Chapter 6

Conclusions

6.1 Summary of the Research

This dissertation emphasizes on applying optimization and heuristic techniques to the scheduling problem. A scheduling is the decisions about how to match activities and resources in order to complete all activities at the required time while simultaneously minimize and maximize some objectives such as cost, customer satisfaction, efficiency, etc.

The first part of this dissertation accentuates on the single machine scheduling problem. The author conducts a literature review on various single machine scheduling problems. One of the common objectives is to deliver goods within the specified due date of customer. Some authors consider tardiness criterion in the objective function. The objectives to deliver goods exactly at due dates is also studied by many researchers due to the arising of Just-In-Time (JIT) Production philosophy. The author focus on this area will use earliness and tardiness penalty in the objective function. The penalty values may be different among jobs based on priority of job, unit cost, etc, in this case the performance measure will be weighted earliness and/or weighted tardiness penalty.

Apart from the due date related objectives, an improvement of production efficiency can be achieved by reducing setup time and cost. One way to reduce setup is to standardize and automate setup procedure. Another way to reduce setup time and cost can also be achieved through efficient scheduling of jobs. The setup time and cost can be classified into two categories, i.e. sequence dependent and sequence independent. The setup that depends on the job to be processed and its preceding job is referred to as sequence dependent setup. While the setup which depends only on the job to be processed is called sequence independent. In the literature, authors consider different objectives, such as to minimize setup time or cost, to minimize only tardiness or earliness/tardiness, and to minimize combined objectives of setup and earliness/tardiness. Many optimization techniques are proposed to solve the problem, such as many variants of dynamic programming algorithms, various types of branch and bound algorithms.

In this dissertation, a more general objective function of single machine scheduling problem that combines many scheduling characteristics is considered. The objective is to minimize the sequence dependent setup cost and weighted earliness/tardiness penalties when the setup time is also sequence dependent. For this problem, the idle time is not permitted, the earliness/tardiness penalties are different among jobs and represented by weights. *Branch and Bound algorithm* (B&B) is proposed to solve the problem. The main objective is to develop an efficient optimization procedure for the general case of single machine scheduling. Hence, a number of single machine scheduling problems found in literature are special cases of the problem under consideration. The proposed scheduling method can be applied to solve these special cases with minor modification of some input parameters. The development of branch and bound algorithm for this problem is achieved in two steps. The first step is a simple branch and bound algorithm with heuristic methods to determine upper bound (B&B1).

The initial feasible solution which will give an upper bound of the objective function is obtained using either *Minimum Setup* or *Earliest Due Date* heuristics. In the second step, the efficient lower and upper bounding procedure are incorporated into basic brand and bound (B&B2). Lower bounds are obtained based on heuristic and *Lagrangian Relaxation*. *Priority Dispatching Rule* with *Local Improvement Procedure* (*Swap* and *Insertion*) is used to derive an initial upper bound. Two dominance criteria, i.e., *Adjacency Condition* and *Non Adjacency Condition*, are incorporated into a branch and bound procedure The dominance criteria is applied to a new creating node so that any adjacent and non-adjacent job must satisfy these conditions, any node which does not satisfy these conditions will be removed from a branch and bound search tree. This procedure can reduce the search space and enhance computational efficiency.

The computational experiment reported that B&B2 is more efficient than B&B1. The B&B 2 can be used to solve the problem with up to 40 jobs while B&B1 can solve only 16 jobs problem within reasonable time. For both cases the computational time increases exponentially with the number of jobs which indicates *NP*-hard nature of the problem. The efficiencies of upper bound, dominance criteria, and lower bound are also evaluated by using computational time, number of generated nodes, and number of generated complete solutions as a performance measure criterion. The results indicated that lower bound is the most significant feature of the algorithm, followed by dominance criteria, while the upper bound is the least significant feature. Since the upper bound is calculated only at the early stage of the computation (initialize step), but the lower bound and dominance criteria are repeatedly determine at every generated node so they are capable of eliminating a larger number of nodes at all stages of computation. The lower bound consider the least cost that will incur if a node is branched further so they predict the effect of unscheduled job while the dominance criteria take into account only the precedence relations of the adjacent and non-adjacent jobs within the node (the scheduled jobs), hence, lower bound has greater effect in eliminating nodes.

The exact algorithm likes B&B can guarantee the optimal solution but the major drawbacks are that they are computational expensive and can be used to solve only small- to medium-sized problem. Thus, the second part of this dissertation introduces a novel meta-heuristic algorithm called *Particle Swarm Optimization* (PSO) to solve large single machine scheduling problems. The objective of the problem is changed to minimize total tardiness where the setup time is sequence-dependent (the earliness penalties and sequence-dependent setup cost is not considered) since many existing solution techniques and benchmark problems adopt this objective. Later on the objective function is modified to cover the single-machined earliness/tardiness problem with sequence-dependent setup cost.

The most significant part of application of PSO to single machine scheduling problem is how to represent a solution and how to translate continuous PSO to discrete job schedule. For this problem, particle is represented as a multi-dimensional point in space. The ranking of position values enable the generation of potential job sequence. The preliminary results have shown that basic PSO has a difficulty in controlling the balance between global exploration and local exploitation which often makes PSO trap in local optima. Therefore, three improvement techniques, i.e., *Regroup & Resize*, *Local Improvement Procedure* (LIP), and *Variable Neighborhood Search* (VNS), are studied in order to find the best techniques to incorporate into basic PSO. Five variants of Hybrid-PSO are tested which are Hybrid-PSO with LIP (with and without backward search), Hybrid-PSO with VNS, Hybrid-PSO with Regroup & Resize, Hybrid-PSO with Regroup & Resize and LIP, and Hybrid-PSO with Regroup & Resize and VNS.

Two benchmark problems of Rubin and Ragatz (1995) are used for testing and the results are compared with the B&B results of Tan *et al*. (2000). The results indicated that Hybrid-PSO with LIP with backward search (*Hybrid-PSO*$_{backlip}$) is superior to other techniques with the least deviation from B&B results and most effective computation time. It can be concluded that LIP is the most effective technique to integrate with PSO for this type of problem. Then, the experiment is carried on to compare Hybrid-PSO with LIP with *Ant Colony Optimization* algorithm (ACO) by Gagné *et al*. (2001), the best known solution approaches in the literature. The *Hybrid-PSO*$_{backlip}$ is competitive to ACO and performs differently with different problem characteristic. Furthermore, the computational results of *Hybrid-PSO*$_{backlip}$ for the single-machine earliness/tardiness problem with sequence-dependent setup cost reveals that PSO is suitable for large-sized problem in terms of solution quality and computational time.

Since the experiment reveal that PSO is effective to the scheduling problem, the third part of dissertation extend PSO to solve more complex type of scheduling problem which is a care worker scheduling problem. Care worker scheduling problem can be modeled as vehicle routing problem with time windows (with limited route time) with slightly different in problem characteristics. This problem is the real application of the home care provider in the UK to support the people who need assistance due to their illness or physical disabilities. The problem was originally considered by *The Welsh Systems Consortium using* manual approach and the Advanced Internet & Emergent Systems (AiMES) Centre at the University of Liverpool using the proprietary software ILOG™ Dispatcher. The objective of the problem is to determine the optimal care worker routes that minimize the distance traveled without violating the time windows and capacity constraints.

Similarly, the most crucial part of application of PSO to care worker scheduling problem is how to represent the schedule from a continuous PSO. The procedure is considerably different and more complex than single machine representation. In this case, particle is represented by position value matrix which implies the assignment priority. The *Heuristic Assignment* procedure is tailored particularly to decode PSO into feasible care worker schedule without violating constraints. To improve the performance of PSO, the search direction of particle is guided by using the *Earliest Start Time Priority with Minimum Distance Assignment* (ESTPMDA) technique. *Local improvement procedures* (LIP), i.e. *insertion and swap*, are also embedded in the PSO algorithm in order to further improve the solution quality. The experiment has been conducted using Taguchi design of experiment in order to find the best combination of parameters for this type of problem. The proposed algorithm performs very well and superior to the existing solution technique using ILOG™ since PSO uses population-based searching technique. Each individual in the population contribute in exploring the search space more thoroughly and share its experience with others in the group. PSO has a learning ability. Each individual is trained from its own memory and also group's memory which enable it to move toward the right search direction. Furthermore, the probabilistic search characteristic of PSO increases the chance for individual in moving into the new search area, escape from local optima, and finding a new optimum solution. The experiment has been conducted to compare the performance of PSO algorithm with the existing technique. The computational results have shown that PSO is superior to previous solution technique for all test cases. Since the main focus of this research is to purpose an alternative new solution technique, the comparisons of PSO with other meta-heuristics are left as further study.

6.2 Key Contributions of the Research

In summary, key contributions of the research include both theoretical and practical contributions:

6.2.1 Theoretical Contributions

1. This research develops efficient upper and lower bounding procedures for branch and bound algorithm to optimally solve more general and complex single machine scheduling problems than those in the literature. Also, it increases the problem size that can be solved by general Branch and Bound algorithm.
2. Branch and bound algorithm can be used to determine a global optimal schedule for this complex problem. Although it can be used to solve only small to medium sized problem, the solution can be used as a benchmark for developing other heuristic techniques for this problem.
3. A number of single machine scheduling problems found in literature are special cases of the problem under consideration in this research. Therefore, the branch and bound algorithm can be used to determine the optimal solutions of these special cases by only modifying some input parameters.
4. A novel meta-heuristic PSO algorithm is introduced to be able to apply to large-sized single machine scheduling problem.
5. PSO can be used to obtain near-optimal solution with fast computational time for large-sized problem. The performance is competing with the best known solution technique in the literature in term of solution quality and computational time.
6. Various improvement heuristics are investigated to incorporate into basic PSO algorithm to enhance its performance particularly for single machine scheduling problem.
7. A systematic approach is developed to improve the existing schedule of home care workers.
8. Various improvement heuristics are analyzed to integrate into basic PSO algorithm to enhance its performance for care worker scheduling problem and also to determine the best combination of parameters for this type of problem.
9. This research is a pioneer development of methodology to enable the PSO algorithm to be efficiently applied to care worker scheduling problem and all classes of similar problems with proven results by experimenting on the real application.

6.2.2 Practical Contributions

1. This research develops many algorithms that can be integrated into a scheduling software of a company. The scheduling criterion is general which can be easily modified to solve many cases of industries.
2. An efficient and superior meta-heuristic algorithm is developed to be practically used by home care providers or integrated into entire care plan system in order to obtain the *best value* service by improving service quality, reducing cost, reducing resources, and saving time in planning.

Publications based on the results of this research are presented as follows.

Akjiratikarl, C., and Yenradee, P., 2004. Branch and Bound Approach for Single-Machine Sequencing with Early/Tardy Penalties and Sequence-Dependent Setup Cost. *International Journal of Industrial Engineering and Management Systems* 3(2): 100-115.

Akjiratikarl, C., Yenradee, P., and Drake P.R., 2006. An Improved Particle Swarm Optimization Algorithm for Care Worker Scheduling. *Proceedings of the 7th Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS 2006),* 17-20 December 2006, Bangkok, Thailand (CD-ROM): 457-466.

Akjiratikarl, C., and Yenradee, P., 2005. Particle Swarm Optimization for the Single Machine Total Tardiness Problem with Sequence-Dependent Setup Time. *Proceedings of the sixth Asia-Pacific Industrial Engineering and Management Conference (APIEMS 2005),* 4-7 December 2005, Manila, Philippines (CD-ROM).

Akjiratikarl, C., and Yenradee, P., 2004. Optimisation of single-machine earliness and tardiness sequencing problem with sequence-dependent setup cost. *Proceedings of the Fifth Asia-Pacific Conference on Industrial Engineering and Management Systems (APIEMS 2004): Applications and Practice* [CD-ROM], 12-15 December 2004, Gold Coast, Australia: 21.11.1 to 21.11.15.

Akjiratikarl, C., and Yenradee, P., 2002. Dynamic Programming with Branch and Bound Algorithm for Optimizing the Single-Machine Early/Tardy Problem with Sequence-Dependent Changeover Cost. *Proceedings of the 7th International Pacific Conference on Manufacturing and Management 2002*, November 27-29, 2002, Bangkok, Thailand: 946-951.

6.3 Recommendations for Further Studies

The further research direction might include:

1. The heuristic approach or hybrid branch and bound with heuristic for single machine scheduling can be developed for larger problems using the results in this research as a benchmark for the evaluation of heuristic algorithm.
2. More experiments can be conducted to compare PSO with other heuristic techniques, i.e. *Genetic Algorithm*, *Tabu Search*, *Evolutionary Algorithm*, etc., in order to find the most efficient technique for this type of problem.
3. PSO algorithm can be further modified or developed to make it more efficient tools for scheduling problem. The potential development are Hybridization with other collaborative heuristics such as *Genetic Algorithm*, *Tabu Search*, *Evolutionary Algorithm*, etc., or experimentation with different solution representation such as discrete or permutation representation, or application of random number generator such as sobol sequence to get more randomize initial solution.
4. The PSO algorithm for care worker scheduling may be extended to cover multiple objective, i.e., minimize number of care workers together with the distance traveled.

5. The PSO algorithm for care worker scheduling may take into consideration of some social issues such as work shift pattern, care worker-clients familiarity, skill matching requirement.
6. The decision support system for the entire care provider system might be developed using PSO algorithm as an embedding feature for scheduling.