

SOLVING NURSE ROSTERING PROBLEM USING PARTICLE SWARM OPTIMIZATION BASED CULTURAL ALGORITHM

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ABSTRACT

Nurse Rostering Problem (NRP) is an optimization problem which deals with the construction and assignment of a work shift to available nurses on a daily, weekly or monthly basis of a planning period. Most existing nurse scheduling algorithms suffer from high computational cost and slow convergence speed while generating a feasible solution. In this paper, Particle Swarm Optimization based Cultural Algorithm (PSOCA) which is characterized with low convergence speed was developed for solving nurse rostering problem. Particle Swarm Optimization (PSO) algorithm was incorporated into the population space of cultural algorithm. The developed Particle Swarm Optimization based Cultural Algorithm was experimented with twenty (20) nurses. Experimental result confirmed that PSOCA was able to solve nurse rostering problem with promising results.

Keywords: Nurse Rostering, Cultural Algorithm, Particle Swarm optimization

1. INTRODUCTION

Nurse Rostering (NR) is concerned with the construction and assignment of shift schedules to available nurses on a daily, weekly or monthly basis. The primary goal is to meet the healthcare service needs at an acceptable cost [15,22]. The effectiveness of the shift schedules impacts the worker morale, healthcare service quality, the recruitment process, the healthcare operations budgets, and the survivability of the healthcare organization in the long run [7]. However, the Nurse Rostering is a hard combinatorial optimization problem common in healthcare organizations which must satisfy hard constraints while the soft constraints are to be met as much as possible [4,16].

Cultural Algorithm (CA) is a technique that incorporates domain knowledge obtained during the evolutionary process so as to make the search procedure more effective [17]. The goal is to increase the learning or convergence rates of the algorithm so as to provide a better response to a large number of problems [1].

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO is easy to implement as there few parameters to adjust. The method can be applied to optimization problems of large dimensions, often producing quality solutions more rapidly than alternative methods [2].

2. LITERATURE REVIEW

Literature on nurse rostering and scheduling is very extensive. One may refer to literature reviews on the subject that provide in-depth studies on this problem such as [6,12]. A wide variety of methods have been used to tackle nurse scheduling which includes: mathematical programming [13], constraint programming [21], heuristics and meta-heuristics, hybrid methods as well as simulation. Even creative methods such as auction systems have been applied to tackle nurses' preferences [9].

Burke et al.[5] hybridize a tabu search approach with algorithms that are based upon human inspired improvement techniques. [20] presented a mixed-integer quadratic programming formulation to calculate the number of nurses from a certain skill category to do a number of shifts per day. Three non-overlapping shift types of 8 hours each are used. The goal function aims at minimizing the difference between a given lower limit for the number of nurses and the variables, which are the number of nurses.

Jaumard et al.[14] propose an exact solution approach for a flexible realistic model of the nurse scheduling problem. The generalized linear programming model applies column generation and branch and bound. It allows full exploration of the set

of feasible solutions. The authors claim that their model is more flexible to address changes in the scheduling environment than a heuristic model is. However, in practice, the conflicting nature of the nurse scheduling constraints makes it very difficult to find feasible solutions.

Cheng and Wu [8] developed a nurse rostering system for solving one particular hospital problem. They make use of the ILOG solver for generating a schedule that satisfies a large set of rules (such as preferred consecutive patterns and shift balance among nurses). The rules are divided into hard and soft constraints. Solutions are generated with a 4-step procedure, that is specifically oriented towards solving the particular problem. This contribution is less generic because of the problem specific modelling but nonetheless, it has been applied in a real modern hospital and as such is a significant relatively recent addition to the literature.

Smith and Wiggins [18] presents an interactive algorithm which helps the scheduler to construct a cyclical schedule. The algorithm takes coverage constraints and days off policies into account and it determines the number of personnel members, which is a staffing decision. Not all the staff members can have rotating schedules, however. In view of more recent developments in nurse rostering, this early heuristic for cyclical schedules cannot really be considered for practical use today.

Berrada et al.[3] combined tabu search with a multi-objective approach (see also goal programming in the above sections). It is interesting that a meta-heuristic is applied instead of an optimization approach but we think that the problem is of relatively low relevance to the real-world situation because it looks only at switching days off and working days for different people.

Dowland and Aickelin [10] makes use of different neighborhood search strategies in a tabu search algorithm. The heuristic oscillates between feasible solutions meeting the personnel requirements and schedules concentrating on the nurses' preferences. At any time of the planning period, the algorithm must provide enough personnel with the requested qualities, while satisfying the people by granting personal requests in a fair manner. The attractiveness of work patterns differs from person to person. Rather than designing a generic, widely applicable algorithm, the model was developed for solving the personnel scheduling problem in one particular hospital and produces very good quality results for that data.

Tanomaru [19] presents a genetic algorithm to solve a staff scheduling problem. The objective is to minimize the total wage cost in a situation where the number of personnel is not fixed. Solutions have to meet the total workforce requirements while respecting the maximum number of individual working shifts. Overtime is allowed, however. Although the problem dimensions are very basic, this is one of the few research papers which allow flexible starting times for the shifts. Solutions for the personnel are represented by 7 pairs of integers, giving the start and stop times per day. For real-life problems, Tanomaru concludes that his heuristic mutation operators might be too time consuming. Also, the number of constraints that are tackled is very low.

Easton and Mansour [11] developed a distributed genetic algorithm for an employee staffing and scheduling problem called 'tour scheduling'. The algorithm aims at minimizing the number of personnel members to fulfill the demands. The fitness function represents violations of constraints and individual solutions are improved with local hill climbing operators. The genetic algorithm works very well for a set of test problems but we think that the model is possibly too simple (e.g. no personal preferences) for real modern applications.

3. METHODOLOGY

In this paper, CA and PSO were used for solving the nurse rostering problem. The cultural algorithm comprises of population space and belief space. In the population space of the cultural algorithm, Particle swarm optimization (PSO) was used. The algorithm (PSOCA) was implemented with twenty (20) nurses.

3.1 Particle Swarm Optimization (PSO) Algorithm

The PSO algorithm used was adopted from (Alade et. al. 2018)

Step 1: Identify the number of particles that will be used to solve the problem.

$$f(R_k^i) \leq f(R_k^{i-1}) \leq \dots \leq f(R_k^1) \quad 1$$

Step 2: Estimate the fitness value of each particle

Step 3: Set P_{best} to the current position if the fitness value of each particle's current position is better than its previous P_{best}

Step 4: Fitness value of the particle is compared with that of the G_{best} . If it is better, the G_{best} is updated

Step 5: Update the velocity and position of each particles using

$$V_{id}^{i+1} = \chi \left(V_{id}^i + q_1 r_1 (R_{id}^i - X_{id}^i) + q_2 r_2 (R_{gd}^i - X_{id}^i) \right) \quad 2$$

$$X_{id}^{i+1} = X_{id}^i + V_{id}^{i+1} \quad 3$$

Step 6: Repeat the process from step 2 until the termination condition is satisfied.

Where

V_{id} is the velocity component of the i th particle in the d th dimension

X_{id} is the position component of the i th particle in the d th dimension

q_1 and q_2 are learning factors; (cognitive, and social)

r_1 , and r_2 are random numbers in $[0, 1]$.

q_1 , and q_2 together with r_1 and r_2 maintain the stochastic influence of cognitive and social components of the particles velocity respectively.

μ_1 and μ_2 are influence factor which represent respectively how population space and cultural framework guides particle's flight.

R_{id} is the individual historical best position of particle i in the d th dimension

R_{gd} is the historical best position component of the G_{best} in the d th dimension

$q_1 r_1 (R_{id}^i - X_{id}^i)$ is a cognitive component which measures the performance of the particles i relative to past performance

$q_2 r_2 (R_{gd}^i - X_{id}^i)$ is a social component which measures the performance of the particles relative to a group of particles or neighbors?

$$\chi = \frac{2}{\left| 2 - \phi - \sqrt{\phi^2 - 4\phi} \right|}$$

χ is constriction factor

$\phi = \phi_1 + \phi_2$ ($\phi_1 > 4$)

ϕ is sum of learning factors

3.2 Cultural Algorithm Pseudo-Code

The cultural algorithm pseudo-code is given as follows:

1. Generate s random schedules (initial population)
2. Initialize the belief space (copying the best individual to the situational belief space)
3. Repeat
4. Evaluate Population $P(t)$
5. Update ($B(t)$, $\text{Accept}(P(t))$)
6. Variation ($P(t)$, $\text{Influence}(B(t))$)
7. $t = t + 1$
8. Select $P(t)$ from $P(t - 1)$
9. Update the belief space (with the individuals accepted)
10. Until the end condition is satisfied

3.3 Formulation of Particle Swarm Optimization based Cultural Algorithm (PSOCA)

In formulating a PSOCA, particle swarm optimization algorithm (PSO) was substituted for the population space of the cultural algorithm framework. The formulated PSOCA was adopted from (Alade et. al., 2018). The formulated particle swarm optimization based cultural algorithm has the following steps:

Step 1: Start

Step 2: Initialize the algorithm parameters of PSOCA.

Step 3: Initialize the particle in both population space and belief space.

Step 4: Replace population space with PSO algorithm, compute the fitness of each particle, update and store the individual best particle of the population space.

Step 5: If accept condition is satisfied, carry on accept operation, send some better particles to belief space.

Step 6: If belief space satisfy reset condition, reset the best particle of belief space.

Step 7: Replace belief space with update formula (using equation 2 and 3) compute fitness of each particle, update and store the best particle of the belief space.

Step 8: If influence condition is satisfied, carry on influence operation, and substitute some better particles of belief space for some worst particle of population space.

Step 9: Check whether the stop condition is satisfy. If the stopping condition is not satisfied then go to step 3.
Otherwise stop and obtain the best solution from the global best position
Step10: End

3.4 Hard and Soft constraints

In general, the objective is to search for a schedule that satisfies a given set of hard constraints. However, in practice, the wishes or preferences of individual nurses must be satisfied as much as possible which can be grouped into soft constraint. HC represents hard constraint and SC represents soft constraint.

Table 1: TYPICAL SHIFT TYPES

SHIFT TYPES	Shift Description	Symbol
1	Morning Shift	M
2	Afternoon Shift	A
3	Night Shift	N
4	Off Day	O

Table 2: CONSTRAINTS USED AND ITS DESCRIPTION

Constraint	Description
HC1	Senior Nurses are to work during the morning shift
HC2	Every nurse is assigned to only a shift per day
HC3	Minimum Working Days Shift coverage should be five (5) days in a week
HC4	Minimum Off Days Shift coverage should be two (2) days in a week
HC5	No nurse should have more than seven (7) day night shift in 28 days
SC1	Number of day off after series of night duty or before.
SC2	Maximum Off Days coverage should be seven (7) days in a week
SC3	Running Shift Nurses request for a particular shift in a roster

4. EXPERIMENTAL RESULT

The developed algorithm was tested with 20 nurses using four different shifts (morning, afternoon, night and off). The results for PSOCA is shown in Table 3. The algorithm was tested under five separate runs.

Table 3 Result after five runs of PSOCA Algorithm

Run	Time (sec)	Fitness value	Hard Constraint violation	Soft Constrains violation	Number of unallocated nurse
1	28	0.70	0	0	0
2	30	0.71	0	0	0

3	32	0.65	0	0	0
4	30	0.80	0	0	0
5	25	0.75	0	0	0
Average	29	0.72	0	0	0

LAUTECH TEACHING HOSPITAL , OGBOOMOSO

Female Ward Roster (Using PSO based Cultural Algorithm)

Tuesday, 1 March, 2018											To											Monday, 28 March, 2018										
Names	RK	DAY1	DAY2	DAY3	DAY4	DAY5	DAY6	DAY7	DAY8	DAY9	DAY10	DAY11	DAY12	DAY13	DAY14	DAY15	DAY16	DAY17	DAY18	DAY19	DAY20	DAY21	DAY22	DAY23	DAY24	DAY25	DAY26	DAY27	DAY28			
Mr A. Adedokun	CNO	O	A	M	M	A	A	O	O	O	A	M	A	M	M	O	O	A	M	A	M	M	A	A	O	O	M	M	A			
Mr T. Adesike	CNO	A	A	O	O	M	M	M	A	A	O	O	M	M	M	M	M	A	A	M	O	O	M	M	M	M	A	O	O			
Mrs M. Ogunlade	PNO	M	M	M	M	A	O	O	M	M	M	O	O	A	M	M	M	M	M	A	O	O	M	M	M	O	O	A	A			
Mrs R. Joshua	PNO	O	O	A	M	A	M	M	O	A	M	M	A	A	O	A	A	O	O	M	M	A	M	M	A	A	M	O	O			
Mrs S. Gideon	PNO	O	A	A	M	M	A	O	M	M	A	A	M	O	O	M	M	M	O	O	A	A	M	M	M	A	O	O	A			
Mrs G. Alajo	PNO	O	O	A	M	A	M	M	O	O	A	M	A	M	M	O	A	M	M	A	A	O	A	O	O	M	M	M	A			
Mrs F. Oyeleusi	PNO	M	M	M	O	O	A	M	O	A	A	M	M	A	O	A	O	O	M	M	M	A	O	A	M	M	A	A	O			
Mrs M. Adesayo	PNO	M	M	M	A	O	O	A	M	M	M	A	O	O	A	M	M	M	A	O	O	A	O	O	A	M	A	M	M			
Mr J. Ojo	MNO	M	M	A	A	M	O	O	A	A	O	O	M	M	A	N	N	N	N	N	N	N	O	O	O	O	O	O	O			
Mrs S. Agbola	MNO	A	A	O	O	M	M	A	A	O	O	M	M	M	M	N	N	N	N	N	N	N	O	O	O	O	O	O	O			
Mrs R. Binuyo	MNO	M	M	M	O	O	A	A	M	M	M	O	O	A	A	N	N	N	N	N	N	N	O	O	O	O	O	O	O			
Mrs T. James	MNO	M	M	M	A	O	O	M	A	O	O	M	M	M	A	O	O	O	O	O	O	O	N	N	N	N	N	N	N			
Mrs H. Olusola	MNO	A	O	O	M	M	M	M	M	M	M	M	A	O	O	O	O	O	O	O	O	O	N	N	N	N	N	N	N			
Mr T. Babu	MNO	A	O	O	M	M	M	A	M	M	M	A	O	O	M	O	O	O	O	O	O	O	N	N	N	N	N	N	N			
Mrs Z. Tanul	MNO	N	N	N	N	N	N	N	O	O	O	O	O	O	O	O	O	A	M	A	M	M	A	A	O	O	M	M	M			
Mrs U. Ganiyu	MNO	N	N	N	N	N	N	N	O	O	O	O	O	O	O	M	M	M	A	O	O	M	O	A	A	M	M	A	O			
Mrs K. Tinuola	MNO	N	N	N	N	N	N	N	O	O	O	O	O	O	O	A	A	M	M	A	O	M	M	M	M	A	O	O	M			
Mrs J. Rambo	MNO	O	O	O	O	O	O	N	N	N	N	N	N	N	N	A	A	O	O	M	M	M	M	M	M	O	O	A	M			
Mrs P. Pelumi	MNO	O	O	O	O	O	O	N	N	N	N	N	N	N	N	A	O	O	M	M	M	M	A	O	O	M	M	M	M			
Mr O. Olatosun	MNO	O	O	O	O	O	O	N	N	N	N	N	N	N	N	M	M	M	O	O	A	M	O	O	A	M	A	M	M			

NOTE:-
M:= Morning Shift
A:= Afternoon Shift
N:= Night Shift
O:= Off_Day

Figure 1: The roster generated from the PSOCA

5. DISCUSSION

Table 3 showed the shifts generated by PSOCA for 20 nurses. It is important to know that the PSOCA was tested 5 times and average of the result was recoded to get accurate result. A schedule that was produced manually has shown that there is an obviously unbalance shift pattern for the nurses. On the other hand, the schedule produced by PSOCA approaches shown more balance in giving a shift to the nurses where all nurses had been successfully assigned to morning, afternoon, night and off accordingly. This led to an average fitness value equal to (0.72) 72% with an average time of 29 seconds to generate a roster. The developed algorithm using the PSOCA approach produced better nurse scheduling due to the moderate fitness value and less time taken to generate a roster. The sample of the roster generated is given in figure 1.

6. CONCLUSION AND FUTURE WORK

In this paper, Particle Swarm Optimization based Cultural algorithm for solving nurse rostering problems was developed and implemented. The algorithm developed consisting of particle swarm optimization algorithm which was incorporated into the population space of cultural algorithm to improve the convergence speed of the algorithm. It is recommended that future research may be geared towards incorporating other population based algorithms into the population space of cultural algorithm.

7. REFERENCES

- [1] Alade Oluwaseun M, Oyeleye Christopher A. Adedeji Oluyinka T, Omidiora Elijah O. and Olabiyisi Stephen O. (2018). Performance Evaluation of PSO, PSOCA and MPSOCA for solving University Timetabling problem. *Annals. Computer Science Series*. 16:2, pp149-154
- [2] Bai Q. (2010). Analysis of Particle Swarm Optimization Algorithm. *Computer and Information Science*, Vol. 3 No. 1, pp 180-184

- [3] Berrada J, Ferland P, Michelon : A Multi- Objective Approach to Nurse Scheduling with both Hard and Soft Constraints, Socio-Economic Planning Science. 1996: 183-193.[16]
- [4] Burke E. K., De Causmaecker P., Berghe V. G. and Van Landeghem H. (2004). The state of art Nurse Rostering Problem. *Applied Intelligence*, Vol. 15, No 3, pp 199-214.
- [5] Burke EK, Bykov Y, and Petrovic S.(2000). A multicriteria approach to examination timetabling, Burke EK, Erben W. (Eds.): Practice and theory of automated timetabling, Third International Conference, Konstanz, Springer. 2000;118-131 [10]
- [6] Burke EK, De Causmaecker P, Vanden Berghe G, Van Landegem H.(2004). The state of the art of Nurse Rostering. *Journal of Scheduling*.7:441–499. [2]
- [7] Cheang, B., Li H., Lim A. and Rodrigues B. (2003). Nurse Rostering Problems- A Bibliographic Survey. *European Journal of Operational Research*, Vol. 151, pp 447-460
- [8] Cheng BMW, and Wu JCK.(1996). Nursing staff rostering using ILOG solver. Final year project report, Department of Computer Science and Engineering, The Chinese University of Hong Kong; [14]
- [9] De Grano L, Medeiros DJ, Eitel D.(2009). Accomodating Individual preferences in nurse scheduling via Auctions and optimization. *Health Care Management Science*. 12:228-242.[6]
- [10] Dowsland K, and Aickelin U (2000): Exploiting problem structure in a genetic algorithm approach to a nurse rostering problem, *Journal of Scheduling*. 3:139-153.[17]
- [11] Easton FF, and Mansour N. (1999). A distributed genetic algorithm for deterministic and stochastic labor scheduling problems. *European Journal of Operational Research*. 118(3):505-523.[19]
- [12] Ernst AT, Jiang H, Krishnamoorthy M, Sier D.(2004) Staff scheduling and rostering: A review of applications, methods and models, *European Journal of Operational Research*. vol 153, 3–27. [3]
- [13] Ikegami Niwa A. A (2003). Subproblem-centric Model and Approach to the Nurse Scheduling Problem, *Mathematical Programming*. 97(3):517-541[4]
- [14] Jaumard Brigitte, Semet Frederic and Tsevi Vovor.(1998) A generalized linear programming model for nurse scheduling. *European Journal of Operational Research*.107(1):1-18[13]
- [15] Kellogg D. L. and Walczak Steven (2007). Nurse Scheduling: From Academia to Implementation or Not? *Interfaces*, Vol. 37, pp 355-369
- [16] Mutingi M. and Mbohwa C. (2014). A Fuzzy-based Particle Swarm Optimization Algorithm for Nurse Scheduling. *Proceedings of the World Congress on Engineering and Computer Science*, Vol II, pp 22-24
- [17] Reynolds R G, and Zhun S. (2001): Knowledge-based function optimization using fuzzy cultural algorithms with volutionary programming. *IEEE Transactions on Systems, Man, and Cybernetics-Part B: Cybernetics*. 31(1): 1-18
- [18] Smith ID, Wiggins A. A computer-based nurse scheduling system, *computers and Operations Research*. 1977;4(3):195-212.[15]
- [19] Tanomaru Julio. Staff scheduling by a genetic algorithm with heuristic operators. Conference: Systems, Man and Cybernetics, 1995. Intelligent Systems for the 21st Century., IEEE International Conference. 1995;3:456-461.[18]
- [20] Warner DM, Prawda J. A mathematical programming model for scheduling nursing personnel in a hospital. *Journal of Management Science*. 1972;19:4:411-422.[11]
- [21] Weil G, Heus K, Francois P, Poujade M.Constraint programming for nurse scheduling. *IEEE Engineering in Medicine and Biology*. 1995;4:417-422.[5]
- [22] Yufa Xu and Xiang Liu (2010): An enhanced Culture-Based Particle Swarm Optimization Algorithm. *International Conference on Artificial Intelligence and Computational Intelligence*. :87-