Faculty of Information and Communication Technology

THE USE OF HEURISTIC ORDERING AND PARTICLE SWARM OPTIMIZATION FOR NURSE SCHEDULING PROBLEM

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THE USE OF HEURISTIC ORDERING AND PARTICLE SWARM OPTIMIZATION FOR NURSE SCHEDULING PROBLEM

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A thesis submitted
fulfillment of the requirements for the degree of Master of Science in Information and Communication Technology

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DECLARATION

I declare that this thesis entitle "The Use of Heuristic Ordering and Particle Swarm Optimization for Nurse Scheduling Problem" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree

Signature : ……

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APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Science in Information and Communication Technology.

Signature	:	……
Supervisor Name	:	**PM DR ABD. SAMAD BIN HASAN BASARI**
Date	:	……

DEDICATION

"It is only those who have knowledge among His servants that fear Allah."

(Qur'an, Fatir 35:28)

First and foremost, I would like to thank Allah for blessing my mind a desire to seek knowledge. Oh Allah, benefit me with what You have taught me and teach me what benefits me and increase me in knowledge.

I would like to thank my family for their continuous support all my life long. I got infinite love from my parents, supportive husband and understanding daughter.

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ABSTRACT

The scheduling of nurse has been the important management functions and directly affected the hospital services and the patient care as well. The challenge of nurse scheduling is the substantial amount of time for assigning shifts to a set of nurses that involves a large set of constraints. To satisfy all the constraints cannot be applied directly due to variability preferences and conflicting interest and objectives between nurses and hospital. The main objective of this research study is to find the optimal solution that can deal with varying preferences in term of skill categories, flexible constraint parameters, flexible coverage and varying the size of nurses. A combination of heuristic ordering and particle swarm optimization (HOPSO) has been proposed to achieve the objectives. The capability of PSO algorithm is enhanced by emphasizing the use of information on the constraints and heuristic ordering for searching optimal solution in both the feasible and infeasible solution spaces. The constraints are adapted to the evaluation function that iteratively evaluates all the solutions. The solution with lowest violation penalty cost is selected and will compare to a new solution. Before the particles update its position, variable neighborhood search (VNS) is applied in order to enhanced the diversity before being trapped in a local optima. The performance of the proposed method is tested on the real problem benchmark dataset in Malaysia public hospital, Universti Kebangsaan Malaysia Medical Centre (UKMMC) that had 8 datasets with the different number of nurses. The comparison of the result of HOPSO, harmony search algorithm (HSA) and heuristic variable neighborhood search (HVNS) is presented. The result show that the proposed HOPSO can generate the schedule in the range between one to twenty-six seconds computational time, followed by the HSA which range between one hundred and eighty-five to three hundred and forty-five seconds and HVNS takes one hundred and thirty-one to eight hundred and twenty seconds. HOPSO can decrease the penalty cost into ninety seven percent improvement than the HSA which is less than fifty percent of improvement. Computational results show that the proposed HOPSO based algorithm is performed better than HSA and HVNS in order to provide a practical solution to the problem.

ABSTRAK

Penjadualan jururawat adalah sangat penting dalam pengurusan hospital kerana ia memberi kesan yang besar kepada perkhidmatan hospital umumnya dan khidmat pesakit khasnya. Cabaran untuk menentukan jadual bekerja kepada setiap jururawat adalah memerlukan masa yang lama kerana senarai kekangan yang banyak. Memenuhi semua kekangan adalah tidak boleh dilakukan secara mutlak kerana berlaku konflik antara kepelbagaian keinginan jururawat dan objektif pengurusan hospital. Maka objektif kajian ini adalah untuk mencadangkan kaedah penyelesaan yang mampu mengurus kepelbagaan kekangan terutama dari segi kategori jururawat, parameter kekangan yang anjal, had jururawat yang anjal dan bilangan jururawat yang pelbagai. Kombinasi Heuristic Ordering dan Particle Swarm Optimization (HOPSO) digunakan untuk mendapatkan penyelesaian yang optimum bagi Nurse Scheduling Problem (NSP). Keupayaan PSO algoritma ditingkatkan melalui penekanan kepada maklumat kekangan dan heuristic ordering ke dalam algoritma PSO asal bagi mendapatkan penyelesaian optimum di dalam ruang feasible dan infeasible. Setiap kekangan diambil kira dalam fungsi penilaian. Hasilan yang mempunyai jumlah penalti yang paling rendah akan dipilih dan kemudian dibandingkan dengan hasilan seterusnya. Algoritma PSO diubahsuai pada bahagian kemaskini posisi partikel iaitu sebelum partikel berpindah ke posisi yang lain, Variable Neighborhood Search algoritma digunakan untuk meningkatkan kepelbagaian penyelesaian sebelum tertumpu kepada local optima. Prestasi HOPSO diuji dngan menggunakan data daripada hospital Universiti Kebangsaan Malaysia. Set data ini mempunyai 8 wad yang mempunyai bilangan jururawat yang pelbagai. Keputusan yang diperolehi dibandingkan dengan keputusan yang diperolehi daripada kajian lepas yang menggunakan data yang sama iaitu kaedah Harmony Search Algorithm (HSA) dan Heuristic Variable Neighborhood Search (HVNS). Hasil perbandingan menunjukkan HOPSO mampu memberi hasil penyelesaian yang yang baik dengan mengambil masa yang paling singkat iaitu antara satu hingga dua puluh enam saat, diikuti HSA satu ratus lapan puluh lima hingga tiga ratus empat puluh lima saat dan HVNS satu ratus tiga puluh satu hingga lapan ratus dua puluh saat. Seterusnya HOPSO memberi sembilan puluh tujuh peratus penambahbaikkan dan diikuti HSA lima puluh peratus penambahbaikan. Keputusan ini menunjukkan bahawa pendekatan HOPSO algoritma yang dicadangkan lebih baik daripada HSA dan HVNS dari sudut efisyen dan efektif untuk menghasilkan penjadualan yang praktikal.

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LIST OF ABBREVIATIONS

PSO	:	Particle Swarm Optimisation
HOPSO	:	Heuristic Ordering Particle Swarm Optimisation
NSP	:	Nurse Scheduling Problem
GA	:	Genetic Algorithm
LS	:	Local Search
ILP	:	Integer Linear Programming
HSA	:	Harmony Search Algorithm
VNS	:	Variable Neighborhood Search
HVNS	:	Hybrid Variable Neighborhood Search
TS	:	Tabu Search
ACO	:	Ant Colony Optimization
ANSP	:	Anaesthesiology Nurse Scheduling
O	:	Day Off
M	:	Morning
E	:	Evening
N	:	Night
NP	:	Non-Polynomial

LIST OF PUBLICATIONS

Published in Journal

1. Norhayati Mohd Rasip, Abd Samad Hasan Basari, Nuzulha Khilwani Ibrahim, Burairah Hussin, "A Guided Particle Swarm Optimization Algorithm for Nurse Scheduling Problem," Applied Mathematics Sciences, vol. 8, no. 113, pp. 5625-5632, 2015.

2. Norhayati Mohd Rasip, Abd Samad Hasan Basari, Nuzulha Khilwani Ibrahim, Burairah Hussin, "Enhancement of Nurse Scheduling Steps Using Particle Swarm Optimization,"Advanced Computer and Communication Engineering Technology Lecture Notes in Electrical Engineering, vol. 315, pp. 459-469, 2014.

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1. Norhayati Mohd Rasip, Abd Samad Hasan Basari, Nuzulha Khilwani Ibrahim, Burairah Hussin, "An Investigation of Intelligent Search Techniques For Nurse Scheduling Improvement in Healthcare Organization," e-Health Symposium 2013, pp. 1-7, 2013.

CHAPTER 1

INTRODUCTION

1.1 Background

In the healthcare organization, nurses are the precious personnel resources that have had a significant role in the supporting system. The important tasks of nurses such as assessing patients, identifies desired outcomes for the patient, plans and care handling, and re-evaluate patients are contributing to ensure continuous hospital services achieved the intentional result (Ernst et al., 2004). Accordingly, the challenging is to maintain the level of performance and a good quality of healthcare services due to as the increasing patient‟s demand to get the best healthcare service and at the same time satisfying the staff requirements on various days and shifts. Furthermore, nurses have a responsibility to carry out the best services around the clock for seven days. All this demand reinforces the importance of finding a way to construct a practicable schedule in a reasonable amount of time. The particular schedule needs to decide a day-to-day shift assignment for each nurse within the scheduling period and must fulfill the indicated requirements. The staff nurse can construct the schedule based on their experience and knowledge, but the high possibility solution will always be doubtful whether the nurse schedule is obtained a good quality or not and several days taken to complete it.

In Malaysia, due to increasing demand of healthcare service, the shortage of nurses and doctors has been identified as a critical problem faced by public hospitals (Barnett et al.,

2010). The World Health Organization (WHO) recommends a nurse-to-patient proportional ratio is 1:200 while the Malaysian nurse-to-patient ratio is 1:599 (Ministry of Health, 2009). At least 174, 000 nurses need to be trained by 2020 to meet the WHO‟s nurse-to-patient (Barnett et al., 2010). However, this ratio is hard to achieve because 5000 nurses retire every year, and only 1500 new nurses are hired yearly (Ministry of Health Malaysia, 2011). Thus, the unbalance allocation of resources to specific time between the nurses (Ibrahim et al., 2011) is an important factor leading to most of the problem such as poor work performance, absenteeism, and high rate turnover. For these reasons, getting the adjust working shift to a few days from the employer is important to support nurses pleasantly.

The nurse scheduling problem is well known by rapid growth in the number of potential solutions and the modest growth of the resources to be scheduled is NP-hard problem (Karp, 2010). NP-hard is the class of the problems that "at least as hard as any problem in NP". Thus, by managing nurse scheduling problem (NSP), it effectively can make great help towards the research community. Likewise solving the condition efficiently is essential for both practitioners and administrators in the hospital because the outcome will offer a certain effect on nurses‟ doing their job, which is firmly identified with the quality of the healthcare.

Although the nurse scheduling problem appears in scheduling problem for decades, many researchers still put the effort in order to find a new solution. One indication for this, Patrick De Causmaeker in 2010 and 2014 organized a competition of nurse scheduling, which took place in 2010 and 2014, which gathered many different competitors utilizing a variety of approaches (Haspeslagh et al., 2014). This competition encourages practitioners and researcher to find the new solution in order to develop further interest in the area and to stimulate new solution approaches by bringing together researchers from different areas.

1.1.1 Shift Assignment

Basically, the nurse scheduling problem is about a shift assignment. The shift assignment has a great impact on the nurses' operational circumstances that are strongly related to the term of action of health care. However, this task is difficult to respond, which, conflicting constraints that are encountered and satisfying the nurses preferences with different shift types combination increases the solution space which affect calculation time significantly. The number of possible shift type combination is explained. For example, Table 1.1, the scheduling period is seven days, the number of the available nurses to assign within that day is four nurses, so the table had 7x5 = 35 elements.

Table 1.1: Example of Empty Nurse Schedule

Nurses	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Nurse 1	?	?	?	?	?	?	?
Nurse 2	?	?	?	?	?	?	?
Nurse 3	?	?	?	?	?	?	?
Nurse 4	?	?	?	?	?	?	?
Nurse 5	?	?	?	?	?	?	?

For each element, there exist 4 possibilities (four symbols), which must fill. Each cell can take at most 4 values, these being: Morning shift, Evening shift, Night shift and day off. The space of the possible solution is: $4^{35} = 1.8 \times 10^{19}$. To find the solution among all possible solution is called a search algorithm and it is not only one solution that fulfills some criteria, but also finding the best solution subject to one criterion which can fulfill a specific degree. In this study is to find an optimal schedule with focuses on handling constraints and preferences arising.

1.1.2 Handling Constraints Problem

Due to the particular service hospital provide, it is important that the hospitals are not understaffed at any time and often to balance the hospital‟s staff requirement and the nurses‟ individual preferences. In the nurse scheduling view, the constraints are needed to handle in horizontal and vertical view. Horizontal constraint is known as soft constraints. The soft constraints are about the shift sequences from starting day until the end of the day within the scheduling period. The vertical constraint is known as a hard constraint which satisfying the minimum number of working nurses for each shift per day.

The hard constraint and soft constraints are needed to be handled is listed as below:

Hard constraints (denoted by H)

(H1) All shifts must have at least the minimum requested number of nurses i.e. coverage demand.

(H2) All nurses cannot work more than one shift per day.

(H3) At least one senior nurse must be present for every shift.

(H4) No isolated working day are allowed. For example, a day-off (O), morning (M) shift then day off (O) which is OMO.

(H5) The maximum working days are 12 days for each fourteen days and the minimum is 10 days.

(H6) The maximum consecutive working days is 4 days.

(H7) For all night shifts, it must be in the form of four consecutive nights that must be followed by two days off.

(H8) All nurses must have at least 2 days off per two-week (fortnight) schedule.

Soft Constraints (denoted by S)

(S1) Attempt to give a fair number of working days and days off to all nurses.

(S2) Attempt to give each nurse at least one day off in the weekend during the allocated roster period.

(S3) Attempt to give four consecutive morning shifts followed by one day off.

(S4) Attempt to give four consecutive evening shifts followed by one day off.

(S5) Attempt to give an evening shift after 2 days off that follows the night shift or day off.

The sequence of the shift from the start until the end of the day within the scheduling period that includes morning (M), evening (E), night (N) and a day off (O) can generate many shift patterns. Shift pattern can distinguish into three categories which as listed below:

i. Prohibited pattern, whereby those patterns are not allowed to occur due to the hard constraints such as four consecutive nights followed by morning shift (NNNNM), this pattern will be prevented because of the imposition of the hard constraint.

ii. Undesirable patterns, where the shift pattern is allowed, but not desirable to be assigned to nurses (violate soft constraint) such as MMEEOM. This indicates the order pattern of consecutive Morning, Morning, Evening, and Evening followed by a day off and followed by a Morning shift. This allows pattern, but it violates the soft constraint

iii. Desirable patterns, which are highly preferable by nurses (no violation of any constraint) such as four consecutive morning shifts followed by a day off (OMMMMOO) or four consecutive evening shifts followed by one day off (EEEEO).

1.2 Problem Statements

In order to provide a good quality of patient services, consideration of satisfaction hospital‟s regulation and individual preferences are very important. To generate nurse schedule in the most efficient way is needed in order to satisfy as many as possible a variety of constraints and at the same time meet the minimum number of nurses for each shift. The constraints also included the varying numbers of nurses from ward to ward. Applying the conventional way for assigning shifts to each available nurse consumes a lot of time. This situation has affected not only the supervisor who need to think about many things, but also nurse frustration due to their preferences are not considered by their supervisor. This dissatisfaction of nurse scheduling can be effected to the nursing vacancy rate and quality of patient care. Therefore, the efficient solution method that can handle the constraint with deal less human factor is needed to generate feasible and quality nurse schedule.

1.3 Research Questions

In this study, preliminary aim is to find a feasible solution for the nurse scheduling problem by using constraint handling method. The primary research questions of this research are as follows:

1. How to handle the constraint problem?
2. How the appropriate technique can be used in order to fulfill the nurses preferences and hospital regulations.
3. How the appropriate technique can be used in minimizing the searching of optimal solution?

1.4 Research Objectives

The primary aim of this research is to answer the key research questions above, and hence, the objectives are given as follows:

1. To propose heuristic ordering and a particle swarm optimization method to minimize the violation of constraints.
2. To evaluate the efficiency of the proposed method by using benchmark datasets.

1.5 Research Scope

The aim of this thesis is to utilize the particle swarm optimization method to real-world applications, specifically the nurse scheduling problem. The research design considers the strength and weakness of each component of particle swarm optimization. Consequently, the optimal solution in this thesis commences on the clarification with the features of the situation data. The focuses are on assigning daily shift for the available nurses within the scheduling period and not include rescheduling process.

This thesis describes and discusses solution approaches, which span the interdisciplinary spectrum of operations research to artificial intelligence method. In order to have a clear direction of this research study, the relationships of problem statements, research questions and research objectives are given in Table 1.2.