CHAPTER 1

INTRODUCTION

1.1 Occupational Industrial Hazards

Millions of workers are everyday at risk of occupational injuries and illness due to the exposure of hazardous tasks and work environment. Workers who are exposed to occupational hazards are found in every area such as agriculture, mining, construction, manufacturing, utilities, transportation, and military.

Only in U.S.A., Department of Labor's Annual Survey of Occupational Injuries and Illnesses (ASOII) stated that conservative estimates of direct cost, based on workers' compensation payments (indemnity and medical services) and other direct costs, are at least ten billions of dollar per year (NIOSH, 1996). The total cost to society is believed to be substantially higher due to various indirect costs, e.g., lost productivity, costs of hiring and training replacement workers, overtime, administrative costs, and miscellaneous transfer payments (NIOSH, 1997).

Even basic tasks such as lifting can be dangerous to worker safety. Workers are often required to expend moderate to high level of physical energy to perform physical tasks such as lifting/lowering, carrying, and loading/unloading. Thus, they are likely to develop excessive fatigue, which can cause occupational accidents and over-exhaustion after work.

Beside the hazardous tasks, the work environment can also be dangerous due to the high exposure of noise, heat, dust, and chemical. In particular, workers are exposed to noise hazard problems in their workplace. Hearing loss affects not only worker performance on the job but also their social activities. According to the National Institute for Occupational Safety and Health (NIOSH), approximately 30 million workers are currently exposed to hazardous noise on the job and an additional 9 million are at risk for hearing loss. Noise-induced hearing loss is one of the most common occupational diseases and the *second* most self-reported occupational illness or injury. Some example of 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).

Numerous methods can be implemented so that the exposure from these occupational hazards can be decreased. With the engineering methods, heavy tasks can be redesigned with the aiding tools or handling equipment; noisy machine can be modified or replaced with the new machine so that the noise level is decreased.

1.2 Job Rotations and Workforce Scheduling

Unfortunately, in many situations, the effective engineering methods are unaffordable or too costly. Thus, the administrative methods are usually suggested. One of the most frequently recommended administrative method to reduce the occupational hazard is *job rotation* (NIOSH, 1981; OSHA, 1983). That is, workers are assigned to do various tasks and also rotate their task at different periods during the day. In this way, the effect from hazardous tasks can be split and shared by many workers, instead of concentrating on some particular workers. Job rotation offers a compromise between safety concern and cost effectiveness (Olishifski and Standard, 1988). *Workforce scheduling*, the more familiar operations research terminology of job rotation, aims to schedule workers to perform tasks under concerned periods.

The usefulness of job rotation is illustrated by a simple example as follows. Suppose three tasks with the energy expenditure of 400, 500, and 700 kilocalorie (kcal) per period, must be assigned to three workers, namely Mr. A, B, and C, respectively. Suppose all workers have the equal working energy capacity of 1800 kcal and there are four periods. Table 1.1 shows the worker-task assignments that no rotation is allowed. Table 1.2 shows the worker-task assignments that rotation is allowed. Table 1.3 shows the assignments with rotation and one additional worker, or Mr. D with the similar working energy capacity of 1800 kcal.

Without rotation, worker C is in most danger, and also worker B. With rotation, worker C is safer but still in danger; while worker A becomes in danger too. Since, the sums of energy expenditure of all three workers are still higher than their energy capacity. It is necessary to include worker D so that all workers are safe.

Table 1.1 The assignments *without* rotation

Worker	Period				Sum (kcal)
	1	2	3	4	
A	400	400	400	400	1600
B	500	500	500	500	2000
C	700	700	700	700	2800

Table 1.2 The assignments *with* rotation

Worker	Period				Sum (kcal)
	1	2	3	4	
A	400	400	700	700	2200
B	500	500	500	500	2000
C	700	700	400	400	2200

Table 1.3 The assignments with rotation and one additional worker

Worker	Period				Sum (kcal)
	1	2	3	4	
A	400	400	700	-	1500
B	500	-	500	500	1500
C	700	700	-	400	1800
D	-	500	400	700	1600

1.3 Problem Statements

Job rotation is clearly useful to alleviate the hazard from the tasks. But there exist no detailed implementation in most textbooks and literatures where job rotation is usually recommended. Since, in practice, it is not easy to rotate workers. In the previous numerical example, all workers have equal working energy capacity. But in reality, workers have different working energy capacities due to their variation in physical fitness. Beside the energy consideration, workers are usually exposed to the high noise level. Considering both energy and noise criteria makes the job rotation problem even more difficult. Moreover, it is usually recommended that the number of workers involved in the hazardous tasks should be minimal (NIOSH, 1998). Clearly, this concern makes the job rotation problem with the minimum number of workers even more complicated. In the area of workforce scheduling, there are also some scheduling problem that aims to minimize the number of workers as their objective (Bhaba, 1986; Vicente et al., 1996; Rangarajan, 1996). But there exist no scheduling problem that focuses on the safety of workers. Most workforce scheduling problems considers only the scheduling costs and completeness of assigned tasks. Although a scheduling problem in the airline industry so-called *crew scheduling* also concerns some safety constraints such as the maximum daily work hour, maximum number of flight legs, and minimum overnight rest period (Qi et al., 2004). However, crew scheduling aims to minimize the scheduling cost. Probably pilots and flight attendants with higher salary are more important than workers in constructions, manufacturing, and other industries.

It is necessary to develop the efficient methods or algorithms for this job rotation problem; so that safety engineers or plant managers will be able to improve the safety of industrial workers more effectively with the assistance of job rotation.

1.4 Objectives of the Study

In this study, this job rotation problem with the minimum number of workers under both noise and energy criteria is called as the Two-Criterion Workforce Scheduling Problem (2WSP). If the noise criterion is only considered, it is called the Workforce Scheduling Problem with Noise Criterion (WSP-N). If the energy criterion is only considered, it is called the Workforce Scheduling Problem with Energy Criterion (WSP-E). The objectives of this study are:

1. To develop the mathematical model and algorithms for WSP-N
2. To develop the mathematical model and algorithms for WSP-E
3. To develop the mathematical model and algorithms for 2WSP

1.5 Organization of the Dissertation

This study is organized as follows.

Chapter 2 reviews the ergonomics backgrounds related to the proposed problems. The first section reviews the industrial noise exposure and the second section reviews the energy expenditure in physical works.

Chapter 3 reviews the existing optimization problems that are closely related to the proposed problem. The job rotation problems related to WSP-N are first reviewed. The One-Dimensional Bin Packing Problem (1BPP) is also reviewed in details; since, WSP-N is a variation of 1BPP. WSP-E also turns out to be a variant of the Variable-Sized Bin

Packing Problem (VSBPP). Moreover, the Two-Dimensional Vector Packing Problem (2DVPP) is reviewed. Since 2WSP can also be identified as a variation of 2DVPP. The algorithms for solving these problems are also reviewed.

In this dissertation, the author first studied WSP-N. Later, WSP-E was considered. Lastly, 2WSP was researched. As a result, the following chapters associated with these problems are arranged according to this sequence.

Chapter 4 introduces WSP-N and its description and mathematical model. The algorithms and hybrid procedure for WSP-N are proposed. A numerical example and computational experiment are illustrated.

Chapter 5 introduces WSP-E and its description and mathematical model. The algorithms and hybrid procedure for WSP-E are proposed. A numerical example and computational experiment are illustrated.

Chapter 6 introduces 2WSP and its description and mathematical model. The algorithms and hybrid procedure for 2WSP are proposed. A numerical example and computational experiment are illustrated.

Chapter 7 concludes the study and recommends the future improvement.