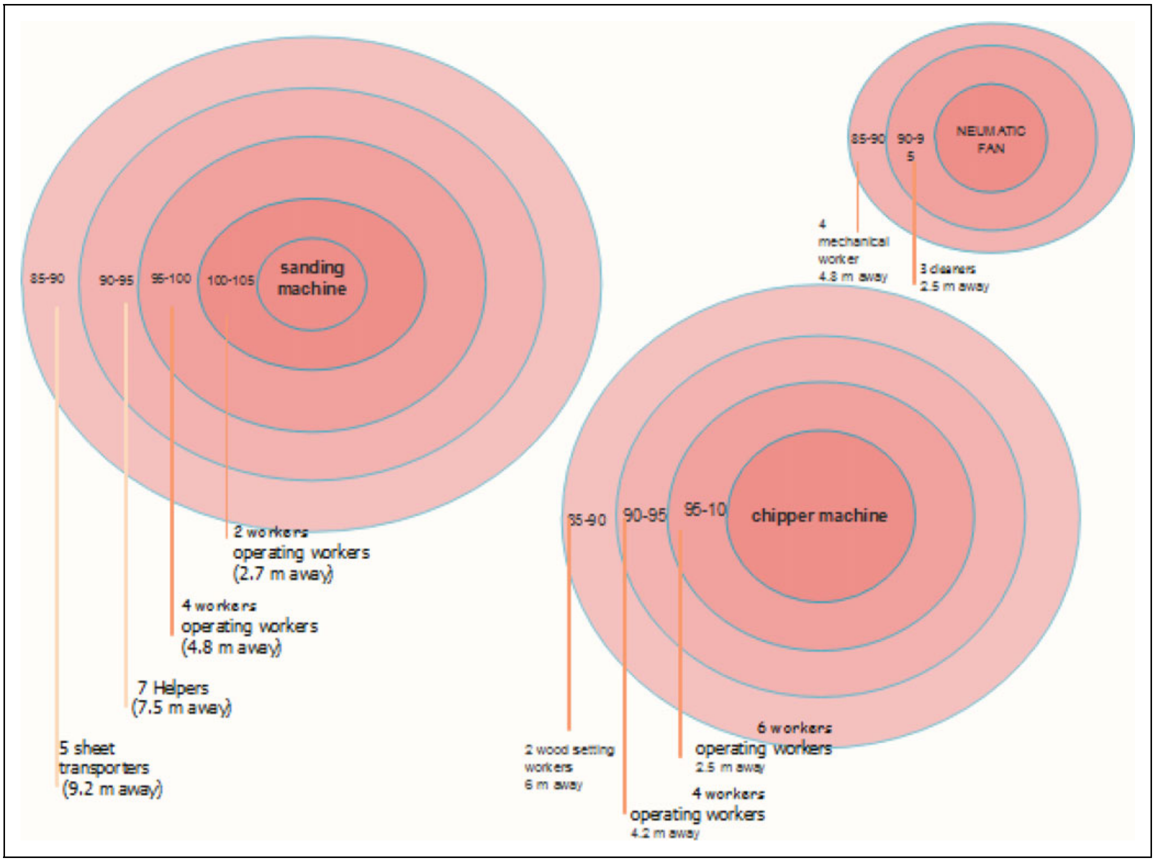

Figure 5. A number of workers affected by the machines that create noise with their respective ranges.

Strata (ranges) in measuring the noise are 85–90, 90–95, and 95–100. Each of the strata has considered as the individual population. And in each stratum, five random readings were taken. Taking a chipper machine as a noise source "$m = 1$". And 1st noise sample measured in range 1 "$de_{1,1,1st}$" as the Table 4 shows. Then, average noise "$r_{avg,(1,3)}$" in range "85–90" is calculated, considering noise source $m = 1$. Overall average effective noise produced by a noise source is calculated from equation (1).

$$r_{avg(m,n)} = \text{Summation of noise emitting from each source}$$

$$= \sum_{n=1}^{n} de_{m,n,s}$$

$$\begin{bmatrix} r_{avg(1,1)} \\ r_{avg(1,2)} \\ \vdots \\ r_{avg,(1,n)} \end{bmatrix} = \frac{\begin{bmatrix} de_{1,1,1st} & + de_{1,1,2nd} & \dots de_{1,1,s} \\ de_{1,2,1st} & + de_{1,2,2\,nd} & \dots de_{1,2,s} \\ \vdots & \vdots & \vdots \\ de_{1,n,1st} & + de_{1,n,\,2nd} & de_{1,n,s} \end{bmatrix}}{S}$$

$$\frac{(de_{1,1,1st} = 88.6, de_{1,1,2nd} = 88.3, \dots, de_{1,1,s} = 85.3)}{5}$$

$$r_{avg(1,1)} = 87 \text{ dB(A)}$$

$$(\overline{\overline{X}})_{(m)} = \frac{\left(\sum_{m=1}^{m}\sum_{n=1}^{n}\left(r_{avg(m,n)}\right)\right)}{r_n} \quad (1)$$

The calculation for various cases worker moving in noise affected area

Calculation of the sound face by moving worker is not that simple as the above calculation for the fixed worker or working in a random manner. Those workers who move internally in the noise source face different noise levels. Some of the workers move randomly in the single noisy area, while the spent variable amount of time in noisy source emitting from different sources, while some of them spent a specific amount of time in the different noisy sources as discussed in section "Methodology". According to WHO and Canadian health occupation, the safe range around noise is the area away from the source where its noise has a level of 85 dB. In other words, moving away from the noise source, the noise becomes decreases until noise reaches to 85 dB, after which the noise do not affect the worker (8 h shift workers). However, for each noise source, this distance is variant, because they do not have

Table 2. Collection of noise data from each machine with respective distances.

Chipper machine		Pneumatic fan		Sanding machine	
Distance	Decibels	Distance	Decibels	Distance	Decibels
100–105 dB					
12	14.2				
1.4	103.6				
1.7	102.5				
2.3	102.1				
2.7	101.4				
95–100 dB					
3.1	99.4	1.4	98.6	1.3	88.6
3.4	98.3	1.6	97.1	1.6	87.2
3.7	97.4	1.9	96.2	1.9	86.7
4.2	96.3	2.2	96	2.2	86.1
4.8	95.3	2.5	95.2	2.5	85.2
85–90 dB					
5.5	94.6	2.7	94.2	2.9	
6.1	94.1	3.1	93.1	3.4	
6.4	93.7	3.5	92	3.8	
6.8	92.8	3.8	91.5	4.5	
7.5	91.4	4.2	90.4	4.8	
80–85 dB					
7.7	88.2	4.6	88.6		
7.9	87.4	4.9	88.3		
8.4	86.6	5.3	87		
8.9	85.8	5.7	86		
9.2	85.3	6	85.3		

the same loudness. In Table 4, the noise produced by the sanding machine is louder than pneumatics machine, and ultimately sanding machine affects the larger area around it. The distance covered from source to the end of 85 dB noise level is a worker is categorized in ranges where various samples are taken in the following algorithm and average is calculated. For calculating their measurements, moving workers are categorized in two cases.

Case 1: known spending time workers

In this case, workers are still in their position while operating machine; they do not move from their own position. The noise they face is measured by dividing the area into many sections named as ranges, and their sampling g is taken for each of the ranges.

Recommending earmuff to fixed worker. Noise reduction ratings indicate ear protector's performance in noise. NRR calculation is compulsory to be known, because each device has its own NRR. A person working in a loud environment exposed to noise of 100 dB, and wearing ear protector of NRR 30 dB, hearing noise would be lowered to 88.5 dB. More powerful earmuff brings his hearing noise to 70 dB, but that is expensive that is why each worker must wear their own earmuff. Those workers who need NRR can use the earmuffs having NRR of 24 can use the earmuffs of NRR of 26 dB, but not less than 24. Protector having NRR of 31 reduces noise up to 85 dB during work. Let the power of earmuff that is NRR be "g_W", its value shows the strength of an earmuff to reduce the noise while worn by the worker during working. The NRR is calculated by using the above formula $2(Q-h)_w+7$. Here specific value for earmuff is calculated if the actual value of noise "Q_W" and "h_W" $=$ 85 is put in place of is put in it. And after finding "g_W", it becomes very easy to suggest equipment for the worker

$$g_W = 2(Q-h)_w + 7 \tag{2}$$

where "Q" value is the variative for each case; it is 50 dB for traffic noise, a person facing traffic noise more than 50 dB is affective for his medical condition. Here is the case of machining, workers facing machine noise have a limit of 85 dB. Replacing "h" by 85 dB in equation (2), gives equation (3). Also replacing "Q" of the equation with "$r_{avg(m,n)}$" putting range average. NRR for ranges is calculated in spite for each individual worker. The earmuffs needed for each fixed worker in Table 5 are calculated by equation (2). The first row of Table 5 represents two workers facing 87 dB must wear noise protector of 12 NRR, reduces hearing noise to 85 dB at a distance of 4–6.2 m from chipper machine. If the use of noise protecting equipment is having NRR greater than 12, they will be safe from the noise of 87 dB and are able to work for more than 8 h. Equation (3) calculates power of earmuff needed to wear for specific workers working in their respective range. For every noise source "m", of their respective range "r", earmuff's strength "$g_{W(m,r)}$" is also calculated in the same manner. In Table 5 first row, noise in the range 85–90 of noise source chipper machine has two workers at a fixed position. They face 87 dB noise must wear at least 12 NRR protector, bringing hearing noise up to 85 dB. The workers'

Table 3. Variables used in the noise equations.

Description	Symbol
Number of ranges developed	r_n
Average noise in specific range "n" emitting from source machine "m"	$r_{avg(m,n)}$
Number of samples	s
Noise sample measured in decibel emitting noise source	de
Noise sample measured in decibel emitting from specific machine in specific range	$de_{m,n,s}$
Actual noise the worker faces before protector	K
Time spent in a noisy environment	t_n
Allowable time needs to spend in a specific noisy environment	A_n
A ration of the time spends to allowable time of a worker spending time	$P_{avg,w}$
Effective noise of a worker facing noise at different places	"$Q_{avg,w}$"
Earmuff strength required to reduce noise to safety level for a worker	g_W

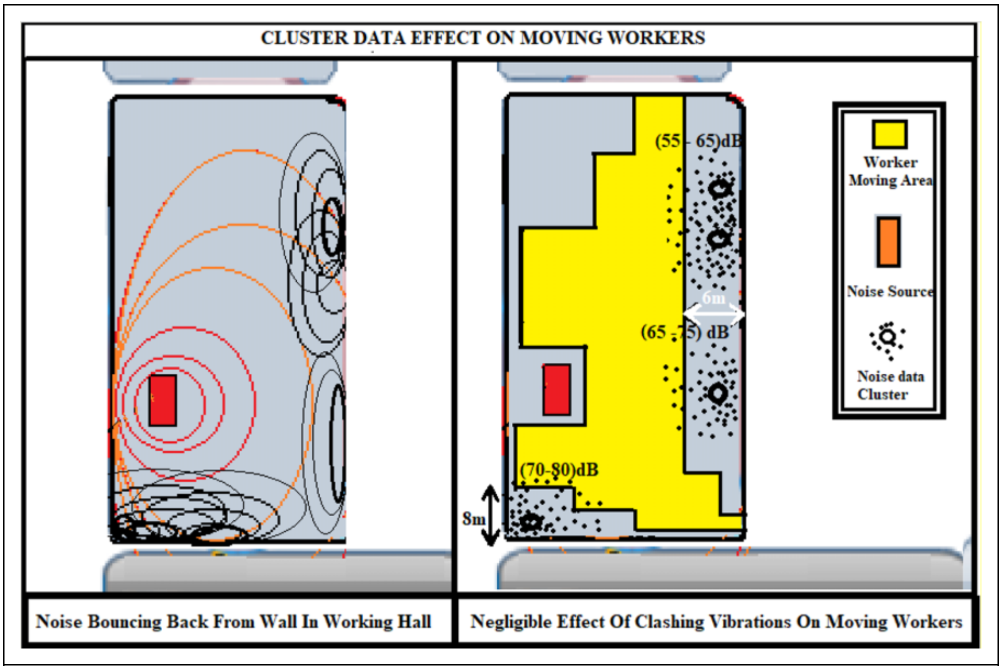

Figure 6. Comparing the effect of bouncing back vibrational noise with a working area of sanding machine.

Table 4. Sampling showing averages in each of the noise ranges in dB(A) for respective machines.

	Effective noise of worker moving in single source spent some time in all ranges						
	Noise range	Measured samples for chipper machine					Average noise $\bar{X}$ ($r_{avg(1,n)}$)dB(A)
$r_{avg(1,1)}$	85–90	88.6	88.3	87.0	86.0	85.3	87.0
$r_{avg(1,2)}$	90–95	94.2	93.1	92.0	91.1	90.4	92.2
$r_{avg(1,3)}$	95–100	98.6	97.1	96.2	96.0	95.2	96.6
		Average machine noise ($\bar{\bar{x}}$)					91.9
	Noise range	Measured samples for pneumatic fans					Average noise $\bar{X}$ ($r_{avg(2,n)}$)dB(A)
$r_{avg(2,1)}$	85–90	88.2	87.4	86.6	85.8	85.3	86.7
$r_{avg(2,2)}$	90–95	94.4	93.2	92.0	91.6	91.1	92.5
		Average machine noise ($\bar{\bar{x}}$)					89.6
	Noise range	Measured samples for sanding machine					Average noise $\bar{X}$ ($r_{avg(3,n)}$)dB(A)
$r_{avg(3,1)}$	85–90	88.2	87.4	86.6	85.8	85.3	86.7
$r_{avg(3,2)}$	90–95	94.6	94.1	93.7	92.8	91.4	93.3
$r_{avg(3,3)}$	95–100	99.4	98.3	97.4	96.8	95.3	97.4
$r_{avg(3,4)}$	100–105	104.2	103.6	102.5	102.1	101.4	102.8
		Average machine noise ($\bar{\bar{x}}$)					95.0

number in their respective range and their radial distances has taken from Figure 5. As the worker must work for 8 h, it is necessary to reduce the noise up to a safe level (noise < 85 dB). Similarly, workers in their respective range wearing earmuffs of calculated NRR given in the last column of Table 5 reduce noise to 85 dB, which is the safe level of the sound for a worker working in 8 h of a shift

$$g_{(m,n)} = 2\sum_{m=1}^{m}\sum_{n=1}^{n} r_{avg(m,n)} - 78 \qquad (3)$$

Strategy-based optimal time spend. The cases define based on the strategy-based, and their main goal is to minimize the noise they are affecting with to the level where workers are able to work for 8 h shifts. The strategy mostly is time spending dependent, as workers spend different timing while traveling from one noise source to another. Those who face excessive noise while spending less time is not much effect compared with the worker facing the same noise level but spent more time. Earmuff or earplugs make their timing optimal, knowing the following strategy.

Table 5. Showing the number of fixed worker and NRR needed.

Radial distance (m)	Noise ranges (dB)	Worker's quantity	Range ($\bar{X}$) average (dB)	Earmuff's strength $g_{(m,n)}$	Noise reduced
Chipper machine					
6–4.2	85–90	2	87.0	11	84.5
4.2–2.5	90–95	4	92.2	21	84.7
2.5–0	95–100	6	96.6	30	85.6
					84.9
Pneumatic fan					
4.8–2.5	85–90	4	86.7	10	84.2
2.5–0	90–95	3	92.5	22	85
					84.6
Sanding machine					
9.2–7.5	85–90	5	86.7	12	84.2
7.5–4.8	90–95	7	93.2	24	84.7
4.8–2.7	95–100	4	97.4	31	84.9
2.7–0	100–105	2	102.8	43	85
					85

Case 2: randomly moving workers

In this case, workers move randomly with unknown spending times to their visited spots, but it is important to know that whether they are moving around a single source or various noisy sources. Once it is known that worker is facing noise from one source or other, then this algorithm makes it easier to calculate an NRR. So, it is further categorized into two classes, workers randomly moving in the same and various sources. A worker is moving around a single source area: these are the types of workers who move from ranges, and they are unpredictable in time spending. In spite of spending specific time in a spot, they move randomly, and their spending timings and location in a noisy area are unknown. As their movements are random, that is why their spending time to each visited spot is either considered equal or taken as a percentage. For such workers, average effective noise of the whole machine "$(\bar{\bar{X}})$" is considered as shown in Table 5. To find NRR for these workers, "Q" of equation (2) is replaced with "$(\bar{\bar{X}})$", and equation (2) becomes as $g_W = 2(\bar{\bar{X}} - h)_w + 7$. This replacement suggests earmuffs for those workers who have no sequence of time spanning time around a single noisy source area, that is, their time span in a specific spot is unknown. Randomly motion scenario of a worker is shown in Figure 7(a), workers move randomly in different ranges in the same noisy area according to their specific jobs. These workers work either in the form of inspection, allowing them to move randomly. The ranges in which they are moving are known, but their spending timing is approximately equal in each of their respective working ranges. Approximation time spends in the specific range are handled with the help of "α". In this case, average noise from which workers are affecting is calculated in approximation, by taking calculated average noise values of the ranges from Table 5 and putting in equation (5). It calculates average effective noise for each worker "w" moving randomly in each range "r" of noisy source "m"

$$de_{(m,r,w)} = \frac{\sum_{m=1}^{m} \sum_{r=1}^{r} (\alpha r)_{avg(m,r)}}{r_n} \tag{4}$$

Range to range moves between sources, with known spending times. Those workers who move range to range and spend known time in each range are taken into measure. Average range noise measured above is used here, working spots are observed measuring their distance from the center of noise effected area (column 1 of Table 5). Workers moving from range to another and their time spent "t_n" in each of spots "n" inside the single noisy area are shown in Figure 7(b) and (d). For such type of workers, ratio of time spent "t" in a specific range, to standard allowable time, "a" (need to spend in that noise range) is calculated. Average noises for each range of chipper machine as already calculated, which are 96.6 dB of range 90–100 and 87 dB of range 85–90 shown in Table 4 by equation (1). Spending times for moving workers in these ranges are $t_1 = 4$, $t_2 = 2$, as shown in Figure 7(b). Allowable times for the average noise levels (96.6 and 87 dB) are $a_1 = 4$ and $a_2 = 2$ are taken from Table 1. Calculating its average effective noise face by worker depends on the timing spends in each of the locations and is denoted by "Q". Before calculating "Q", ratio of the time spent to standard allowable time is calculated and is denoted by "P" of the spending time "t" relevant to standard allowable time, (time spent at each noise level)/(allowable time) = $(t/a)_n$. "$Q_{avg,w}$" in equation (5). First, finding ratios of time spent to allowable time for a worker in a specific industrial environment is shown in equation (5). In this scenario worker, the effective noise level determination for

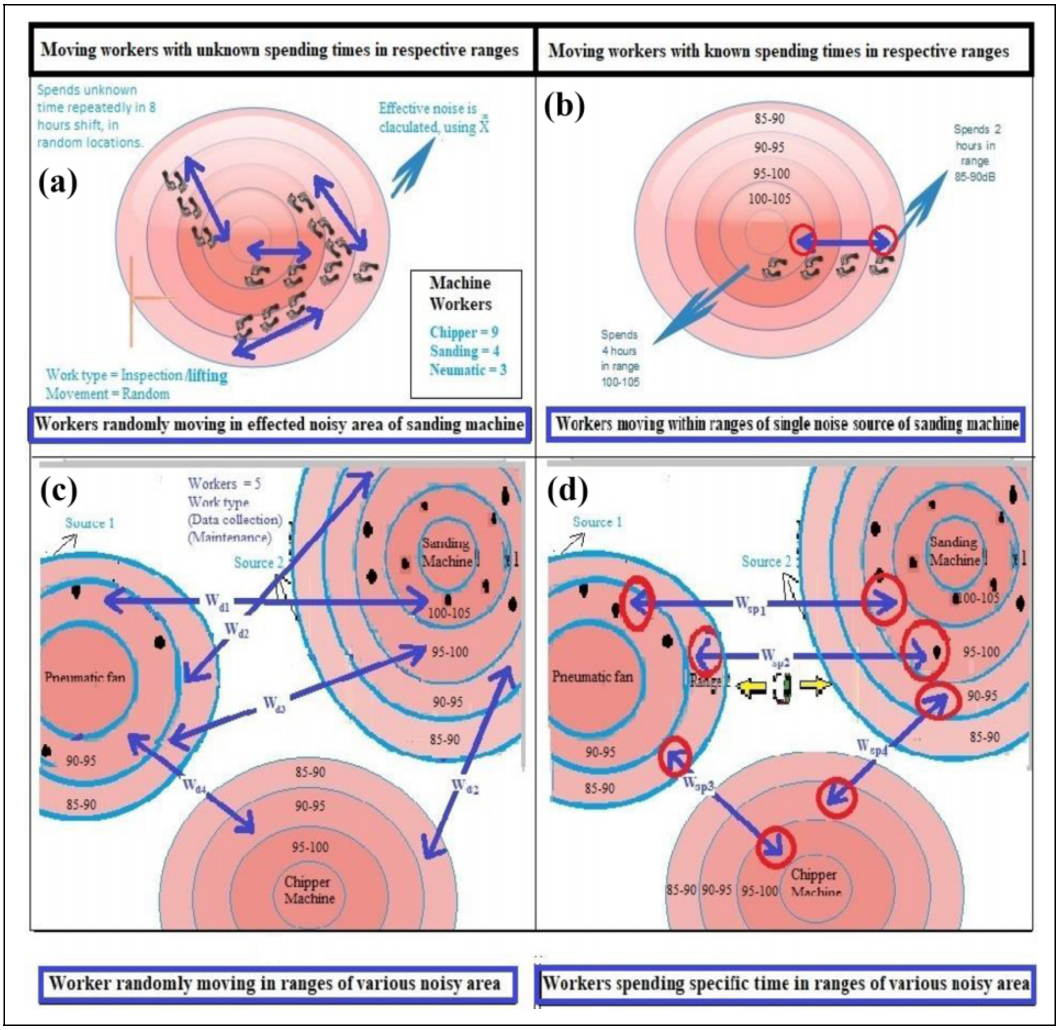

Figure 7. Single noisy source areas along with worker's spending time in their respective ranges.

moving worker at various places is calculated using equation (5). "$P_{avg(r_n)}$" be the ratio of the spent by allowable time for a worker in a range "n". To find the value of "P", the time spend "t" in each range "r" of the noise source is noticed, and standard allowable spending duration "a" requires for a worker in this range, is selected from Table 1. The selection of "a" is according to spending time of worker. The "P" value is calculated, which is the effective noise level of moving worker "w" moving in a single source, that is, the noise level from which workers are affecting in 8 h of shift while moving inside the area of the same source. The value of "P" comes as 1.6, and Q_W for a worker "w" comes as 93 dB. Equation "$de_{avg(w)}$" is used to find value of "a". Person faces noise "Q_W" of 93 dB in real sense. This value of "Q_W" is different from those of the 96.6 and 87 dB, due to varying timing worker is spending in a different location. This type of sound will need some protection of equipment, having a proper NRR. The NRR is calculated using equation (3), that is, NRR. "g_W" required for the workers "w", facing noise of two different noise areas is given as

$$\begin{bmatrix} P_{avg(1,r)} \\ P_{avg(2,r)} \\ \vdots \\ P_{avg(m,r)} \end{bmatrix} = \begin{bmatrix} \left(\frac{t}{a}\right)_{1,1} & + \left(\frac{t}{a}\right)_{1,2} & \cdots \left(\frac{t}{a}\right)_{1,r} \\ \left(\frac{t}{a}\right)_{2,1} & + \left(\frac{t}{a}\right)_{2,2} & \cdots \left(\frac{t}{a}\right)_{2,r} \\ \vdots & \vdots & \vdots \\ \left(\frac{t}{a}\right)_{m,1} & + \left(\frac{t}{a}\right)_{m,2} & \cdots \left(\frac{t}{a}\right)_{m,r} \end{bmatrix}$$

$$P_{avg(w)} = \sum_{m=1}^{m} \sum_{r=1}^{r} \left(\frac{t}{a}\right)_{(w,r)} \tag{5}$$

Table 6. Showing moving workers spending known times around the same source, and NRR needed.

Moving workers with known time spending in their respective ranges

Worker	Spend time t1	dB1	Allowable time (a)	t2	dB2	Allowable time (a)	t3	dB3	Allowable time (a)	Ratio	Effective noise	NRR needed
1	4	86.7	7	1	86.7	7	0	–	–	0.71	87	12.15
2	1	96.6	0.54	2	97.4	0.49	0	–	–	6.1	102.8	42.69
3	2	87	7	3	86.7	7	0	–	–	0.7	87.6	12.15
4	1	97	0.5	0.5	102.8	0.35	0	–	–	3.4	99	30.02
5	1	87	7	0.3	92.2	3	2	96.6	0.45	2.5	97	34.78
6	1	92.2	3	1	96.6	0.4	0	–	–	2.1	96	28.28
7	1	86.7	7	0.8	1	0.3	2	102.8	0.35	4.2	100.4	37.83
8	3	92.5	3	1	97.4	0.49	3	102.8	0.35	5.8	102.4	42.60
9	4	86.7	7	1	86.7	7	0	–	–	0.71	88.4	12.15
10	1	92.5	3	0.5	102.8	0.35	2	97.4	0.5	3.7	100.4	36.12

NRR: noise reduction rate.

$$Q_{avg,w} = 16.61\ Log_{10}\begin{bmatrix} P_{avg(1)} \\ P_{avg(2)} \\ \vdots \\ P_{\ avg(n)} \end{bmatrix} + 90$$

$$Q_W = 16.61\ Log_{10}\left(P_{avg(w)}\right) + 90 = 93 \qquad (6)$$

Example illustration.

$$Spending\ times\ t_1 = 2,\ t_2 = 4$$

$$Allowable\ times,\ a_n = \frac{Lower\ range\ timing + \ upper\ range\ timing}{2}$$

$$\text{For 96 dB } a_1 = \frac{1 + 1.5}{2}\ 0.75\text{ h.}$$

$$\text{And for 86 dB } a_2 = \frac{4 + 8}{2} = 6\text{ h}$$

from Table 1

$$P_{avg(1,2)} = \left(\frac{2}{0.75} + \frac{4}{6}\right) = 3.42$$

Actual facing noise

$$Q_{avg,w} = 16.61\ Log_{10}(3.42) + 90 = 98.9\text{ dB(A)}$$

Industrial data collection for moving workers spending a specific amount of time is given in Table 6, each range of their repeated noisy machine is having one unique worker, who move to another range of the same or different machines. Equation (6) is used to calculate the actual noise faced form different sources or various ranges in them by moving workers. The time spent and average noise faced by every worker are given, as the time spending in each location is repetitive for each location, that is why these workers in Figure 7(d) are categorized in another this case. These workers are different from those who are in Figure 7(c), as they are represented by (w_{dn}). The average noise is exactly the same as measured in the earlier through equation (1). Some of the workers spent know the time in other ranges as shown in the second column of Table 6, where "$w_{(spn)}$" are those workers "n", who spent specific "SP" amount of time in the range. In chipper machine, workers "$w_{(sp1)}$" and "$w_{(sp2)}$" who move from range of sanding machine to pneumatic fan, while workers "$w_{(sp3)}$" walk between chipper machine and pneumatic fan, and "$w_{(sp4)}$" between chipper and sanding machine are mentioned in Table 7.

Because all these four workers are moving toward the same positions. "h" in equation (6) as noise is reduced for the workers moving in the single source, spending some time during working after wearing the protectors. Earmuffs having reduction rate value "g_W" of 23 can easily reduce the noise of these three machines up to 85 dB which is a safe noise level. But it is to be noted that this noise reduction is just for the worker who moves in the noise source areas. For confirmation, equation (7) shows the reduction of noise from 91.9 dB to safe level "h_W" by wearing the protector having "g_W" of 23. And increases allowability of time for the worker from 2 to 8 h. Strength number of earmuff = 2 (actual noise − (NRR − 7))/2 or Equation (7). Formulae for different situations are given in Table 8, which makes it easy for an observer to calculate noise level and NRR needed for each worker.

$$h_W = Q_{\text{avg};W} - (g_W - 7)/2 \qquad (7)$$

Earmuffs handling

In MDF industry, the following type of worker should use the equipment having the NRR given in front of it. These are the minimum levels of the NRR which these workers need for the protection of the noise up to 85 dB of sound. Some of the NRR is greater because they are facing a

Table 7. Showing fixed position worker moving in various sources.

Workers moving in the same noisy machine source			
Ranges (dB)	Worker $(w_{sp,n})$	Time spent $(t_{sp,n})$	Average noise of each range $(Q_{sp,n})$
Chipper machine			
85–90	3	5	87.0
	4	3	87.0
	5	3	87.0
90–95	6	3	92.2
	8	1	92.2
	5	2	92.2
95–100	3	2	96.6
	5	2	96.6
	6	4	96.6
Pneumatic fan			
85–90	1	4	86.7
	3	2	86.7
	2	5	86.7
90–95	8	1	92.5
	10	3	92.5
Sanding machine			
85–90	9	3	86.7
	7	2	86.7
	9	4	86.7
	1	3	86.7
90–95	10	2	93.2
	7	2	93.2
95–100	8	1	97.4
	4	3	97.4
	2	4	97.4
100–105	7	2	102.8
	10	2	102.8
	8	3	102.8

greater amount of noise in the industry. Some of them are still a worker who works in the same position in the industry. Some of these workers are moving; they move from one place to another to transport the wooden sheet or they are the wood setter. For fixed and randomly moving workers, data for the type of worker, NRR needed, and a number of workers are given in Table 9.

Equipment cost

Equipment used by the workers results in some cost related to MDF industry because these earmuffs cannot be given blindly to workers, which cost in greater amount and its result do not come optimal. The earmuffs they use lead to different cost related to their specific NRR. The equipment having greater NRR will cost greater than those having small NRR. In Table 10, the number of workers is multiplied with the cost/NRR, and the result of total cost of each type of NRR has taken out in the last column. And then the total cost has been evaluated by summing the whole costs of used earmuff, comes as Rs. 85,100. Cost analysis is easily evaluated with the help of Table 10 having a number of workers and type of earmuff.

Around the chipper machine, there are 12 fixed and five moving workers working. The noise affected area around this machine is greater, so the workers are facing the average sound of the 91.9 dB. The noise affected area means an area where workers face the sounds greater than the 85 dB(A). Similarly, around the infeasible noisy area of the pneumatic fan, there are seven fixed workers and five moving workers and is producing the average sound of 89.6 dB in the noise affected area. Similarly, the workers working around the sanding machine are greater than the chipper and the pneumatic fan, because of covering most of the affected area. The seven fixed and seven moving workers are operating other functions. Sanding machine is a highly noise-producing machine, as its purpose is finishing, slides, that is why it produces more sound. The average sound and NRR number for randomly moving workers among different sources and with in the same noise source are given in Table 11, which are moving around the affected area of the same source.

Result and discussion

The main focus was on the use of specific equipment for the worker in an environment to reduce their noise up to a safe level where they could work for 8 h. The industry knows that applying this algorithm which hearing protector is chosen for a specific worker. Average noise in Figure 8 reveals that average calculated noise levels are greater than "standards" allowable noise for 8 h of shift. It led that labor facing current noise is not feasible for their health. Wearing ear protector, reduction in noise occurs and their health is not affected and they work for longer time span. The result has taken after data implementation was taken, including the comparison of the actual and the recommended protective environment for workers, their difference can be seen graphically. Noise reduces, and the standard noise level for each of the machines is shown in Figure 8, where the black line shows facing noise. Comparison of the facing and standard noise after wearing the earmuffs is also shown in the second part of Figure 8, where noise has been reduced up to safe level. Once NRR is found, then it is easier to select the equipment for the worker. The following comparison in Figure 8 is for fixed workers; it generally shows that up to how much level excessive noise of each machine can be reduced up to safe level, after using noise protectors. The sanding machine decibel is little greater than the standard, but it is negligible. Earmuffs give a good result by wearing; by this, the worker can increase their working tie, that is, they can work for 8 h which is their shifting time. Otherwise, they will be affected mentally or physically.

Percentage reduction helps in comparative analysis machine's noise reduced through protectors. The graph in Figure 9 shows worker's safety percentage from machine's

Table 8. Showing the equation for different cases of moving workers.

Condition	Formula: Noise (Q)	Formula: NRR of earmuff (g_w)
Random movement "d" around same source	$Q_W = 16.61\ Log_{10}(\bar{\bar{x}}(w)) + 90$	$g_W = 2(\bar{\bar{x}} - h)_w + 7$
Known spending time around same source	$Q_W = 16.61\ Log_{10}(de_{(m,r,w)}) + 90$	$g_W = 2(de_{(m,r,w)} - h)_w + 7$
Random movement "d" of worker "w", around different source "m"	$Q_W = 16.61\ Log_{10}(de_{(d,m)}) + 90$	$g_{(d,m,w)} = 2(de_{(d,m)} - h)_w + 7$
Known specific time "sp" known ranges of different noise source "m"	$Q_W = 16.61\ Log_{10}(de_{(sp)}) + 90$	$g_{sp,w} = 2(de_{(sp)} - h)_w + 7$

NRR: noise reduction rate.

Table 9. Showing the number and type of workers in ranges.

NRR needed for each of the workers in the whole industry

Serial number	Fixed worker's NRR	Type of worker	Number of workers
1	41	Sanding machine operator	2
2	32	Sanding machine operator	4
3	29	Chipper operators	6
5	29	Sheet transporter	4
6	24	Wood setting workers	2
7	22	Chipper operators	4
8	22	Mechanical workers	4
9	20	Cleaners	3
10	12	Sanding machine helper	5

Randomly moving workers

Serial number	NRR needed	Type of worker	NRR needed	Type of worker	Numbers of workers
1	11	Inspector	11	Wood unloader	1
2	11	Sampling collector	11	Wood unloader	2
3	11	Inspector	11	Wood unloader	3
5	21.4	Inspector	21.4	Parts transporter	2
6	21.4	Data collector	21.4	Parts transporter	2
7	21.4	Inspector	21.4	Parts transporter	2
8	30.2	Sampling collector	30.2	Sheet setter	2
9	30.2	Sampling collector	30.2	Sheet transporters	2
10	30.2	Sampling collector	30.2	Parts transporter	2
11	21.4	Sampling collector	21.4	Parts transporter	2
12	30.2	Sampling collector	30.2	Wood loader	1
13	30.2	Inspector	30.2	Wood loader	1
14	30.2	Inspector	30.2	Wood loader	1
15	10.4	Sampling collector	10.4	Wood loader	1
16	10.4	Data collector	10.4	Wood loader	2
17	10.4	Inspector	10.4	Parts transporter	2
18	22	Sampling collector	22	Sheet setter	2
19	22	Sampling collector	22	Sheet transporters	2
20	10.4	Sweeper	10.4	Sheet transporters	2
21	10.4	Inspector	10.4	Sheet transporters	1
22	10.4	Sampling collector	10.4	Sheet transporters	1
23	10.4	Data collector	10.4	Sheet transporters	1
24	23.4	Inspector	23.4	Sheet setter	3
25	23.4	Sampling collector	23.4	Sheet setter	3
26	31.8	Manager	31.8	Sheet setter	1
27	31.8	Sampling collector	31.8	Sheet setter	3
28	31.8	Data collector	31.8	Parts transporter	2
29	42.6	Inspector	42.6	Parts transporter	1
30	42.6	Sampling collector	42.6	Parts transporter	3
31	42.6	Sampling collector	42.6	Parts transporter	1
32	42.6	Data collector	42.6	Parts transporter	2

NRR: noise reduction rate.

Table 10. Specific NRR needed for the type and number of workers in the industry.

Serial number	NRR used	Number of workers using NRR	Cost/NRR	Cost
1	10.4	10	700	7000
2	11	6	850	2100
3	12	5	800	4000
4	21.4	6	1100	6600
5	22	7	1500	13,500
6	23.4	4	1200	4800
7	24	2	1500	3000
8	20	3	1000	3000
9	29	10	1700	17,000
10	31.8	6	1800	10,800
11	42.6	7	1900	13,300
Total		66		85,100

NRR: noise reduction rate.

noise reduction. The worker working in the sanding machine is protected more with ear protectors. Sanding machine's noise has greatly reduced wearing the muff. In Figure 9, the sanding machine in the graph shows a greater reduction in the noise compared with the other two machines. Then, the chipper machine, and then the 0.05 reduction in the pneumatic fan. The greater reductions due to the greater number of workers working in the sanding machine area and equipment used here were of higher NRR.

Conclusion

This article applied a mathematical algorithm for optimum selection of noise reduction equipment such as earmuff and earplug for different working places depending upon the exposure to noise. In this study, a noise level measuring methodology is used for fixed and moving workers. For this purpose, MDF industry is considered as a case study.

Table 11. NRR required for the randomly moving worker.

Randomly moving worker									
Among different source					Within same source				
Workers "w_{dn}"	Range	Spend time approximation	Facing noise	NRR needed	Workers "w_{dn}"	Spend time approximation	Range	Facing noise	NRR needed
Chipper machine									
1	85–90	2	87	11	19	2	85–90	87	11
5	85–90	3	87	11	4	3	85–90	87	11
3	85–90	2	87	11	15	2	85–90	87	11
8	90–95	4	92.2	21.4	16	4	90–95	92.2	21.4
9	90–95	1	92.2	21.4	18	1	90–95	92.2	21.4
6	90–95	4	92.2	21.4	15	4	90–95	92.2	21.4
7	90–95	2	96.6	30.2	19	2	100–105	96.6	30.2
2	95–100	3	96.6	30.2	15	3	100–105	96.6	30.2
4	95–100	2	96.6	30.2	16	2	100–105	96.6	30.2
Pneumatic fan									
12	85–90	2	86.7	10.4	21	2	85–90	86.7	10.4
13	85–90	3	86.7	10.4	19	3	85–90	86.7	10.4
10	85–90	2	86.7	10.4	23	2	85–90	86.7	10.4
15	90–95	1	92.5	22	18	1	90–95	92.5	22
14	90–95	4	92.5	22	20	4	90–95	92.5	22
Sanding machine									
29	85–90	2	86.7	10.4	19	2	85–90	86.7	10.4
27	85–90	2	86.7	10.4	17	2	85–90	86.7	10.4
26	85–90	3	86.7	10.4	19	3	85–90	86.7	10.4
32	85–90	3	86.7	10.4	21	3	85–90	86.7	10.4
33	90–95	2	93.2	23.4	20	2	90–95	93.2	23.4
28	90–95	1	93.2	23.4	17	1	90–95	93.2	23.4
31	95–100	2	97.4	31.8	18	2	95–100	97.4	31.8
35	95–100	3	97.4	31.8	21	3	95–100	97.4	31.8
35	95–100	2	97.4	31.8	21	2	95–100	97.4	31.8
37	100–105	1	102.8	42.6	17	1	100–105	102.8	42.6
36	100–105	4	102.8	42.6	20	4	100–105	102.8	42.6
34	100–105	3	102.8	42.6	18	3	100–105	102.8	42.6

NRR: noise reduction rate.

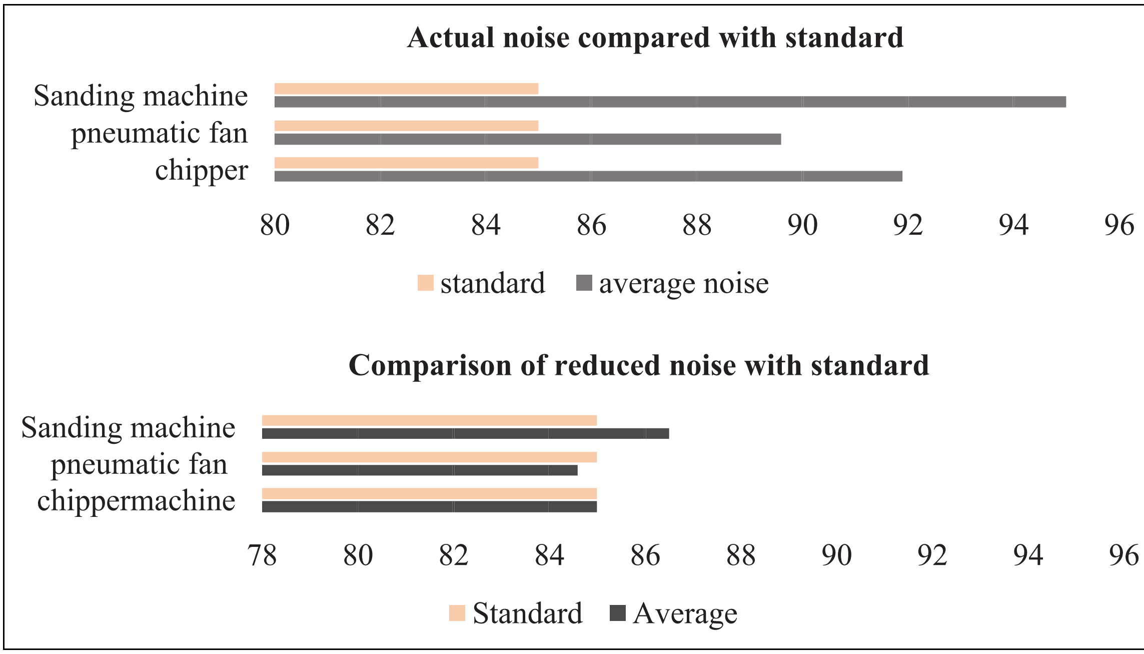

Figure 8. The comparison between the actual noise sources and the standard. The reduction of the noise up to the standard level of noise.

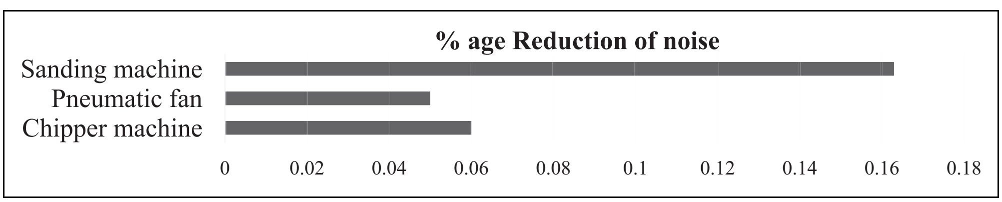

Figure 9. The graphical representation of the percentage reduction of the noise sources.

Table 12. Showing recommended NRR and hearing loss severity due to higher noise frequency.

Random moving worker							
Range	Workers among different source "wdn"	Workers with n same sources "wdn"	Average facing noise	Average noise frequency (Hz)	Hearing loss (actual scenarios)	Using NRR for severe hearing loss	Using NRR
Chipper machine							
85–90	1	19	87	5060	Severe	11	41
85–90	5	4	87	5060	Severe	11	41
85–90	3	15	87	5060	Severe	11	41
90–95	8	16	92.2	7040	Profound	21.4	51.4
90–95	9	18	92.2	7040	Profound	21.4	51.4
90–95	6	15	92.2	7040	Profound	21.4	51.4
90–95	7	19	96.6	7040	Profound	30.2	60.2
95–100	2	15	96.6	8020	Profound	30.2	60.2
95–100	4	16	96.6	8020	Profound	30.2	60.2
Pneumatic fan							
85–90	12	21	86.7	7060	Severe	10.4	40.4
85–90	13	19	86.7	7060	Severe	10.4	40.4
85–90	10	23	86.7	7060	Severe	10.4	40.4
90–95	15	18	92.5	9070	Profound	22	52
90–95	14	20	92.5	9070	Profound	22	52

(continued)

Table 12. (continued)

Random moving worker							
Range	Workers among different source "wdn"	Workers with n same sources "wdn"	Average facing noise	Average noise frequency (Hz)	Hearing loss (actual scenarios)	Using NRR for severe hearing loss	Using NRR
Sanding machine							
85–90	29	19	86.7	12,050	Severe	10.4	40.4
85–90	27	17	86.7	12,050	Severe	10.4	40.4
85–90	26	19	86.7	12,050	Severe	10.4	40.4
85–90	32	21	86.7	12,050	Severe	10.4	40.4
90–95	33	20	93.2	93.2	Profound	23.4	53.4
90–95	28	17	93.2	93.2	Profound	23.4	53.4
95–100	31	18	97.4	97.4	Profound	31.8	61.8
95–100	35	21	97.4	97.4	Profound	31.8	61.8
95–100	35	21	97.4	97.4	Profound	31.8	61.8
100–105	37	17	102.8	102.8	Profound	42.6	72.6
100–105	36	20	102.8	102.8	Profound	42.6	72.6
100–105	34	18	102.8	102.8	Profound	42.6	72.6

NRR: noise reduction rate.

The results show that implementation of the developed algorithm reduced the effect of noise on workers by 6.9%, 5%, and 16.3% for the chipper machine, pneumatic fan, and sanding machine, respectively, that were identified as the major source of noise at the case study industry. This percentage reduction in the noise level helped the workers to be in the safe level of noise that is 85 dB and protect them from hearing loss severity due to frequency variations.

Hearing loss limits of sound relevant to frequency can clearly be observed with this approach. The frequency with their respective workers in the ranges of original scenario is given in Table 12, which shows hearing loss severity of each worker, that is, workers facing the high amount of frequency working around each machine will lose their hearings accordingly. Applying the above formulation and algorithm, these hearing issues can be minimized up to a much lower level as shown in Table 12.

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