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An economic policy for noise control in industry using genetic algorithm

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ABSTRACT

Noise control in industrial workplaces is enforced by health and safety regulations in order to prevent or reduce risks to personnel. Apart from compliance with rules, the adverse effects of noise on productivity have always been a challenge for industry. As a consequence, practical solutions, ranging from protection aids to acoustic damping and isolation, have occasionally been employed. These unplanned remedies do not necessarily aim at higher risk locations and hence may impose significant and unjustified expense on the company. In this paper, the optimum combination of treatments is investigated using binary integer programming with objective cost function. The model constraints include recommended noise doses for highly exposed operators as well as budget limits. In addition, sound specification of the sources, treatment effects and relevant production information are incorporated into the model through structured databases. Then a genetic algorithm is utilized in a Matlab environment and final results are obtained. The procedure is applied to an example of a press shop and the validity of the results is approved.

1. Introduction

Noise nuisance in industry, particularly in manufacturing plants, is more crucial than in other working areas. According to NIOSH statistics, 14% of the world's working population is exposed to a noise level of about 90dBA. In manufacturing, this rate increases to 35% and hence becomes even more difficult to tolerate (NIOSH, 1998). Numerous complaints of noise, received constantly from industrial workers, give clear evidence for this argument. Although the reported discomforts are mainly focused on direct hearing impairment, noise impression on human health is not confined to hearing loss or shifts in sensing thresholds (Irle et al., 1998). It can also have serious physiological and psychological consequences, including heart disease, drowsiness and lack of concentration (Szalma and Hancock, 2011; Arezes and Miguel, 2005). Long exposure to noise can even generate acute disorders in sleeping and learning and cause poor reactions to warnings, which in turn can lead to more hazardous situations (Eleftheriou, 2010; Gramopadhye and Wilson, 1997).

Review of the literature reveals that plenty of research studies on noise control are focused on urban areas and its technical issues. Specifically, noise produced by construction activities and transportations, e.g. airport neighborhoods are broadly investigated (Black et al., 2007; Ballesteros et al., 2010; Dekkers and Straaten, 2009; Henrique and Zannin, 2008). However, economic outcomes of noise control, especially in industrial environments have rarely been discussed (Beevis, 2003; Walker and Tait, 2004).

In this research, various noise treatments in industries are identified and the related costs are evaluated. The cost function of the model is defined by the sum of the cost reductions both from noise levels and the exposure times. The constraints include the allowable time of exposure and the budget limit. Due to the nature of the model, conventional optimization techniques cannot be applied. Therefore, a genetic algorithm is used, and a computer program is developed. The solution gives the optimum combination of the options, i.e. an optimum policy for noise control taking account of the total cost of its implementation. The model is then verified by sample data and proved to be informative and applicable.

2. Industrial noise characteristics

In its ordinary sense, noise is simply defined as unwanted sound. Similar to other wave motions, sound is defined by its physical properties such as intensity, pressure level, frequency and bandwidth (Crocker, 2007). However, undesired sound in industry has different characteristics compared to other places such as construction sites or highways, especially in the frequency component, loudness and uniformity. A large electrical machine, for example, can generate sound over almost the entire audible frequency range (16–20,000 Hz). Intermittent but steady-level noise with a high energy spectrum is another common type in factories, produced by impact metal forming, molding processes, etc. These exclusive

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features have led the health and safety associations to introduce special regulations for industrial noise (Wang et al., 2003).

Reviewing the latest version of occupational noise guidelines from OSHA,[1] OHSAS,[2] HSE,[3] ASGIH[4] and BS[5] shows that these are mainly providing general instructions and recommendations on implementation or evaluation of safety management systems (MagerStellman, 1998). In fact, the only stated limits are for sound pressure levels (SPL) relative to exposure time. Integration of these two measures is called 'noise dose' and is expressed by the following equation.

$$D_i = \sum_{j=1}^{n} \frac{t_{SPL_{ij}}}{A_{SPL_{ij}}} \tag{1}$$

where D_i is the noise dose for ith operator, n is the number of exposure status, $t_{SPL_{ij}}$ is the time spent at j sound pressure level for operator i and $A_{SPL_{ij}}$ is the allowed time at j sound pressure level for operator i, obtained from the following equation.

$$A_{SPL_{ij}} = \frac{480}{2^{(L_{ij}-85)/3.01}} \tag{2}$$

L_{ij} is the jth sound pressure received at the location of operator i. The constant '3.01' represents the exchange rate in dBA, comprising the effect of exposure time and sound pressure (NIOSH, 1998). Because different standards designate different limits, the corresponding D_i disagrees with each other. For example, for an 8 h shift, the maximum allowable pressure level by OSHA is 85 dBA, whereas ACGIH determines it to be 90 dBA (MagerStellman, 1998). In accordance with most standard guidelines, in this paper, 85 dBA for 8 h is taken as the basis.

3. Noise control policy

To tackle the noise dilemma, a straightforward approach is to examine the problem in terms of its three basic elements: sound arises from a source (noise emission); travels over a path (noise propagation and transmission); and affects a receiver or listener (noise exposure) (Crocker, 2007). In other words, all noise controls work at the noise source, along the noise path, or with the receiver. However, there are other attributes for noise, such as reflection, dispersion, absorption and refraction, which are beyond the scope of this research.

Despite the simple structure of noise, explained above, there are a variety of noise sources, channels and exposures within a factory which makes noise control complicated. A primary solution is all-or-nothing action, which means that management either opts for a full treatment of the problem or takes no action at all. Obviously, each of these solutions is not practical due to budget limits and regulations, respectively. Therefore, a combination of treatments with different intensity should be used so that the noise attenuation will be optimized. The key to noise control is finding this combination, i.e. a noise control policy which is both effective and economic. It is important to know not only what controls can work, but also how costly the solutions are to design and install.

3.1. Emission control

The industrial source of noise can be one or any number of mechanical devices that radiate noise or vibratory energy. Such a situation occurs when several machines are operating at the same time.

The solutions to an industrial source of noise problem are varied, for example: using softer materials for impacting surfaces; using dynamic absorbers; increasing damping of machine elements; staggering time of machine operations in a plant; applying proper maintenance and machine relocations, etc. (Mohammadi, 2008; Aurich et al., 2012). Source modifications constitute the best practice but are sometimes difficult to implement. Often control of the path or with the receiver may be the better options available.

In order to measure the noise level at the source, a general sound level meter can be used (Harris, 1998). The background noises must be eliminated in advance so that the accuracy of the measurement is guaranteed. Since the measurement at exact locations of the source is not practical, the distance to noise source (e.g. press machines for the example in Section 5) is set to 1 m in radial. This distance is taken based on the NIOSH standard and is equally applied to all SPL measurements (NIOSH, 1998).

3.2. Transmission control

The most obvious transmission path by which noise travels is a direct line-of-sight air path between the source and the listener. Noise also travels along structural paths. Noise can travel from one point to another via any one path or a combination of several paths. The most useful applications of equipment to reduce this problem are: using barriers; installing total or partial enclosures; using absorbent materials; using damping materials; or using flexible ductwork (Crocker, 2007).

3.3. Exposure control

Theoretically, the treatment of noise at the receiver (called 'personal protective equipment' in this paper) should be the final action when all other possibilities are exhausted. Nonetheless, most industries are willing to expend more on this solution than the rest. In fact, labor satisfaction gained by this type of intervention leads managers to invest in them. Additionally, personal equipment is usually less expensive than other control solutions.

There are two different classes of treatment at the receiving end, including earplugs and earmuffs, and concrete personal enclosures. Noise reduction by these methods is usually favoured by the managers and not particularly welcomed by the operators, because most of the operators feel uncomfortable with the limitations caused by the protection devices. Hence, other techniques such as controlling the time of exposure, discussed in Section 1, are sometimes preferred. It should be remarked that each operator can be exposed to different noise sources at the same time, so the resultant SPL should be calculated for each operator (Petrick et al., 1996).

3.3.1. Decibel addition

The total noise exposure for each operator is the result of the emitted noise from different sources. When the SPL measurements at individual sources, as explained in Section 3.1, were completed, the corresponding noise pressure at each operator location could be obtained by Eq. (3) (Lu and Hong, 2005).

$$L_{pij} = L_{wj} + 10\log\left[\frac{1}{4\pi r_{ij}^2} + \frac{4}{R}\right] + 10\log\frac{\rho c}{400} \tag{3}$$

where L_{pij} is the SPL from jth source received by ith operator, L_{wj} is the SPL produced by jth source, r_{ij} is the distance between jth source and ith operator, R is the room constant which is obtained from Eq. (4). ρC is a constant which is dependent on the ambient conditions. For normal air condition $\rho C = 428$ (Crocker, 2007).

[1] Occupational safety and Health Administration.
[2] Occupational Health and Safety Assessment Series.
[3] Health and Safety Executive.
[4] American Conference of Governmental Industrial Hygienists.
[5] British Standards.