CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

In this study, the author proposed the new safety-based workforce scheduling problems, which are:

1. The Workforce Scheduling Problem with Noise Criterion (WSP-N)
2. The Workforce Scheduling Problem with Energy Criterion (WSP-E)
3. The Two-Criterion Workforce Scheduling Problem (2WSP)

The objectives of all three problems are the same, i.e., to minimize the number of workers performing the required hazardous tasks. However, WSP-N considers only the noise exposure measured at the tasks, while WSP-E concerns only the energy cost associated with the tasks. For 2WSP, both noise and energy criteria are considered.

The objectives of this study are to develop the algorithms for solving the three proposed problems. The algorithms for WSP-N, WSP-E, and 2WSP can be categorized into heuristics, exact algorithms, and hybrid procedures as shown in Table 7.1.

Table 7.1 Algorithms for WSP-N, WSP-E, and 2WSP

Algorithms	WSP-N	WSP-E	2WSP
Lower bounds	L_n	L_e	LB_1, LB_2
Heuristics - List algorithms - Dual strategy - Other	 MFFD-N DFDS-*x* for WSP-N BnB-H	 MFFD-E DFDS-*x* or WSP-E -	 2MFFD, 2MBFD, 2MFFDc, 2MBFDc 2DFDS-*x* -
Exact algorithms	BB-N	BB-E	BB_1, BB_2, BB_3
Hybrid procedures	MFFD-N + DFDS-1000 + BnB-H + BB-N	MFFD-E + DFDS-1000 + BB-E	2DFDS-5000 + BB_2

It is discovered that WSP-N is a variant of the One-Dimensional Bin Packing Problem (1BPP). WSP-E also turns out to be a variant of the Variable-Sized Bin Packing Problem (VSBPP). And 2WSP can also be identified as a variation of the Two-Dimensional Vector Packing Problem (2DVPP). As a result, many existing methods for solving these packing problems are studied and modified for WSP-N, WSP-E, and 2WSP. Algorithms for each problem are summarized in details as follows.

7.1 Algorithms for WSP-N

The lower bound for WSP-N, L_n, is the maximum between a simple lower bound L_{n1}, assuming that noise weights can be splitted, and a more sophisticated lower bound L_{n2} which split all subtasks into three groups according to their noise weights. L_{n2} dominates L_{n1} in all test problems.

Three types of heuristics for WSP-N, namely MFFD-N, DFDS-*x*, BnB-H, are developed. MFFD-N is a modification of FFD heuristic for 1BPP, which generates a feasible solution from the non-decreasing list of noise weights. DFDS-*x* for WSP-N applies the dual strategy by constructing the solution at the initial number of workers. If the feasible solution is found, DFDS-*x* tries to construct the feasible solution at the lower number of workers until it fails. DFDS-*x* utilizes an algorithm modified from the LPT heuristic for $P_m|-|C_{max}$, the swap procedures specially designed for improving the solution, and the random search with limited number of moves. BnB-H is a branch-and-bound scheme that yields a feasible solution for WSP-N. Based from the computational experiment, DFDS-1000 (DFDS-*x* with 1000 moves) is on average superior than BnB-H and MFFD-N.

An optimization method for WSP-N, namely BB-N, is developed. BB-N is a branch-and-bound method, which applies the dominance rule. The efficiency of implementing BB-N alone is low. But BB-N significantly improves many solutions when used as the last step in the hybrid procedure. Based from the computational experiment, the hybrid procedure for WSP-N can find the maximum number of optimal solutions for 265 out of 300 randomly generated WSP-Ns.

7.2 Algorithms for WSP-E

A lower bound, L_e, is developed. Note that the workers of WSP-E are not identical due to the fact that their working energy capacities are different. The initial number of available workers and their energy capacities must be known. L_e is the possibly minimal number of *strongest* workers. L_e assumes that the energy expenditure of each task can be spitted. All algorithms for WSP-E only choose the strongest workers first, not any workers.

Two heuristics for WSP-E, namely MFFD-E and DFDS-*x*, are developed. MFFD-E is similar to MFFD-N but considers the energy criterion instead. DFDS-*x* for WSP-E is also similar to DFDS-*x* for WSP-N but considers the energy criterion instead. A branch-and-bound method, BB-E, is developed. BB-E is similar to BB-N but its branching scheme is different from BB-N due to non-identical workers. This difference makes BB-E more computationally expensive than BB-N. Based from the computational experiment, the efficiency of BB-E in the WSP-E hybrid procedure is lower than that of BB-N in the WSP-N hybrid procedure. The hybrid procedure for WSP-E can find the maximum number of optimal solutions for 263 out of 300 randomly generated WSP-Es.

7.3 Algorithms for 2WSP

Two lower bounds, namely LB_1 and LB_2, are developed. $LB_1 = \max\{L_n, L_e\}$ and LB_2 is the maximum between the optimal solution of (1) the 2WSP problem solved as WSP-N and (2) the 2WSP problem solved as WSP-E. These optimal solutions are generated by their associated one-criterion hybrid procedures. LB_2 is more computationally expensive but more efficient than LB_1. Similar to WSP-E, the initial number of available workers for

2WSP must be known, and all algorithms only produce a solution with the strongest workers first.

Many list heuristics are developed, which are 2MFFD, 2MBFD, 2MFFDc, and 2MBFDc. When assigning the tasks to the workers, these list algorithms must consider both noise and energy criteria. 2DFDS-*x* is an efficient heuristic for 2WSP with the same concept of DFDS-*x* concerning both criteria.

Three specially designed exact algorithms, namely BB_1, BB_2, and BB_3, are developed. They are all the branch-and-bound schemes. Many techniques for eliminating unnecessary branches and fathoming nodes are proposed. BB_3 is the most efficient among the three but the hybrid procedure, combining 2DFDS-5000 and BB_2, are more efficient than BB_3 alone. The hybrid procedure can find the maximum number of optimal solutions for 158 out of 200 randomly generated 2WSPs.

7.4 Recommended Future Works

For future studies, one is recommended to focus on these following issues.

- More existing algorithms for 1BPP in the literature should be studied and modified so that they may solve WSP-N, WSP-E, and 2WSP more efficiently.
- Worst-case bounds of MFFD-N and MFFD-E should be derived since they are just a direct modification from FFD; it is possible to follow the same method of proving FFD to obtain their bounds.
- More possible ways of swapping algorithms of DFDS-*x* heuristic should be developed. For example, it is possible to swap two subtasks assigned to a worker with two subtasks assigned to two different workers.
- Stronger lower bounds should be developed so that more problems can be solved for optimum.
- Techniques in BB_2 and BB_3 of 2WSP can be used to improve the efficiency of BB-N and BB-E.
- Algorithms for 2WSP should be modified so that they can solve 2DVPP.
- More realistic constraints of worker-task assignment should be considered. For example, some worker might not be able to perform some tasks due to lack of skill.
- Other hazardous criteria can be considered such as exposure to heat, chemicals, and radiation.
- User-friendly computer software that can solve WSP-N, WSP-E, and 2WSP, should be developed.