MODELING MEDICAL DOCTOR ROSTERING USING HYBRID GENETIC ALGORITHM-PARTICLE SWARM OPTIMIZATION

ZANARIAH ZAINUDIN

Faculty of Computing
Universiti Teknologi Malaysia

MODELING MEDICAL DOCTOR ROSTERING USING HYBRID GENETIC ALGORITHM-PARTICLE SWARM OPTIMIZATION

ZANARIAH ZAINUDIN

A thesis submitted in fulfilment of the requirements
for the award of the degree of
Master of Science (Computer Science)

Faculty of Computing
Universiti Teknologi Malaysia

March 2014

To my beloved mother, Ramlah Ab Samad and late father, Zainudin Ujang, and my brothers, Zulkarnain and Iskandar Mirza and also my lovely sister, Zarinah and Zuraidah

ACKNOWLEDGMENT

I would like to express my sincere thanks to Dr. Azurah A.Samah as my supervisor and for her encouragement, patient guidance and valuable advices. Despite of her busy schedule, she always available to support my research work during my years at Universiti Teknologi Malaysia. She corrected my work patiently, taught me how to improve my research work and encourage me to report my research work to make me move nearer and nearer to my goal and objective. Also many thanks to Assoc. Prof. Dr. Siti Zaiton Mohd Hashim (Faculty of Computing) and Dr Adlina Abd Samad (Language Academy) for taught me and improve my research work.

My sincere appreciation also goes to all my friends, (Nurfazrina Mohd Zamry, Norsyaliza Abd Razak, Siti Aishah Ibrahim, Nilam Nur Amir Sjarif) not only for continuous help, but also for their friendship support.

I would like to thanks to Dr Redzuan and Dr Awatif for their valuable information during the data collection and validation process. Without their helps, this research work will hardly be done smoothly and successfully. Finally, I would like to thank all my family members and my beloved one for their patience and financial support.

ABSTRACT

Rostering plays an important role in most manufacturing, production and healthcare systems. Manual staff rostering as opposed to a computerized system, particularly for medical doctors is usually challenging, tedious and tiresome, whereby the tasks involved too much time consumption due to changes in business rules, shortage of healthcare professionals, and overwork. Besides that, soft constraints as bearable ones as well as hard constraints which must be addressed are issues that must be taken into account during the rostering process. Due to these problems, modelling of a medical doctor rostering using Hybrid Genetic Algorithm-Particle Swarm Optimization (Hybrid GA-PSO) is proposed as a means to minimize the total violation constraints to obtain maximum satisfaction among medical doctors as well as satisfying all the hard constraints and as many soft constraints possible. Hybrid GA-PSO is represented by a population of working days which are then determined using evolutionary inspired operators, searching and updating process. In addition, observations and interview sessions with the person in-charge were carried out to obtain additional data and identify constraints in relation to medical doctor rostering at Hospital Sultanah Aminah (HSA), Johor Bahru, Johor. In this study, the different levels of importance for the hard and soft constraints based on the requirements to create the duty roster were identified. The performance of medical doctor rostering using Hybrid GA-PSO method was measured in terms of total violation constraints and accuracy, as well as comparisons with standard Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). Results of this study show that Hybrid GA-PSO has the ability to produce feasible duty roster that could save time and distribute the workload fairly to the medical doctors. The Hybrid GA-PSO provides a solution to not only improve the computation of the rostering system, but has also produced an efficient and effective duty roster for medical doctors and staff.

ABSTRAK

Penjadualan memainkan peranan yang penting dalam industri pembuatan, pengeluaran dan kesihatan. Perjadualan kakitangan secara manual berbanding dengan sistem berkomputer khususnya untuk doktor perubatan merupakan tugas yang mencabar, membosankan dan meletihkan, di mana tugas tersebut mengambil masa yang lama disebabkan oleh perubahan pada perniagaan, kekurangan staf professional serta kerja yang berlebihan. Selain itu juga, kekangan lembut harus ditangani manakala kekangan keras wajib ditangani adalah isu-isu yang perlu diambil kira semasa proses penjadualan. Disebabkan oleh masalah-masalah ini, pemodelan penjadualan doktor menggunakan Hibrid *Genetic Algorithm-Particle Swarm Optimization (*Hibrid GA-PSO*)* dicadangkan sebagai salah satu cara untuk meminimumkan jumlah pelanggaran kekangan bagi memperolehi prestasi maksimum yang memuaskan di kalangan doktor perubatan, di mana ia dapat memenuhi semua kekangan keras dan sebanyak mungkin kekangan lembut. Hibrid GA-PSO diwakili oleh hari bekerja seseorang doktor di mana ia akan ditentukan menggunakan evolusi pencarian dan proses mengemaskini. Di samping itu, pemerhatian dan temubual dengan pegawai yang bertanggungjawab telah dijalankan untuk mendapatkan data tambahan dan mengenal pasti kekangan berhubung dengan penjadualan doktor perubatan di Hospital Sultanah Aminah (HSA), Johor Bahru, Johor. Dalam kajian ini, di mana kepentingan kekangan keras dan kekangan lembut berdasarkan keperluan untuk membina jadual kerja telah dikenal pasti. Prestasi penjadualan doktor perubatan menggunakan Hibrid kaedah GA- PSO diukur dari segi jumlah pelanggaran kekangan dan ketepatan, dan prestasinya dibandingkan dengan *Genetic Algorithm* (GA) dan *Particle Swarm Optimization* (PSO) piawai. Keputusan kajian ini menunjukkan bahawa Hibrid GA-PSO mempunyai keupayaan untuk menghasilkan jadual kerja yang sesuai dimana ia akan menjimatkan masa dan mengagihkan beban kerja secara adil untuk doktor perubatan. Hibrid GA-PSO menyediakan satu penyelesaian bukan sahaja untuk meningkatkan sistem penjadualan secara berkomputer, tetapi juga telah menghasilkan satu jadual kerja yang tepat dan berkesan untuk doktor perubatan dan kakitangan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AB	Agents-Based
B&P	Branch & Price
CBR	Case-Based Reasoning
CBRG	Case-Based Repair Generation
CGB	Column Generation Based
CH	Constructive Heuristics
CLP	Constraints Logic Programming
DA	Decomposition Approach
GA	Genetic Algorithm
GCS/SS	Guided Complete Search/Simplex Solver
GRASP	Greedy Random Adaptive Search Procedure
H	Heuristic
HH	Hyper-Heuristic
IGA	Indirect GA
ILP	Integer Linear Programming
IP	Integer Programming
LP	Linear Programming
LP	Linear Programming
LS	Local Search
MA	Memetic Algorithm
MIP	Mixed Integer Programming
MO-MP	Multi-Objective Mathematical Programming
NN	Neural Network
PSO	Particle Swarm Optimization
SA	Simulated Annealing
SS	Scatter Search

TS	Tabu Search
VNS	Variable Neighborhood Search
HS	Heuristic Search
EA	Evolutionary Algorithm
LSN	Local Search Network
CS	Cyber Swarm
MM	Mathematical Models
IP	Integer Programming

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

In an organization, in providing services or goods, the process of constructing duty roster, or rostering, for its staff is normally carried out so as to ensure customer's satisfaction. Initially, the number of staff with particular skill to meet the specific service is determined. To meet the required staffing levels at different times, staffs are allocated to shifts, and duties are then assigned to the individual staff working in each shift. At the same time, all industrial regulations associated with the particular workplace must be observed during the process. However, it is extremely difficult to find an acceptable duty roster to these highly constrained and complex problems and it is even more difficult to determine a feasible duty roster that minimize costs, meet employee preferences, distribute shifts equitably among employees and satisfy all the workplace constraints.

Some researchers have previously suggested a few definitions of rostering, but they all agreed that rostering is assigning or allocating resources (staff) to the one slot (work)) meanwhile scheduling is arrange or plan (an event) to take place at a particular time (Adrian Brezulianu, 2010; Wren, 1996. Some of the definitions of rostering, as given by previous authors and as defined in the Oxford Dictionary, are given below. Understanding its definition is essential in order to appreciate the problems associated with rostering.

Adrian Brezulianu (2010) defined staff rostering as follows:

> *"The staff rostering, or more specific, the shift rostering is defined as a problem of placing resources (employees) into slots in a pattern, in such way to accomplish given constraints."*

The definition by Wren (1996) is given below:

> *"A duty roster, often called a rota or roster, is a list of employees who are working on any given day, week, or month in a workplace. A duty roster is necessary for the day-to-day operation of any retail store, manufacturing facility and some offices. The process of creating a duty roster is called rostering. An effective workplace duty roster balances the needs of employees, tasks, and in some cases, customers."*

Oxford Dictionary defines rostering as follows:

> *"A plan for carrying out a process or procedure, giving lists of intended events and times. Assigning an appropriate number of workers to the jobs during each day of work."*

In any business, particularly in healthcare industry, staff rostering is usually a challenging and tiresome task due to rapid changes in rules to create the duty roster, shortage of healthcare professional as well as budget constraints. The person-in charge who performs this task will have to keep track all employees, distributing hours fairly and avoiding overlaps among the staffs.

In many organizations, those involved in developing staff duty roster normally would require decision support tools to help provide the right employees at the right time and at the right cost, while simultaneously trying to achieve a high

level of job satisfaction among the employees. Consequently, researchers have come up with various approaches or techniques to solve the rostering problems. However, before a good rostering model can be developed, it is essential to understand the associated problems and to determine the characteristics of the potential techniques in order to deal with the complex rostering problem.

The rostering problem normally arises in a wide variety of domains, including healthcare institutions (medical doctors and nurses duty rosters), educational (university lecturers and school teachers duty rosters), transport (trains and buses schedules), and sport (roster of matches between pairs of team). The most common variants of healthcare rostering problem are the Nurse Rostering Problem (NRP) and Medical Doctor Rostering Problem. The two rosters are based on a general pattern; however, there is a slight difference between the two due to the complexity of the structure of a department and the different constraints posed on the doctors and nurses.

The focus of this study is on the development of rostering medical doctors in one department of a Malaysian public hospital, particular looking into the assignment of doctors in the night-morning shift. To ensure the reliability of the medical doctor's duty roster, the information regarding the rostering must be well informed to all doctors involved so that they can handle accidents and emergencies cases effectively at any given time. Currently, staff rostering in most Malaysian public hospital is being done manually, and this has resulted in too many flaws in the duty roster due to the lack of required information and poor communication among the staff. Hence, in this study, staff rostering using optimization algorithm, such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), is implemented to generate a feasible duty roster for medical doctors. A feasible duty roster is a solution that satisfies all the hard constraints under any circumstances. Hard constraints are constraints that must be satisfied simultaneously, while soft constraints are those that should be fulfilled, if possible (Puente et al.,2009).

1.2 Problem Background

Numerous organizations have attempted to develop effective duty rosters in order to optimize their resources, and hence enhance the efficiency of the organisation. Some organizations have used the mathematical approach, such as linear programming, but most are still carried out manually.

In healthcare organizations, usually 10 to 20 hours is spent by the person-in-charge of planning the duty roster in order to optimise the available resources and simultaneously satisfy the staff involved (Wren, 1996). However, when the duty roster does not meet the needs at a certain point of event, a new duty roster is created and this will disturb the duty roster created earlier. Consequently, it is difficult to determine the quality of the duty roster due to the constraints and the number of decisions that needs to be made (Wren, 1996). Therefore, creating a feasible duty roster for medical doctors will reduce the time spent on each rostering and making changes to staff workload. As a result, this will enable the staff responsible for creating the duty roster to do other management tasks.

The task of periodically producing a duty roster begins with the consideration of both a number of resources (workforce, usually) and a set of features to be considered in order to make optimal use of these resources (structure of the work: shift types, holidays, hard and soft constraints to be satisfied, etc.). An initial approach to solving the above-mentioned problem implies the utilization of mathematical programming (MP) – linear programming, goal programming, single-objective MP, multi-objective MP – (Bailey, 1985; Beaumont, 1997; Warner, 1976). MP can most certainly be applied to simple cases involving a small number of staff restrictions. Alternative and more recent approaches are mostly based on constraint programming and heuristics and meta-heuristics procedures. (Ernst et al., 2004) identified 28 different categories of methods that have been used on personnel scheduling problems including: constraint logic programming, constructive heuristics, expert systems, genetic algorithms, integer programming, set partitioning, simple local search and simulated annealing. In general terms, these techniques provide

good result in the sense that they satisfy most of the conditions stipulated at the outset even though they may not be the best. Since Bailey, (1985) who used mathematical programming techniques to generate nurse rosters optimised with respect to staffing costs, under-staffing costs, and shift pattern based on violation of constraints, a number of meta-heuristic approaches have been explored including Genetic Algorithms (Aickelin & Dowsland, 2004), simulated annealing (Bailey et. al., 1997), Tabu Search (Bester et. al., 2007; Dowsland, 1998), and Hyper-Heuristics (Burke et. al., 2003). More recently, Aickelin et. al., (2007) have proposed a new Memetic Evolutionary Algorithm to achieve explicit learning in rule-based nurse rostering, and Burke et al. (2008) have proposed a hybrid heuristic ordering and variable neighbourhood search to optimise the solution of the problem.

The motivation to undergo this study is that creating a duty roster is not easy as it seems. To establish custom-made duty roster for medical staff is a challenging task that does not respond to a general pattern given the complexity of such a department's structure due to a number of factors such as divided zones, number of staff and work mode. To create a duty roster, firstly, the divided zones are categorised into Green Zone, Yellow Zone, and Red Zone, where each zone is based on how chronic a disease is. Secondly, the number of staff available in the hospital must be taken into account; in this case Hospital Sultanah Aminah (HSA) has 22 medical doctors. Lastly, the work mode is a combination of shifts and duties. The type of work carried out by the doctors in the hospital under study does not differ from that of similar departments in all Malaysian Public Hospital. However, the working modes of doctors are dependent on whether the day is a working day or day off. For example, Saturdays, Sundays, local, regional and national holidays, Christmas Day and New Year's Eve are all categorized as holidays where most staff do not work while doctors, depending on their duty roster, still have to work. Furthermore, if for any particular reason, the medical doctor could not present himself at work, he must find another doctor to replace him.

1.3 Problem Statement

Over the years, academicians and medical practitioners have widely studied the problems associated with staff rostering. Various rostering concepts have been utilised in trying to cope with the real-world challenges of the management system. Moreover, the importance of solving rostering problems has triggered various approaches or techniques to solve these rostering problems. The rostering problem is a well-known scheduling problem which assigns resources (i.e nurses or medical doctors) to shifts per day taking both hard and soft constraints into account. The objective is to minimize the total violations of the hard and soft constraints.

Rostering problems are well-known over-constrained problems. They are very difficult to solve manually due to their nature of large numbers of often conflicting objectives that must be taken into consideration while constructing the duty roster, such as different categories of nurses, different types of working shift, different coverage demand of shifts for each day, and popular/unpopular shifts (Puente et al., 2009). Many optimization algorithms have been proposed to solve rostering problem with different constraints. Some algorithms have been shown to be superior in solving some of the instances but not in others cases. Various population-based and local search based meta-heuristic algorithms have been developed to solve rostering problems, which include GA, Tabu Search (Beddoe and Petrovic, 2007; Craenen and Paechter, 2008), Neighborhood Search (Abdullah et al., 2007; Burke et al., 2010), Genetic Algorithm (Tsai and Li,2008; Mendes et al., 2009), Particle Swarm Optimization (Chu et al., 2006) and many others (Aickelin and Dowsland, 2000). In (Downsland, 1998), the performance of scatter genetic algorithm and memetic algorithm (population-based) were better compared to other search algorithms such as Tabu Search. Consequently, in this study, the use of other population-based methods for medical doctor rostering problem (Hybrid GA-PSO) is investigated.

In order to develop a good rostering model, it is crucial to comprehend the problem and to identify the characteristics of the potential techniques. Currently,

duty roster in the hospital are generated normally one month in advance and would take several days to complete. The duty roster has no past historical record, and does not include implicit needs of medical-staff regarding the promotion of work safety and work-family conciliation (Wren, 1996).

In order to answer the issues raised above, the following research questions are outlined:

I. What are the constraints for the medical doctor rostering?
II. Can the model using Hybrid GA-PSO generate feasible medical doctor rostering?
III. Will the algorithm find a feasible result for a given constraint?

In this study, hybrid method that combines GA and PSO algorithm is developed to satisfy the hard and soft constraints for the medical doctor duty roster. The justification for using Hybrid GA-PSO in this study is that Hybrid GA-PSO can deliver a feasible result in a slightly shorter time, compared to that when using other approaches, by taking advantage of the compensatory property of GA and PSO (Premalatha and Natarajan, 2010). The study presents and compiles the results gathered from the method. The performance of the Hybrid GA-PSO is analyzed in terms of specific performance measure (total violation of hard and soft constraints and accuracy of duty roster) and is then compared to that of the Standard GA and Standard PSO method. Based on the previous studies, the researchers measured the feasibility of the generated duty roster by the total violation of hard and soft constraints and the accuracy of duty roster (Puente et al, 2009, Premalatha and Natarajan, 2010).

The hypothesis of this study is stated as:

"By hybridizing GA-PSO, it can lead to a better performance and more accurate duty roster with minimum total violation of hard and soft constraints".

1.4 Objectives

The objectives of this study are:

I. To identify constraints involved in rostering of medical doctors.
II. To develop a model using Hybrid GA-PSO to generate a feasible medical doctor rostering.
III. To evaluate the feasibility of the generated medical doctor rostering.

1.5 Scopes

The scopes of this study are:

I. This study is conducted based on the Malaysian Healthcare environment. The preliminary investigation and data collection are done to obtain information related to Malaysian hospitals and services to the Malaysian community. The case study of this study is at Emergencies Department, Hospital Sultanah Aminah (HSA), Johor Bahru.
II. The modeling of Hybrid GA-PSO is based on the selected case study.
III. This study does not consider re-rostering (changes from human factors required) after a duty roster is produced.

1.6 Thesis Organization

This thesis is organized into six chapters. Chapter One briefly explain the background of the study, statement of problem, objectives, scopes and thesis organization. Chapter Two presents a comprehensive literature reviews regarding rostering, types of rostering problems, rostering processes, staff rostering and background of case study of Hospital Sultanah Aminah (HSA), Johor Bahru. In chapter Two, background study of public hospitals in Malaysia is presented to give reader a clear understanding of Malaysian healthcare system and procedure. In Chapter Three, a thorough description on research methodology is provided on the operational framework regarding on how the study is conducted. Then, in Chapter Four a brief discussion of the modelling and problem formulation is given and also with the description of the implementation of the hybrid model from problem formulation into coding phases. Next, Chapter Five provides a discussion on the analysis of results and performance measures. Finally, Chapter Six summarizes and concludes all work carried out in this study, while stating recommendations for future works.

REFERENCES

Abdennadher, S., and Schlenker, H., 1999. Nurse scheduling using constraint logic programming, AAAI/IAAI, 838–843.

Abdullah, S., Ahmadi, S., Burke,E. K., Dror, M., and McCollum, B. , 2007. A tabu-based large neighbourhood search methodology for the capacitated examination timetabling problem. *Journal of the Operational Research Society Palgrave Macmillan.*58, 1494–1502

Aickelin, U. andDowsland, K. A., 2000.Exploiting problem structure in a genetic algorithm approach to a nurse rostering problem.*Journal of Scheduling.*3(3), 139-153.

Aickelin, U. and White, P., 2004. Building better nurse scheduling algorithms.*Annals of Operations Research.*128, 159-177.

Aickelin, U., and Dowsland, K. A., 2004.An indirect Genetic Algorithm for a nurse-scheduling problem. *Computers & Operations Research.*31 (5), 761-778.

Akihiro, K., Chika, Y. andHiromitsu, T., 2005.Basic solutions of nurse scheduling problem using 3d-structured binary neural networks.*Transactions of Information Processing Society of Japan.*46,41-47.

Al-Betar, M. A., and Khader, A. T., 2009. A harmony search algorithm for university course timetabling. Annals of Operations Research, 194(1), 3-31.

Altamirano, L., Riff, M.C., and Trilling, L., 2010. A PSO algorithm to solve a real anaesthesiology nurse scheduling problem.*2010 International Conference of Soft Computing and Pattern Recognition (SoCPaR),* 139 – 144.

Ayob, M., Jaradat, G. M., Hamdan, A.R., Sarim, H.M., Nazri, M. Z. A., 2011.Solving the viva presentations timetabling problem: A case study at

FTSM-UKM, *Proceedings of the 2011 International Conference on Electrical Engineering and Informatics, ICEEI 2011*.

Azaiez, M. N. and Al Sharif, S. S., 2005.A 0-1 goal programming model for nurse scheduling.*Computers and Operations Research*. 32, 491-507.

Bai, R., Burke, E.K., Kendall, G., Li, J., and McCollum, B., 2010. A Hybrid Evolutionary Approach to the Nurse Rostering Problem.*IEEE Transaction on Evolutionary Computation*, IEEE Computational Intelligent Society, 14(4), 580-590.

Bard, J. F. andPurnomo, H. W., 2005.Hospital-wide reactive scheduling of nurses with preference considerations.*IIE Transactions*. 37, 587-608.

Bard, J. F. andPurnomo, H. W., 2005a.A column generation-based approach to solve the preference scheduling problem for nurses with downgrading.*Socio-Economic Planning Sciences*.39, 193-213.

Bard, J. F. andPurnomo, H. W., 2005b Preference scheduling for nurses using column generation.*European Journal of Operational Research*. 164, 510-534.

Bard, J. F. andPurnomo, H. W., 2005b.Short-term nurse scheduling in respose to daily fluctuations in supply and demand.*Health Care Management Science*. 8, 315-324.

Bard, J. F. andPurnomo, H. W., 2005c.A column generation-based approach to solve the preference scheduling problem for nurses with downgrading.*Socio-Economic Planning Sciences*.39, 193-213.

Bard, J. F. andPurnomo, H. W., 2006. Incremental changes in the workforce to accommodate changes in demand. *Health Care Manage Sci*. 9, 71-85.

Bard, J. F. andPurnomo, H. W., 2007. Cyclic preference scheduling of nurses using a lagrangian based heuristic. *Journal of Scheduling*.10, 5-23.

Bard, J. F., 2004a. Selecting the appropriate input data set when configuring a permanent workforce.*Computers and Industrial Engineering*. 47(4), 371-389.

Bard, J. F., 2004b. Staff scheduling in high volume service facilities with downgrading. *IIE Transactions*. 36(10), 985-997.

Bartak, R., 1999. Constraint programming: In pursuit of the holy grail, in: Proceedings of WDS99, Prague, 10.

Baumelt, Z., Sucha, P. andHanzalek, Z., 2007. Nurse scheduling web application.

Beasley, D., Martin, R. R., and Bull, D. R., 1993. An overview of genetic algorithms: part 1. Fundamentals.*UNIVERSITY COMPUTING.*5(2), 58.

Beasley, J.E., 1996. Advances in Linear and Integer Programming, *Oxford University Press*.

Beddoe, G. R., and Petrovic, S., 2006. Selecting and weighting features using a genetic algorithm in a case-based reasoning approach to personnel rostering. *European Journal of Operational Research.*175 (2), 649-671.

Beddoe, G. R., andPetrovic, S., 2006. Selecting and weighting features using a genetic algorithm in a case-based reasoning approach to personnel rostering. *European Journal of Operational Research*, 175, 649-671.

Beddoe, G., and Petrovic, S., 2007. Enhancing Case-Based Reasoning for Personnel RosteringWith Selected Tabu Search Concepts. *Journal of the Operational Research Society.*58,1586–1598.

Belian, J., 2006.Exact and heuristic methodologies for scheduling in hospitals-problems, formulations and algorithms.*4OR: A Quarterly Journal of Operations Research.* 5(2), 157-160.

Belien, J., Demeulemeester, E., and Cardoen, B., 2009. A decision support system for cyclic master surgery scheduling with multiple objectives.*Journal of Scheduling, Springer Netherlands.*12(2), 147-161.

Bergh J. V., BeliënJ., BrueckerP. D., DemeulemeesterE.,Boeck 1. D., 2013. Personnel scheduling: A literature review. *European Journal of Operational Research*, 226(2013), 367–385.

Berrada, I., Ferland, J.A., and Michelon, P., 1996. A multi-objective approach to nurse scheduling with both hard and soft constraints, *Socio-Economic Planning Science,* 30 (20), 183–193.

Borning, A., Benson, B. F., and Wilson, M., 1992. Constraint hierarchies, LISP and Symbolic Computation, *Computer Science & Engineering*, 5 (3), 223–270.

Borning, A., Duisberg, R, and Benson, B. F. ; Kramer, K. Woolf, M., 1987. Constraint hierarchies, *in: Proceedings of ACM Conference on Object Oriented Programming Systems, Languages and Applications*, *ACM*, 48–60.

Brucker, P., Qu, R., Burke, E., and Post, G., 2005. A decomposition, construction and postprocessing approach for nurse rostering.*In: Multidisciplinary International Conference on Scheduling: Theory and Applications*, 397-406.

Brusco, M. and Jacobs, L., 2001. Starting-time decisions in labor tour scheduling: an experimental analysis and case study. *European Journal of Operational Research*. 131, 459-475.

Burke, E. K., Causmaecker, P. D., Berghe, G. V., and Landeghem, H. V., 2004. The state of the art of nurse rostering, *Journal of Scheduling*, 7(6), 441-499.

Burke, E. K., Cowling, P., Causmaecker, P.D., and Berghe, G.V., 2001. A memetic approach to the nurse rostering problem, *Applied Intelligence*. 15(3), 199–214.

Burke, E. K., Curtois, T., Qu, R., and Berghe, G.V., 2009. A Scatter Search Approach to the Nurse Rostering Problem.*Journal of the Operational*.61, 1667–1679.

Burke, E. K., Li, J., and Qu, R., 2010. A Hybrid Model of Integer Programming and Variable Neighbourhood Search For Highly-Constrained Nurse Rostering Problems. *European Journal of Operational Research*. Elsevier B.V., 203(2), 484 -493.

Burke, E. K., Cowling, P., Caumaecker, P. D. andBerghe, G. V., 2001.A memetic approach to the nurse rostering problem.*Applied Intelligence special issue on Simulated Evolution and Learning*. 15(3), 199-214.

Burke, E. K., Curtois, T., Post, G., Qu, R. andBerghe, G. V., 2007. A hybrid heuristic ordering and variable neighbourhood search for the nurse rostering problem. *European Journal of Operational Research*.

Burke, E. K., Curtois, T., Post, G., Qu, R., and Veltman, B., 2008.A Hybrid Heuristic Ordering and Variable Neighbourhood Search for the Nurse Rostering Problem.*European Journal of Operational Research, Elsevier B.V*, 188(2), 330-341.

Burke, E. K., Curtois, T., Qu, R. andBerghe, G. V., 2007.A scatter search for the nurse rostering problem.*Computer Science Technical Report*. University of Nottingham.

Burke, E. K., Hyde, M., Kendall, G., and Woodward, J., 2010. A Genetic Programming Hyper-Heuristic Approach Evolving Two Dimensional Strip Packing Heuristic. *IEEE Transaction on Evolutionary Computation*, 1-14.

Burke, E. K., Kendall, G., andSoubeiga, E., 2003. A Tabu-Search Hyperheuristic for Timetabling and Rostering.*Journal of Heuristics, Springer,*9(6), 451-470.

Burke, E. K., MacCarthy, B. L., Petrovic, S. and Qu, R., 2006.Multiple-retrieval case-based reasoning for course timetabling problems. Journal of Operations Research Society, 57(2), 148-162.

Burke, E.K., Causmaecker, P. D., andBerghe, G. V., 1999. A Hybrid Tabu Search Algorithm for the Nurse Rostering Problem.*Simulated Evolution and LearningLecture Notes in Computer Science.Springer*, 1585, 87-194.

Burke, E.K., Causemaecker, P. D., Petrovic, S., and Berghe, G. V., 2003.Variable Neighborhood Search for Nurse Rostering Problems.*Annals of Operations Research*, 153 -173.

Burke,E. K., Hyde, M., Kendall, G., and Woodward,J., 2008. A Genetic Programming Hyper-Heuristic Approach Evolving Two Dimensional Strip Packing Heuristic. *IEEE Transaction on Evolutionary Computation*, 1-14.

Burns, R. N., and Koop, G. J. , 1987. A Modular Approach to Optimal Multiple-Shift Manpower Scheduling, *Operations Research*, 35(1), 100–110.

Burns, R. N., 1978. Manpower Scheduling With Variable Demands And Alternate Weekends Off, *INFOR*,16, 101–111.

Cacchiani, V., Caprara, A., and Toth, P., 2010. Non-Cyclic Train Timetabling And Comparability Graphs. *Operations Research Letters,* 38, 179-184.

Cai, X. and Li, K. N., 2000. A genetic algorithm for scheduling staff of mixed skills under multicriteria.*European Journal of Operational Research*. 125, 359-369.

Cardoen, B., Demeulemeester, E., and Belien, J., 2009. Optimizing a Multiple Objective Surgical Case Sequencing Problem.*International Journal of Production Economics,*119 (2), 354-366.

Ceschia, S., and Schaerf, A., 2011.Local search and lower bounds for the patient admission scheduling problem.*Computers & Operations Research,* 38(10), 1452–1463.

Cheng, B. M. W., Lee, J.H.M., and Wu, J.C.K., 1996. A Constraintbased Nurse Rostering System Using A Redundant Modeling Approach. *8th International Conference on Tools with Artificial Intelligence (ICTAI _96),November 16–19*, 140–148.

Chiaramonte, M. V., 2008. Competitive nurse rostering and rerostering.*Arizone State University*.

Chun, A. H. W., Chan, S. H. C., Lam, G. P. S., Tsang, F. M. F., Wong, J., and Yeung, D. W. M., 2000. Nurse Rostering At The Hospital Authority of Hong Kong, *AAAI/IAAI*, 951–956.

Constantino, Dario, L.S., Melo, E. L., Romão, W., and Ademir A., 2011. A Heuristic Algorithm For Nurse Scheduling With Balanced Preference Satisfaction. *Proceedings of the 2011 IEEE Symposium on Computational Intelligence in Scheduling (IEEE-CISched 2011),* 39-45.

Craenen, B. G. W., and Paechter, B., 2006. A Tabu Search Evolutionary Algorithm for Solving Constraint Satisfaction Problems. *Parallel Problem Solving from Nature - PPSN IXLecture Notes in Computer Science, Springer*, 4193, 152-161.

Creswell, J. W.,2007. *Qualitative inquiry & research design: choosing among five approaches.United States of America : Sage Publications*.

DanielWrightP., andMahar S., 2013.Centralized nurse scheduling to simultaneously improve schedule cost and nurse satisfaction. *Omega*, 41, 1042–1052.

Demeester, P., Souffriau, W., Causmaecker, P. D., and Berghe, G. V., 2010. A Hybrid Tabu Search Algorithm for Automatically Assigning Patients to Beds.*Artificial Intelligence in Medicine,* 48 (1), 61-70.

Dias, T. M., Ferber, D. F., Souza, C. C. andMoura, A. V., 2003. Constructing nurse schedules atlarge hospitals. *International Transactions in Operational Research, 10*, 245-265.

Dohn A., and Mason A., 2013.Branch-and-price for staff rostering: An efficient implementationusing generic programming and nested column generation. *European Journal of Operational Research*, 230(2013), 157–169.

Dohn, A., Mason, A., and Ryan, D., 2010. A Generic Solution Approach to Nurse Rostering.*Report 5.2010.*

Dowsland, K. A., Herbert, E. A, Kendall, G. and Burke, E., 2006. Using tree search bounds toenhance a genetic algorithm approach to two rectangle packing problems.*European Journal of Operational Research.*168, 390-402.

Dowsland, K. and Thompson, J., 2000. Solving a nurse scheduling problem with knapsacks, networks and tabu search.*Journal of the Operational Research Society,* 51, 825-833.

Drake R. G., 2013. The Nurse Rostering Problem: From Operational Research ToOrganizational Reality?*Journal of Advanced Nursing,* 21(2), 765-770.

EberhartR. and Shi Y., 1998.Comparison between geneticalgorithms and particle swarm optimization.Lecture Notes in Computer Science,1447, 611–616.

Engelbrecht. A. P. , 2005. Fundamentals of Computational Swarm Intelligence.*John Wiley & Sons, Chichester, UK.*

Ernst, A. T., Jiang, H., Krishnamoorthy, M., and Sier, D., 2004. Staff scheduling and rostering: A review of applications, methodsand models, *European Journal of Operational Research*, 153(1), 3–27.

Esmin, A., Lambert-Torres, G., and Alvarenga, G. B., 2006. Hybrid Evolutionary Algorithm Based on PSO and GA Mutation. In: *Proceedings of Sixth International Conference on Hybrid Intelligent System IEEE*, 2006, 57.

Freuder, E. C., and Wallace, R.J., 1992. Partial Constraint Satisfaction, *Artificial Intelligence*, 58 (1–3), 21–70.

Fung, S. K. L., Leung, H. F. and Lee, J. H. M., 2005.Guided complete search for nurse rostering problems.*In Proc. of the 17th IEEE International Conference on Tools with Artificial Intelligence.*IEEE Computer Society. 1082-3409.

Glass, C.A., and Knight, R.A., 2010. The Nurse Rostering Problem: A Critical Appraisal of The Problem Structure. *European Journal of Operational Reseach*. 202(2), 379-389.

Glover, F., and Marti, R., 2006.*Tabu*Search. Metaheuristic Procedures for Training Neutral NetworksOperations Research, *Computer Science Interfaces Series*, 36(2), 53-69.

Goncalves, J. F., Mendes, J. J. M., and Resende, M. G. C., 2008. A genetic algorithm for the resource constrained multi-project scheduling problem.*European Journal of Operational Research*, 189(3), 1171-1190.

Goodman, M. D., Dowsland, K. A., and Thompson, J. M., 2009.A grasp-knapsack hybrid for a nurse-scheduling problem.*Journal of Heuristics,* 15(4), 351-379.

Hadwan M., Ayob M., Nasser R. SabarN. R., and Qu R., 2013. A Harmony Search Algorithm for Nurse Rostering Problems.*Journal of Information Sciences,* 32(8), 754-766.

Hadwan, M., and Ayob, M., 2010.A Constructive Shift Patterns Approach with Simulated Annealing for Nurse Rostering Problem.*International Symposium in Information Technology*. June 2010. Kuala Lumpur: IEEEXplore, 1-6.

Ho.S. F.,I.Safaai, D., and Hashim.,S. Z. M. 2009. A Study on PSO-based University Course Timetabling Problem. In: *IEEE 2009 International Conference on Advanced Computer Control, Singapore*, 648-651.

Hojati, M. and Patil, A. S., 2011.An Integer Linear Programming-based Heuristic for Scheduling Heterogeneous, Part-time Service Employees.*European Journal of Operational Research,* 209(1), 37–50

Horio, M., 2005. A method for solving the 3-shift nurse scheduling problem through a general project scheduler based on the framework of RCPSP.

Hung, R.,1995. Hospital Nurse scheduling. *Journal of Nursing Administration*, 25(8), 21–23.

Isken, M., 2004.An implicit tour scheduling model with applications in healthcare.*Annals of Operations Research*, 128(1-4), 91-109.

Jaffar, J., Michaylov, S., Stuckey, P.J., and Yap, R.H.C., 1992. The CLP (R) Language and System. *ACM Transactions on Programming Languages and Systems*,14 (3) 339– 395.

Jaffar, J., and Maher, M.J., 1994. Constraint Logic Programming: A survey, *Journal of Logic Programming*, 19(20),pp.503– 581.

Jan, A., Yamamoto, M., and Ohuchi, A., 2000. Evolutionary Algorithms for Nurse Scheduling Problem. *In: Proceedings of the 2000 Congress on Evolutionary Computation CEC00, IEEE Press*, 196–203.

Jaradat, G.M., and Ayob, M., 2011. Scatter search for solving the course timetabling problem. *2011 3rd Conference on Data Mining and Optimization (DMO)*, 213 – 218.

Jaumard, B., Semet, F., and Vovor, T., 1998. A Generalized Linear Programming Model for Nurse Scheduling, *European Journal of Operational Research*, 107, 1–18.

Kostreva, M. M., and Genevier, P. , 1989. Nurses Preferences Vs. Circadian Rhythms In Scheduling, *Nurse Management*, 20(7), 50–62.

Kostreva, M. M., and Jennings, K.S.B., 1991. Nurse Scheduling on A Microcomputer, *Computers and Operational Research*,18(8), 731–739.

Kumar, V., 1992. Algorithms for Constraint Satisfaction Problems: A survey, *AI Magazine*, 13(1), 32–44.

Lavieri, M. S., and Puterman, M. L., 2009.Optimizing Nursing Human Resource Planning in British Columbia.*Health Care Management Science*, 12(2), 119–128.

Lee, J. S., Lee, S., Chang, S., Ahn, B. H., 2005.A Comparison of GA and PSO for Excess Return Evaluation in Stock Markets. In: *IWANAC 2005, LNCS 3562*, 221-230.

Levner, E., Kats,V., Pablo, D. A. L. D., and Cheng, T. C. E., 2010. Complexity of Cyclic Scheduling Problems: A State-Of-The-Art Survey. *Computers & Industrial Engineering,* 59(2), 352-361.

Li G., Zhao F., Guo C. and Teng H., 2008.Parallel Hybrid PSO-GA Algorithmand Its Application to Layout Design, *Advances in Natural Computation,Springer Berlin*, 4221,749-758

Li, H., Lim, A. and Rodrigues, 2003. B.,A hybrid AI approach for nurse rostering problem. *In Proc.of the 2003 ACM symposium on Applied computing.* Melbourne. IEEE Press.

Lo, C. C., and Lin, T. H., 2011. A Particle Swarm Optimization approach for physician scheduling in a hospital emergency department.*2011 Seventh International Conference on Natural Computation (ICNC),* 1929 – 1933.

MaenhoutB, andVanhoucke M, 2013, An integrated nurse staffing and scheduling analysis for longer-term nursing staff allocation problems. *Omega,* 41, 485–499.

Maenhout, B., andVanhoucke, M., 2008.Branching Strategies in a Branch-and-Price Approach for a Multiple Objective Nurse Scheduling Problem.*Working Papers of Faculty of Economics and Business Administration, Ghent University, Belgium 08/495, Ghent University, Faculty of Economics and Business Administration.*

Maenhout, B., and Vanhoucke, M., 2010.A Hybrid Scatter Search Heuristic for Personalized Crew RosteringIn The Airline Industry. *European Journal of Operational Research*, 206(1),155–167.

Maenhout, B., and Vanhoucke, M., 2010.Branching Strategies in a Branch-And-Price Approach for a Multiple Objective Nurse Scheduling Problem. *Journal of Scheduling* 13(1), 77-93.

Majumdar, J. andBhunia, A. K., 2007.Elitist genetic algorithm for assignment problem withimprecise goal.*European Journal of Operation Research*, 177, 684-692.

Matthews, C. H., 2005. Using linear programming to minimize the cost of nurse personnel.*Journal of Health Care Finance*. 32, (1), 37-49.

Megeath, J. D., 1978. Successful Hospital Personnel Scheduling, *Interfaces*, 8(2), 55–60.

Mendes,J. J. M., Goncalves, J. F., and Resende, M. G. C., 2009. A Random Key Based Genetic Algorithm for the Resource Constrained Project Scheduling Problem. *Computers & Operations Research*, 36 (1), 92-109.

Meyer, H., and Hofe, M., 1997. A Plan: Personal Assignment As A Problem of Hierarchical Constraint Satisfaction, *in: Proceedings of the Third International Conference on the Practical Application of Constraint Technology*, 257–272.

Meyer, H., and Hofe, M., 2001. Nurse Rostering As Constraint Satisfaction With Fuzzy Constraints And Inferred Control Strategies. *in: E.C. Freuder, R.J. Wallace (Eds.), Constraint Programming and Large Scale Discrete*

*Optimization, DIMACS Series in Discrete Mathematics and Theoretical Computer Science,*57, DIMACS, 67–99.

Miller, H. E., William, P., and Gustave, J. R., 1976. Nurse Scheduling Using Mathematical Programming, *Operations Research*, 24(5), 857–870.

Minichiello, V., Aroni, R., and Hays, T., 2008. In-Depth Interviewing: Principles, Techniques, Analysis. Sydney: Pearson Education.

Moz, M., andPato, M.V., 2007.A genetic algorithm approach to a nurse rerostering problem.*Computers and Operations Research,* 34, 667–691.

Moz, M., andPato, M.V.,2007. A genetic algorithm approach to a nurse rerosteringproblem.*Computers and Operations Research,* 34, 667–691.

Musa, A. A., and Saxena, U., 1984. Scheduling Nurses Using Goal-Programming Techniques. *IIE Transactions.University of Illinois at Springfield DOLCE Project*, 16, 216– 221.

Naomie Salim, Shamsuddin, S. M., Deris, S., Alias, R.A., Ibrahim, S., Sallehuddin, R., Hashim S., Z., M., Rahman A., A., Jawawi, D. N., A., Rahim, N., Z., and A., Salim, J., 2010. Handbook of Research Methods In Computing. *Malaysia:Faculty of Science & Information System*.

Naudin, É., Chan, P. Y. C., Hiroux, M., Zemmouri, T., and Weil, G. ,2012. Analysis of three mathematical models of the Staff Rostering Problem. Journal of Scheduling, 15(1), 23-38.

Nissen, V., and Gunther, M., 2009.Staff Scheduling with Particle Swarm Optimisation and Evolution Strategies.*Evolutionary Computation in Combinatorial Optimization, Lecture Notes in Computer Science,* 5482, 228-239.

Ohki, M., Uneme, S., and Kawano, H., 2010.Effextive Mutation Operator and Parallel Processing for Nurse Scheduling.*Studies in Computational Intelligence*, Volume 299, 229-242. Springer.

Omran, M. G. H., 2004. Particle Swarm Optimization Methods for Pattern Recognition and Image Processing.PhD Thesis.*Faculty of Engineering, Built Environment and Information Technology, University of Pretoria*.

Parsopoulos, K. E., and Vrahatis, M. N., 2002.Initializing the Particle Swarm Optimizer Using Nonlinear Simplex Method. In: *Advances in Intelligent Systems, Fuzzy Systems, Evolutionary Computation*, 216-221.

Parsopoulos, K. E., Laskari, E. C., and Vrahatis, M. N., 2001.Solving L1 norm errors in variables problems using Particle Swarm Optimizer. In: *M.H. Hamza(Ed.), Artificial Intelligence and Applications*, Anaheim, CA, USA: IASTED/ACTA Press, 185-190.

Petrovic, S., Berghe.G.V., 2012. A comparison of two approaches to nurse rostering problems. Annals of Operations Research, 194(1), 365-384.

Premalatha K. and Natarajan A. M., 2010.Hybrid PSO and GA models for Document Clustering.*International Journal Advance Soft Computing Appliance,*2(3), 1-19.

Puente, J., Gomez, A., Fernandez, I., and Priore, P,. 2009. Medical doctor rostering problem in a hospital emergency department by means of genetic algorithms. Computers & Industrial Engineering, 56 (4), 1232–1242.

Punnakitikashem, P., 2007. Integrated nurse staffing and assignment under uncertainty.*The University of Texas at Arlington*.

Ramli, R., and Ahmad, S. N. I., 2011. Innovative Neighbor Generations InTabu Search Technique for a Nurse Rostering Problem, *In International Proceedings of Computer Science and Information Technology: Information and Electronics Engineering (ICIEE), Bangkok, Thailand, 28-29 May*.

Robinson J., Sinton S., and Rahmat Y., 2002. Particleswarm, genetic algorithm, and their hybrids:Optimization of a profiled corrugated horn antenna.*In IEEE Antennas and Propagation Society International Symposium and URSI National Radio Science Meeting, San Antonio, TX, 2002*, 234-237.

Santos H. G., Toolo T. A. M., Ribas S., and Gomes R. A. M., 2012.Integer Programming Techniques for the NurseRostering Problem.Lecture Notes in Computer Science, 4552, 1008-1020.

Sharif, O., Unveren, A., and Acan, A., 2010.Evolutionary Multi-Objective Optimization for Nurse Scheduling Problem.*Fifth International Conference on*

Soft Computing, Computing with Words and Perception. September 2009. Famagusta: IEEEXplore. 1-4

Shi, Y., 2004. Particle Swarm Optimization.IEEE in Electronic Data Syatems.8-13.

Shi, Y., and Eberhart, R. C., 1999.Empirical study of Particle Swarm Optimization. In: *proceeding of the 1999 Congress on Evolutionary Computation*, Piscataway, NJ: IEEE Service Center, 1945-1950.

Silvestro, R. and Silvestro, C., 2000. An evaluation of nurse rostering practices in the National Health Service, *Journal of Advanced Nursing*, 32(3), 525–535.

Sivanandam, S.N. and Deepa, S.N., 2008. Introduction to Genetic Algorithms, Springer

Souai, N., and Teghem, J., 2009. Genetic algorithm based approach for the integrated airline crew-pairing and rostering problem.*European Journal of Operational Research,*199 (3), 674-683.

Soubeiga, E., 2003. Development and application of hyperheuristics to personnel scheduling.*The University of Nottingham*.

Steyn N. and Dyk L. V., 2013.Nurse Scheduling Decision Support SystemsAs A Workforce Management Technology SolutionIn Public Healthcare. *Southern African Institute of Industrial Engineering* 2013.654-668.

Suman, B. and Kumar, P., 2006. A survey of simulated annealing as a tool for single and multiobjective optimization.*Operational Research Society.*57, 1143-1160.

Tackling, F. E. , 1998. Scheduling problems using integer programming, *Master Thesis, University of Wales, Swansea.*

Tamiz, M., and Yaghoobi, M.A., 2010. Nurse Scheduling by Fuzzy Goal Programming. *Lecture Notes in Economics and Mathematical System 638.*

Tang J, Zhang G, Lin B and Zhang B, 2010. A Hybrid PSO/GA Algorithm for Job Shop Scheduling Problem,*Advances in Swarm Intelligence, Springer Berlin,* 6145, 566-573.

Thompson, G. M., 2007. Solving the multi-objective nurse scheduling problem with a weighted cost function.*Ann Oper Res.* 155, 279-288.

Topaloglu, S., and Selim, H., 2009.Nurse scheduling using fuzzy modeling approach.*Fuzzy Sets and Systems.* 161(1) , 1543–1563.

Tsai, C. C., and Li, S. H. A. , 2008. A two-stage modeling with genetic algorithms for the nurse scheduling problem.*Expert Systems with Applications*, 36(5), 9506–9512.

Tucker, A., 1991. Computing Curricula: Report of the ACM/IEEE-CS Joint Curriculum Task Force.*New York: ACM Press.*

Valouxis, C., and Housos, E., 2000. Hybrid Optimization Techniques For The Workshift And Rest Assignment Of Nursing Personnel. *Artificial Intelligence in Medicine,* 20(1). 155–175.

Vanhoucke, M., andMaenhout, B., 2010.Branching strategies in a branch-and-price approach for a multiple objective nurse scheduling problem.*Journal of Scheduling*, 13(1), 77-93.

Vlah, S., Lukač, Z., and Pacheco, J., 2010.Use of VNS heuristics for scheduling of patients in hospital.*Journal of the Operational Research Society* (2011) 62, 1227–1238.

Vogt, W. P. , 2007. Quantitative Research Methods for Professionals. *United States of America: Pearson Education.*

Warner, D. M., 1976. Scheduling Nursing Personnel According To Nursing Preference: A Mathematical Programming Approach, *Operations Research*, 24 (5), 842–856.

Warner, D. M., and Prawda, J., 1972. A Mathematical Programming Model For Scheduling Nursing Personnel In A Hospital, *Management Science*, 19 (4), 411–422.

Warner, M., 1976. Nurse staffing, scheduling, and reallocation in the hospital. *Hospital & Health Services Administration*, 77–90.

Whitley, D., 1994. A Genetic Algorithm Tutorial. *Statistics and Computing*, 4(2), 1-37

Winstanley, G., 2004. Distributed and devolved work allocating planning.*Applied Artificial Intelligence*. 18, 97-115.

Wren, A., 1996. Scheduling, Timetabling And Rostering—A Special Relationship? *Practice andTheory of Automated Timetabling, First International Conference*, Edinburgh, Springer, Lecture Notes in ComputerScience, 1153, 45–75.

Xiea L., Kliewerb N., and Suhla L., 2013.Integrated Driver Rostering Problem in Public Bus Transit.*Procedia - Social and Behavioral Sciences,* 54 (2012), 656 – 665.

Yin P. Y., and Chiang Y. T., 2013.Cyber Swarm Algorithms for Multi-ObjectiveNurse Rostering Problem.*International Journal of InnovativeComputing, Information and Control*, 9(5), 2043-2063.

Yin, R. K., 2009. Case Study Research: Design and Methods (4th Ed.). *United States of America: Sage Publications.*