NURSE ROSTERING: A TABU SEARCH TECHNIQUE WITH EMBEDDED NURSE PREFERENCES

Thesis submitted to UUM College of Arts and Sciences in fulfillment of the requirements for the degree Master of Science (Decision Science) Universiti Utara Malaysia

by

SITI NURIN IMA BINTI AHMAD

Kolej Sastera dan Sains
(UUM College of Arts and Sciences)
Universiti Utara Malaysia

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

SITI NURIN IMA AHMAD

calon untuk Ijazah **MASTER**
(candidate for the degree of)

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title):

"NURSE ROSTERING: A TABU SEARCH TECHNIQUE WITH EMBEDDED NURSE PREFERENCES"

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada : ***06 Oktober 2010.***
That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on: ***October 06, 2010.***

Pengerusi Viva: *(Chairman for Viva)*	**Assoc. Prof. Dr. Engku Muhammad Nazri Engku Abu Bakar**	Tandatangan *(Signature)*
Pemeriksa Luar: *(External Examiner)*	**Assoc. Prof. Dr. Abas Md Said**	Tandatangan *(Signature)*
Pemeriksa *Dalam*: *(Internal Examiner)*	**Dr. Mohd Kamal Mohd Nawawi**	Tandatangan *(Signature)*
Nama Penyelia/Penyelia-penyelia: *(Name of Supervisor/Supervisors)*	**Assoc. Prof. Dr. Razamin Ramli**	Tandatangan *(Signature)*

Tarikh:
(Date) ***October 06, 2010***

PERMISSION TO USE

In presenting this thesis in fulfillment of the requirements for a graduate degree from Universiti Utara Malaysia, I agree that the University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes, may be granted by my supervisor(s) or, in their absence, by the Dean of Research and Graduate Studies, College of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made from any material from my thesis.

Request for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Dean of Research and Graduate Studies

College of Arts and Sciences

Universiti Utara Malaysia

06010 UUM Sintok

Kedah Darul Aman

ABSTRACT

The decision making in assigning all nursing staffs to shift duties in a hospital unit must be done appropriately because it is a crucial task due to various requirements and constraints that need to be fulfilled. The shift assignment or also known as roster has a great impact on the nurses' operational circumstances which are strongly related to the intensity of quality of health care. The head nurse usually spends a substantial amount of time developing manual rosters, especially when there are many staff requests. Yet, sometimes she could not ensure that all constraints are met. Therefore, this research identified the relevant constraints being imposed in solving the nurse rostering problem (NRP) and examined the efficient method to generate the nurse roster based on constraints involved. Subsequently, as part of this research, we develop a Tabu Search (TS) model to solve a particular NRP. There are two aspects of enhancement in the proposed TS model. The first aspect is in the initialization phase of the TS model, where we introduced a semi-random initialization method to produce an initial solution. The advantage of using this initialization method is that it avoids the violation of hard constraints at any time in the TS process. The second aspect is in the neighbourhood generation phase, where several neighbours need to be generated as part of the TS approach. In this phase, we introduced two different neighbourhood generation methods, which are specific to the NRP. The proposed TS model is evaluated for its efficiency, where 30 samples of rosters generated were taken for analysis. The feasible solutions (i.e. the roster) were evaluated based on their minimum penalty values. The penalty values were given based on different violations of hard and soft constraints. The TS model is able to produce efficient rosters which do not violate any hard constraints and at the same time, fulfill the soft constraints as much as possible. The performance of the model is certainly better than the manually generated model and also comparable to the existing similar nurse rostering model.

ABSTRAK

Tugasan membuat keputusan dalam menjana jadual syif kepada kakitangan kejururawatan di dalam sesuatu unit hospital adalah sukar dan mesti dilakukan sewajarnya dengan mengambil kira segala kekangan dan keperluan yang perlu dipenuhi. Jadual syif, juga dikenali sebagai jadual tugas, mempunyai kesan yang besar kepada situasi pengoperasian jururawat yang sangat berkaitan dengan tahap kualiti penjagaan kesihatan. Biasanya, ketua jururawat memerlukan masa yang secukupnya untuk menjana sesuatu jadual manual syif terutama sekali apabila terdapat banyak permintaan dan keperluan kakitangan. Namun, ada ketikanya adalah sukar untuk memastikan yang semua keperluan dan kekangan dapat dipenuhi. Sehubungan itu, kajian ini bertujuan mengenal pasti kekangan yang berkaitan yang dikenakan dalam menyelesaikan masalah penjadualuan jururawat (NRP) dan mengkaji kaedah yang berkesan untuk menjana jadual syif jururawat berdasarkan kekangan yang terlibat. Seterusnya, satu model *Tabu Search* (TS) dibangunkan untuk menyelesaikan satu NRP tertentu. Terdapat dua aspek penambahbaikan dalam model TS yang dicadangkan. Aspek pertama adalah dalam fasa pembentukan awal model TS, yang mana kaedah pembentukan awal berasaskan separa rawak untuk menghasilkan penyelesaian awal telah diperkenalkan. Kelebihan menggunakan kaedah tersebut adalah ia dapat mengelak berlakunya pelanggaran kekangan keras pada mana-mana masa dalam proses TS. Aspek kedua adalah dalam fasa penjanaan kejiranan, yang mana beberapa jiran perlu dihasilkan sebagai sebahagian daripada pendekatan TS. Dalam fasa ini, dua kaedah penjanaan kejiranan yang berbeza dan khusus untuk NRP diperkenalkan. Model TS yang dicadangkan kemudiannya dinilai keberkesanannya, yang mana 30 sampel telah diambil untuk tujuan analisis. Beberapa penyelesaian yang sesuai (i.e. jadual tugas) telah dinilai berdasarkan kepada nilai penalti minimum. Nilai penalti diberikan berdasarkan kepada perbezaan pelanggaran kekangan keras dan lembut (kekangan yang boleh dilonggarkan). Model TS mampu menghasilkan jadual tugas yang cekap yang tidak melanggar mana-mana kekangan keras dan pada masa yang sama, memenuhi segala kekangan lembut sebaik yang mungkin. Prestasi model tersebut adalah lebih baik daripada model yang dijana secara manual dan setanding dengan model jadual tugas jururawat sedia ada yang terhampir.

ACKNOWLEDGEMENTS

One above all of gratitude, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my constitution wanting to give up and throw in the towel, thank you so much Dear Allah.

I am heartily thankful to my supervisor, Associate Professor Dr. Razamin Ramli, whose encouragement, supervision and support from the preliminary to the concluding level enabled me to develop an understanding of the subject. This thesis would not have been possible unless Mr. Abdullah, the programmer who assisted me on how to use the software needed for my nurse roster model.

It is a pleasure to thank those who made this thesis possible such as my beloved husband, Abdul Rahman Bin Ariffin who gave me the moral support I required. I am grateful to my parents and my siblings, who helped me to take care of my kids for a while to accomplish my master at UUM.

I owe my deepest gratitude to my friends, Zara, Bi Lin, Kasim, Salman, Ilmi, Afidah and Uma Rani. Without their assistance, I would not have gotten any ideas for correcting my thesis. Lastly, I offer my regards and blessings to all of those who supported me in any respect during the completion of this thesis.

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

NSP	:	Nurse scheduling problem
NRP	:	Nurse rostering problem
OR	:	Operation research
AI	:	Artificial Intelligence
LP	:	Linear programming
IP	:	Integer programming
NLP	:	Non-linear programming
MIP	:	Mixed-integer programming
CP	:	Constraint programming
GP	:	Goal programming
NP	:	Network programming
RM	:	Redundant modeling
ES	:	Expert system
SA	:	Simulated annealing
GA	:	Genetic algorithm
MA	:	Memetic algorithm
TS	:	Tabu search
H	:	Heuristics
CH	:	Constructive heuristics
MP	:	Mathematical programming
GP	:	Goal programming
ACO	:	Ant colony optimization
CSP	:	Constraint satisfactory problem
CBR	:	Case-based reasoning
EA	:	Evolutionary approach
EDA	:	Estimation of distribution algorithm
M	:	Morning shift

E	:	Evening shift
N	:	Night shift
NO	:	Night off day
WO	:	Weekly off day
PO	:	Public off day

CHAPTER ONE

INTRODUCTION

Manpower scheduling (or rostering) is concerned with the scheduling of human resources to meet temporal operational requirements in ways that satisfy the goals and policies imposed by the management, labour union and the government (Lau, 1996). Manpower scheduling is crucial in the management of a service organisation. One example is related to the nursing services in a hospital organisation.

As a rule, the nursing services in hospital wards must be available at all times with no breaks for weekends and holidays since the service is the critical type. Moreover, this job is a very high risk job because it is a difficult and tiring work, which involves patient safety and health care. In manpower scheduling, it is strongly suggested that, as the day progresses, a worker should be assigned for work no earlier than the shift he worked the day before so that he maintains a healthy biological clock (Lau, 1996).

In recent developments, it is observed that the scheduling of nurses has been widely studied and there are many approaches being developed for special circumstances. A wide variety of constraints can be imposed on the rosters depending on the legal, management and staffing requirements of individual organisations (Beddoe & Petrovic, 2005). The roster quality and optimality are highly subjective. Therefore, it is impossible to represent similar systems to develop the nurse roster.

The contents of the thesis is for internal user only

REFERENCES

Aickelin, U., & Dowsland, K.A. (2004). An indirect genetic algorithm for a nurse-scheduling problem, *Computers & Operations Research*, 761 – 778.

Aickelin, U., & Li, J. (2007). An estimation of distribution algorithm for nurse scheduling, *Journal of the Operational Research Society*, 155: 289 – 309.

Aickelin, U., & White, P. (2004). Building better nurse scheduling algorithms, *Annals of Operations Research*, 128, pp 159 – 177.

Azaiez, M.N., & Al Sharif, S.S. (2005). A 0 – 1 goal programming model for nurse scheduling, *Computer & Operations Research*, 32: 491 – 507.

Bai, R., Burke, E. K., Kendall, G., Li, J. & McCollum, B. (2008). A hybrid evolutionary approach to the nurse rostering problem, *IEEE Transaction on Evolutionary Computation.*

Bailey, R.N., Garner, K.M., & Hobbs, M.F. (1997). Using simulated annealing and genetic algorithms to solve staff scheduling problems, *Asia-Pacific Journal of Operational Research*, 14, 27-43.

Baker, K.R. (1976). Workforce allocation in cyclic scheduling problems: a survey, *Operational Research Quarterly,* 27 (1,ii): 155 – 67.

Bard, J.F., & Purnomo, H.W. (2004). Preference scheduling for nurses using column generation, *European Journal of Operational Research*, 1-25.

Bard, J.F., & Purnomo, H.W. (2007). Preference scheduling for nurses using column generation, *Journal of Scheduling*, 10: 5 – 23.

Beddoe, G.R., & Petrovic, S. (2005). Selecting and weighting features using a genetic algorithm in a case-based reasoning approach to personnel rostering, *European Journal of Operational Research.*

Bellanti, F., Carello, G., Croce, F.D., & Tadei, R. (2001). A tabu search approach to a nurse rostering problem, *Proceedings of the 4th Metaheuristics International Conference, MIC 2001.*

Bellanti, F., Carello, G., Croce, F.D., & Tadei, R. (2004). A geedy-based neighborhood search approach to a nurse rostering problem, *European Journal of Operational Research*, 153, 28-40.

Berrada, I., Ferland, J.A., & Michelon, P. (1996). A multi-objective approach to nurse scheduling with both hard and soft constraints, *Socio-Economic Planning Science*, 30 (3), 183-193.

Bester, M.J., Nieuwoudt, I., Jan, H., & Van Vuuren. (2007). Finding good nurse duty schedules : a case study, *Journal of Scheduling*, 10: 387-405.

Brucker, P., Qu, R., Burke, E., & Post, G. (2007). A decomposition, construction and post-processing approach for nurse rostering, *MISTA 2005*, 397-406.

Brusco, M.J., & John, T.R. (1995). The effect of demand characteristics on labour scheduling methods, *International Journal of Operations & Productions Management,* 15(1): 74 – 88.

Burke, E.K., Causmaecker, P.De, & Vanden Berghe, G. (1998). A hybrid tabu search algorithm for the nurse rostering problem, *Proceedings of the 2nd Asia Pacific Conference, Simulated Evolution and Learning Volume, Canberra, 1.*

Burke, E.K., Causmaecker, P.De, Petrovic, S., & Vanden Berghe, G. (2001). Variable neighbourhood search for nurse rostering problems, *Proceedings of the 4th Metaheuristics International Conference, MIC 2001,* Porto, 2, 755-776.

Burke, E.K., Causmaecker, P. De, Petrovic, S., & Vanden Berghe, G. (2001). Fitness evaluation for nurse scheduling problems, *Proceedings of the Congress on Evolutionary Computation, CEG 2001,* Seoul, 1139-46.

Burke, E.K., Causmaecker, P. De, Petrovic, S., & Vanden Berghe, G. (2002). A multi criteria meta-heuristic approach to nurse rostering, *Proceedings of the 2002 congress on evolutionary computation, CEC 2002*, Honolulu Hawaii, 1197-1202.

Burke, E.K., Cowling, P., Causmaecker, P. De, & Vanden Berghe, G. (2001). A memetic approach to the nurse rostering problem, *Applied Intelligent*, 15 (3), 199-214.

Burke, E.K., & Newall, J.P. (1999). A multi-stage evolutionary algorithm for the timetable, *The IEEE Transactions on Evolutionary Computation*, 3.1, 63-74.

Burke, E.K., Causmaecker, P. De, Petrovic, S., & Vanden Berghe, G. (2004). Variable neighbourhood search for nurse rostering problems, *Proceedings of the 4th Metaheuristics International Conference, MIC 2001.*

Cheang, B., Li, H., Lim, A., & Rodrigues, B. (2003). Nurse rostering problems – a bibliographic survey, *European Journal of Operational Research*, 151, 447-460.

Chen, J.G., & Yeung, T.W. (1992). Development of a hybrid expert system for nurse shift scheduling, *International Journal of Industrial Egronomics* 9, 315-327.

Cheng, B.M.W., Lee, J.H.M., & Wu, C.K. (1997). Nurse rostering system using constraint programming and redundant modeling, *IEEE Trans Information Technol Biomed*, 1, 44-54.

Davis, L. (1991). Handbook of genetic algorithms, *New York: Van Nostrand Reinhold.*

Dawkins, R. (1989). The evolution of evolvability, *Artificial Life,* 201 – 220.

Dawkins, R. (1976). Hierarchical organisation: a candidate principle for ethology, *Growing Points in Ethology,* 7 – 54.

Dias, T., Ferber, D., Souza, C., & Moura, A. (2003). Constructing nurse schedules at large hospitals, *International Transactions in Operational Research*, 245 – 265.

Dorigo, M., & Blum, C. (2005). Ant colony optimization theory: A survey, *Theoritical Computer Science*, 344 (2 – 3): 243 – 278.

Dowsland, K. (1998). Nurse scheduling with tabu search and strategic oscillation, *European Journal of Operational Research*, 106, 393-407.

Engku Muhammad Nazri Engku Abu Bakar. (2001). *A heuristic to scheduling security personnel at local universities in Malaysia.* Unpublished Ph.D. Thesis. Universiti Utara Malaysia, Malaysia.

Gutjahr, W.J., & Rauner, M.S. (2004). An ACO algorithm for a dynamic regional nurse-scheduling problem in Austria, *Computers & Operations Research.*

Glover, F. (1989). Tabu Search – Part I, *ORSA Journal on Computing,* 1(3): 190 – 206.

Glover, F. (1990). Tabu Search – Part II, *ORSA Journal on Computing,* 2(1): 4 – 32.

Glover, F. (1995). Tabu thresholding: improved search by nonmonotonic trajectories, *ORSA Journal on Computing,* 7(4): 426 – 442.

Glover, F. (1997). Tabu Search, *Kluwer Academic Publisher, Boston.*

Glover, F., & Laguna, M. (1997). Tabu Search, *Kluwer Academic Publisher, Boston.*

Hertz, A. (1991). Tabu search for large scale timetabling problems, *European Journal of Operational Research*, 54, 39-47.

Hasegawa, S., & Kosugi, Y. (2006). Solving nurse scheduling problem by integer-programming-based local search, *IEEE International Conference.*

Ikegami, A., & Niwa, A. (2003). A subproblem-centric model and approach to the nurse scheduling problem, *Mathematical Programming,* 97: 517 – 541.

Kawanaka, H., Yamammoto, K., Yoshikawa, T., Shinogi, T., & Tsuruoka, S. (2001). Genetic algorithm with the constraints for nurse scheduling problem, *Journal of Scheduling.*

Kellogg, D.L., & Walczak, S. (2007). Nurse scheduling: from academia to implementation or not?, *Interfaces,* 37, 4.

Kolodner, J. (1993). Case-based reasoning, *Morgan Kaufmann Publishers Inc., San Francisco, CA, USA.*

Kundu, S., & Acharyya, S. (2008). A SAT approach for solving the nurse scheduling problem, *IEEE Region 10 Conference TENCON.*

Lao, H. C. (1996). On the complexity of manpower shift scheduling, *Computer & Operation Research*, 23(1), 93 – 102.

Li, H., Lim, A., & Rodrigues, B. (2003). A hybrid AI approach for nurse rostering problem, *Proceedings of the 2003 ACM Symposium on Applied Computing, SAC, Melbourne*, 730 – 735.

Li, J., & Aickelin, U. (2003). A bayesian optimization algorithm for the nurse scheduling problem, *Proceedings of 2003 Congress on Evolutionary Computation*, CEC 2003, 2149 – 2156.

Li, J., & Aickelin, U. (2004). The application of bayesian optimization and classifier systems in nurse scheduling, *Proceedings of the 8th International Conference on Parallel Problem Solving from Nature, PPSN VIII*, 581 – 590.

Liao, C.J., & Kao, C.Y. (1997). Scheduling nursing personnel on a microcomputer, *Health Manpower Management*, 23(2 – 3): 100 – 6.

Maenhout, B., & Vanhoucke, M. (2008). Comparison and hibridization of crossover operators for the nurse scheduling problem, *Annals of Operations Research,* 159: 333 – 353.

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

Michalewicz, Z., & Fogel, D.B. (2000). How to solve it: modern heuristics, *Springer-Verlag, Berlin, Germany.*

Millar, H.H., & Kiragu, M. (1998). Cyclic and non-cyclic scheduling of 12 h shift nurses by network programming, *European Journal of Operational Research*, 104, 582-592.

Moz, M., & Pato, M.V. (2005). A genetic algorithm approach to a nurse rerostering problem, *Computer and Operations Research.*

Ohki, M, Uneme, S., & Kawano, H. (2008). Parallel processing of cooperative genetic algorithm for nurse scheduling, *4th International IEEE Conference "Intelligent Systems".*

Oughalime, A., Ismail, W.R., & Yeun, L.C. (2008). A tabu search approach to the nurse scheduling problem, *International Symposium on Information Technology,* 1: 1 – 7.

Ozkaharan, I., & Bailey, J.E. (1988). Goal programming model subsystem of a flexible nurse scheduling support system, *IIE Transactions* 20(3), 306-315.

Ozkaharan, I. (1991). An integrated nurse scheduling model, *Journal of Social and Health System,* 3, 79-101.

Nonobe, K., & Ibaraki, T. (1998). A tabu search approach to the constraint satisfaction problem as a general problem solver, *European Journal of Operational Research*, 106, 599-623.

Parr, D., & Thompson, J.M. (2007). Solving the multi-objective nurse scheduling problem with a weighted cost function, *Annals of Operations Research,* 155: 279 – 288.

Randhawa, S.U. & Sitompul, D. (1993). A heuristic-based computerized nurse scheduling system, *Computers and Operations Research,* 20, 837-844.

Ramli, R., Khader, A. T., & Mustafa, A. (2002). Nurse scheduling models: recent advancements and future directions, *International Conference on Operations Research for DevelopmntI,* 27-30 December, Chennai, India.

Ramli, R. (2004). An evolutionary algorithm for the nurse scheduling problem with circadian rhythms, *Unpublished PhD Thesis*, Universiti Sains Malaysia, Malaysia.

Sitompul, D. (1992). Design and implementation of a heuristic-based decision support system for nurse scheduling, *Unpublished Doctoral Thesis*, Oregon State University.

Sitompul, D., & Randhawa, S.U. (1990). Nurse scheduling models: a state-of-the-art review, *Journal of the Society for Health Systems,* 2(1): 62 – 72.

Taillard, J., Philip, P., Chastang, J.F., Dienfenbach, K., & Bioulac, B. (2001). Is self-reported morbidity related to the circadian clock?, *Journal of biological rhythms,* 16 (2): 183 – 90.

Thornton, J.R., & Sattar, A. (1997). Nurse rostering and integer programming revisited, *International Conference on Computational Intelligence and Multimedia Applications, ICCIMA'97*, 49-58.

Valouxis, C., & Housos, E. (2000). Hybrid optimization techniques for the workshift and rest assignment of nursing personnel, *Artificial Intelligence in Medicine*, 20, 155-175.

Vanhoucke, M., & Maenhout, B. (2005). NSPLib – A nurse scheduling problem library: A tool to evaluate (meta-) heuristic procedures., *ORAHS Proceedings.*

Warner, D.M. (1976). Scheduling nursing personnel according to nursing preferences: a mathematical programming approach, *Operations Research*, Vol. 24, No. 5, 842-856.

Wren, A. (1996). Scheduling, timetabling and rostering – a special relationship?, *Lecture Note in Computer Science*, Vol. LNCS 1153, 46-75.