CHAPTER 1

INTRODUCTION

Noise-induced hearing loss is one of the most common occupational diseases and the second most self-reported occupational illness or injury. Exposure to high noise levels is a leading cause of hearing loss and may also result in other harmful health effects. In the USA, it has been estimated that 30 million workers are currently exposed to hazardous noise on the job and an additional 9 million workers risk getting hearing loss (NIOSH, 1998). A major cause that contributes to this problem is a lack of effective noise control programs in the workplace. An example of the economic impact of hearing loss is in British Columbia; from 1994-1998, the workers' compensation board paid $18 million in permanent disability awards to 3,207 workers suffering hearing loss. An additional $36 million was paid out for hearing aid (NIOSH, 1998).

The Occupational Safety and Health Administration (OSHA, 1983), the U.S. government agency, recommends the hierarchy of noise control in the following order: (1) engineering approach, (2) administrative approach, and (3) the use of hearing protection devices (HPDs). In fact, most employers do not follow the recommendation of noise control strategy stated by OSHA. When the noise control program is needed for preventing workers from noise hazard, employers tend to use only HPDs as a noise control measure. Although, the engineering and administrative controls are recommended to control noise problems, employers or practitioners may not want to select them into noise control program. This problem may result from the following reasons.

(1) The engineering controls normally require high investment.

(2) The engineering controls need individuals who are highly proficient in this field. Therefore, competent external consultants may be contracted to provide service if in-house highly specialized personnel are not available.

(3) The modification of machines for reducing noise may not be allowed if it affects productivity.

(4) Some administrative controls, for instance, reschedule machine-operating times and change job schedules which may affect productivity or be impossible.

(5) Administrative control may require special knowledge to implement it, such as job rotation.

(6) Using HPDS seems to be the simplest solution and most economical approach.

Nevertheless, from an engineering viewpoint, the use of HPDs for noise hazard prevention may be an improper measure because there are some drawbacks. Hearing protective devices can be considered as uncomfortable and irritating equipment. Besides, they may have an effect on work efficiency because of their cumbersomeness. Therefore, in high noise level workplaces, employers must be aware when providing the noise control measure to their workplaces. If the engineering control and administrative control are not enough to control noise levels to permissible limits, HPDs then will be used as the final resort to noise control. Moreover, it is vital to note that the use of HPDs is just considered to be an interim measure and is not acceptable as a permanent solution to noise problems.

Sanders and McCormick (1993) recommended that a combination of noise controls be used to achieve the desired level of abatement. However, to find an appropriate combination of noise controls is a difficult task especially when requirements such as allocated budget and permissible noise level need to be concurrently considered. Therefore, this research tries to develop a noise hazard prevention strategy that takes three approaches into consideration. Within given budget, the engineering controls will be selected first. If this fails to prevent workers from high noise levels, the administrative control is then considered. The HPDs will be used as the supplementary measure in the proposed noise hazard prevention strategy.

In the hazardous or dangerous situation, the proper warning systems are also required to alert workers to be aware of the unsafe situation. This research considers both the evaluation of the auditory warning systems and the installation of auditory signals to the industrial workplaces for sufficient audibility. Even if the noise hazard prevention program is implemented, the high noise level might still exist. To comply with safety regulations and standards, employers are required to install alarm devices in their facilities to alert workers of hazardous and/or dangerous situations. Alarm devices may generate auditory signals, visual signals, or both types of signals when hazardous or dangerous situations are detected. Among them, the use of auditory signals seems to be a better choice for industrial facilities than the use of other types of signals. This is mainly due to the fact that workers can perceive (hear) the signals even if they are not watching or are working in areas where they cannot see the alarm devices. The International Organization for Standardization (ISO) has also published international standards on auditory danger signals for workplaces. They are: (1) ISO 7731:1986 – Danger signals for work places – Auditory danger signals, and (2) ISO 11429:1996 – Ergonomics – System of auditory and visual danger and information signals.

When studying the safety regulations and standards relevant to the auditory warning system, it is found that some parts are stated as "specifications" while some are stated as "performance." Specification standards specify explicitly what must be done, while performance standards tend to be vague and employers might have all kinds of latitude to set up their own version of an auditory warning system in their workplace (Asfahl, 1999). For example, the Occupational Safety and Health (OSHA) standards discuss the "employee alarm system" in Part 1901.95 (Title 29 – Code of Federal Regulations) as a reference for the design of an alarm system (OSHA, 1983). However, OSHA only enforces the installation of the alarm system without giving the details such as the number of alarm devices and their locations. As a result, the number of alarm devices found in most industrial facilities, and their locations, tends to be determined using a "convenience" basis rather than an "objective" basis. Examples of common alarm locations are at the corner of the facility, on the wall on top of the entrance/exit, and at the ceiling of the facility. For any workplace, given the number of alarm devices and the locations where they are presently installed, it is worthwhile to ask the following question: "*Is the audibility of the auditory warning system adequate for alerting workers of dangerous situations?*"

Since the regulations do not provide the necessary details for the design of auditory warning, safety practitioners or engineers may confront difficulty in designing the effective auditory warning systems. Moreover, the design of auditory warning systems for adequate audibility also requires high technical skill and mathematical knowledge. Sometimes, safety practitioners or engineers may locate alarm devices at the positions which are convenient to install them, but the alarm signal that workers receive may be too low or too high. Therefore, the heuristic (as a practical tool) for designing the auditory warning system should be developed to assist them to design the warning system of which the signal level can adequately alert all workers to hazardous situations.

1.1 Scope and Objectives

This research mainly discusses two major ergonomic problems: noise hazard prevention and design of auditory warning systems. For the noise hazard prevention, there are three noise control approaches including (1) engineering approach, (2) administrative approach, and (3) the use of hearing protection devices (HPDs). In this research, for engineering controls, only controlling at the machine and controlling along the path (i.e., using the barrier to block the noise transmission path) are considered. The former implies that machine noise is reduced. Thus, all worker locations will benefit from such noise control. Note that for a given machine, there could be several engineering control methods for reducing machine noise. The latter, however, will reduce noise levels at some worker locations (only those locations where the barrier can block the noise transmission path). The only administrative control considered in this research is job rotation. This is mainly because job rotation has been widely recommended in the literature, and mathematical models of the job rotation problem have been well defined. Basically, workers are allowed to rotate among worker locations so that the maximum daily noise exposure that any worker receives does not exceed 90 dB*A*. In practice, HPDs should be worn only at very noisy worker locations. There are many types of HPD available, with different noise reduction ratings (NRR) and prices. At any given location, suitable types of HPD to be used must be specified.

For the auditory warning system, this research focuses on the adequate audibility of workers. Other factors, such as the effect of sex and age on auditory sensitivity and frequency selectivity, are not taken into account.

The objectives of this research are as follows.

(1) To develop an optimization procedure for noise hazard prevention.

As stated above, noise hazard is still a major occupational hazard. According to the U.S. Occupational Safety and Health Administration (OSHA), a noise conservation program is required in situations where the noise level exceeds 90 dB*A* (OSHA, 1983). To reduce the workplace noise level, engineering controls are to be considered first. If they are not feasible or not sufficient to reduce noise hazard, administrative controls such as job rotation should be considered next. The use of HPDs is specified as the last resort of noise reduction and should be applied only when engineering and administrative controls fail to prevent the daily noise exposure of workers from exceeding a permissible level. HPDs should be used to assist, not to replace, engineering and administrative controls. At present, the implementation of noise controls is only a guideline. Often, employers choose not to follow the OSHA's hierarchy of noise control due to a large capital investment that is normally required for engineering controls and the difficulty in implementing engineering and administrative controls. As a result, only HPDs (earplugs, earmuffs, etc.) are often provided to workers for noise protection. In this research, noise control strategy will be the combination of noise control approaches to control noise to achieve the desired level of abatement. We firstly study an optimization procedure for finding an optimal strategy for industrial noise control under both budget and noise level concerns. Six mathematical models are developed to yield the optimal noise control strategy. The order of priority for applying noise controls also follows the OSHA's hierarchy of noise control.

(2) To develop a decision support system for noise hazard prevention.

The ultimate goal of this research is to develop a Decision Support System (DSS) for noise hazard prevention. Therefore, a DSS for designing an effective noise hazard prevention (NHP) program based on the given noise condition, preferred solution procedure, and noise control budget is proposed.

When the size of the problem is quite large, the optimization approach usually fails to find the optimal solution; therefore, genetic algorithms and heuristics are then developed to find the near-optimal solution for noise control programs. The proposed GAs will be included as a module in the NHP program. The decision support system for noise hazard prevention is developed on Microsoft Access using Visual Basic for Application (VBA). The NHP program consists of four important modules:

- Database module

This module stores the machine data, engineering noise control technique data, and HPD data

- Input module

The input module provides a user-friendly interface between the users and the NHP program to assist them in inputting additional data (e.g., additional workers for job rotation) and a desired solution procedure. The user may choose to follow the OSHA's hierarchy of noise control or choose the noise control procedure based on his/her preference

- Solution algorithms module

The Solution algorithms module is designed to utilize heuristics and genetic algorithms to generate a *near-optimal* noise hazard prevention solution according to the selected solution procedure and allocated budget

- NHP solution module

This module displays a noise hazard prevention solution that includes the recommended noise control techniques and the resulting daily noise exposures of all workers.

(3) To develop a heuristic algorithm for designing the optimal auditory warning systems for adequate audibility.

Since the safety practitioners usually want a practical tool that can easily be used to design the effective auditory warning system, this research developed a heuristic to find the number of alarm devices, including their locations in industrial facilities, which adequately alert all workers to unsafe situations. For the study of auditory warning systems, we consider an auditory warning system to be sufficiently audible if it meets the signal intensity requirement of the International Standard, ISO 7731, which states that "the auditory signal is clearly audible if the signal sound level exceeds the level of ambient noise by at least 15 dB*A*." For workers with normal hearing or mild hearing loss, the signal sound level (measured at the worker's ear) shall be not less than 65 dB*A* to ensure its audibility (ISO 7731:1986). The current research developed by Nanthavanij and Yenradee (1994 and 1999) and Nanthavanij (1995) is reviewed. Their research used the optimization method to solve the mathematical model and also has some limitations. Then, this research proposes a heuristic algorithm to determine the number of alarm devices (with known signal sound level) and their locations for generating an adequately audible auditory warning signal. The proposed algorithm is also intended to minimize a maximum combined signal sound level among the given worker locations. This heuristic algorithm is developed to be a practical tool for safety practitioners or engineers.

1.2 Overview of the Dissertation

This dissertation contains eight chapters as following.

Chapter 1 is an introduction of the research. The problem statement and significance of the noise hazard prevention and the design of auditory warning system are presented in this chapter. An overview of the dissertation is also included in this chapter.

Chapter 2 is the literature review in the following topics: industrial noise, industrial noise hazard prevention, genetic algorithms, Decision Support Systems, and auditory warning systems in industrial workplace.

Chapter 3 presents six mathematical models representing the noise hazard prevention problem and the design procedures for noise hazard prevention, including engineering-based procedure, HPD-based procedure, and mixed procedure.

Chapter 4 discusses a genetic algorithm for the selection of engineering controls. The experiments for finding the suitable GA parameters and GA operators are provided and the investigation of GA performance is presented as well.

Chapter 5 covers the heuristic genetic algorithm for workforce scheduling with minimum total worker-location changeover. The heuristic crossover and heuristic mutation are described. The numerical examples with different size of problems are done to investigate the GA performance.

Chapter 6 presents the DSS program for the noise hazard prevention problem. The conceptual design and detail of each module are also included in this chapter.

Chapter 7 is the evaluation and optimal design of auditory warning systems for adequate audibility. This chapter presents the evaluation of auditory warning systems, the mathematical models for designing the auditory warning system, and the heuristic approach. The comparison between optimization approach and heuristic approach is also discussed.

Chapter 8 is the conclusions of the research. This chapter includes a summary and the key contributions of the research. The recommendations for future studies are also given.