A real time hierarchical shift design process at nursing homes A 2-stage Technique

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Abstract— the demand for nursing homes has grown as a result of the ageing of the population. "Multi-shift, high time-varying demand, hierarchical and collaborative" characterizes nursing practice. The number of nurses needed in a 24-hour period will vary greatly depending on the time of day; hierarchical means that different levels of nurses' abilities exist; collaborative means that different levels of employees collaborate to serve the elderly. Because of the high time-varying demand, the number of nurses needed in a 24-hour period will vary greatly. SDP and hierarchical staffing issues are the focus of our research, which includes the design of each shift's time frame to accommodate demand times and how to deploy hierarchical employees to the shifts. The two-stage technique will be used to tackle the issue. In the first step, we construct the shift schedule and calculate the number of employees required for each shift based on the characteristics of high time-varying demand. According to the restrictions of hierarchical coordination and collaboration, we calculate the number of employees required for each shift at each level in the second step. Different demand variations are studied and useful conclusions are made from the sensitivity analysis. Our findings may help nursing facilities cope with increased demands and personnel shortages by providing efficient decision-making tools and methodologies.

Key words: Hierarchical staffing; shift design problem; aging population; nursing homes; healthcare

I. INTRODUCTION

As the world's population becomes older, so does the number of elderly individuals. Nursing facilities have risen to fill a void left by the failure of family caregivers to satisfy the demands of an ageing population. The following features also characterise the job of the nursing staff in charge of caring for the elderly in nursing homes: the number of staff required in a 24-hour period varies substantially depending on the period. (2) there can be multiple shifts in a day covering the same time period; (3) employees will be classified into different levels according to their abilities, and the workers with higher level need more cost; (4) due to the different service quality provided by nursing workers of different levels, it is necessary for these workers to collaborate to serve the elderly. These features show that nursing home staffing is a complex combinatorial optimization problem. However, most nursing homes use manual scheduling, which takes more time and results in lower efficiency while also easily appearing poor service quality due to understaffing and waste of cost and resources due to overstaffing. So they desperately need a type of efficient and systematic scheduling solution. This study examines the issues that now plague nursing facilities, as well as the effects that fluctuations in demand for certain time periods have on the process of designing shifts.

Hospitals, banks, and contact centres are just a few of the places where shift design problem(SDP) occurs[1-4]. Y. Chen[1] highlights the relevance and difficulties of workforce allocation. Some researches[1,2,5] separated a day into multiple times, and variables such as understaffing and overstaffing were examined, which is comparable to our work as we also take the demand in each period into account. The task scheduling problem (TSP) was addressed by Lapègue [6], and shifts were created based on the duration of the job, but this is not the same as our issue.

Hierarchical labour scheduling issue is frequent in many industries. To be effective, workers, according to TSP Volland and Andreas, etc.[4,7,8], must possess the requisite skills. A task just required one worker in their issue, but our hierarchical staffing problem will mix employees at multiple levels. Seckiner [9] arranged a hierarchical workforce with changeable demands depending to the amount of personnel with various levels required each day. Based on [9], Oezgueven [10] made improvements to the model. In all of these models, it is assumed that a worker with a greater level of education may replace a person with a lower level of education. As a result of the hierarchical nature of nursing home staffing, the better-qualified worker may guide the less-qualified one. Besides, In our situation, the need of workers with various levels was decided by the limits of hierarchical cooperation instead of preset, which is also distinct from them.

With so many variables, the set-covering approach [11] was used to find a solution to the SDP. Afterwards, Aykin [12] adopted implicit modelling approach for SDP, which considerably enhanced the solution efficiency. Since our challenge incorporates shift design and hierarchical cooperation, a two-stage modelling technique will be utilised. The two-stage technique may represent the model more simply and plainly. Using heuristics approaches in both phases [13,14], these papers[6,13,14] both explained the application of the two-stage method in detail. Additionally, Dahmen[14] demonstrated the method's efficacy in terms of solution quality and operation time. A genetic algorithm or a hybrid algorithm, as proposed by P. Pakpoom[16], may also be used to solve the problem[2,15], as can tabu search[2,15].

This paper's challenge is characterised by high time changing, multiple shift, hierarchical and collaborative qualities. We'll focus on finding a solution to the issue presented by these qualities, and the following is an explanation of what this article is all about: Section 2 presents and examines the challenge of multi-shift design and multi-level staff scheduling. In Section 3, a two-stage model will be constructed, and the issue will be solved using a genetic algorithm and heuristics. The sensitivity analysis approach is used in Section 4 to get some managerial insight with realistic guiding importance, and Section 5 concludes the paper and suggests future research directions.

II. PROBLEM DESCRIPTION

A. *Global Structure*

Due to the nature of nursing labour, nursing facilities are in a difficult condition to attract staff, which further affects the scarcity of nursing finances. Despite the importance of these issues, no comprehensive solution has yet been established. This article will provide an innovative approach to resolving these issues.

Firstly, as the nursing labor has the characteristics of high time-varying and various shifts, it is required to plan suitable shifts. Secondly, it also has the characteristics of hierarchical and collaborative, so the collocation of workers at various levels should be addressed. On this premise, the article will employ a two-stage technique. The first step is to create shifts that are highly time-variable, and then use a genetic algorithm to calculate the time schedules for each shift and the number of nurses required for each shift. When determining final staffing numbers, the restrictions of hierarchical cooperation are applied to the constraints of shift arrangements that have been established in the first step.

B. *Assumptions*

Some assumptions are offered for our situation, and the specifics are as follows:

1. The shift may only start and finish within the given period, and the shifts are separated into several categories according to the start time, such as morning shift, day shift, afternoon shift and night shift.

2. The length of each shift must be within 4h-8h.

3. Each day, a single employee is limited to working one shift.

4. Multiple shifts need to be booked each day and multi shifts are permitted to span the same time period.

5. The demand of each time period within 24 hours a day may be different, but the demands of each period must be addressed.

III. APPLICATION OF TWO-STAGE METHOD

A. *Parameter Definition*

We have the following definitions for our problems:

1. First, let's set the start time of each shift to t=0, 1, 2, 3,..., 23. 2. The shift may only start within the provided time, e.g., if the value of t is 0, the start time of the shift is 0 o 'clock in the evening. In addition, we use h to denote the shift's length, which ranges from 4 to 8.

2. S symbolises shift, and Sth stands for the shift which is begun at time t and has a duration of h, Sth contains all conceivable combinations of shifts.

3. We use k to denote distinct shift kinds. When k is 1, 2, 3 and 4, it represents morning shift, day shift, afternoon shift and night shift accordingly, and dk denotes the total number of shift type corresponding to k.

4. A 24-hour period was denoted by I I = 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31..., 23. The total number of people needed in time I is represented by bi, and bi must be an integer.

5. m denotes the rank of each employee, m=1,2,3. When m is 1, it signifies senior staff. When m takes 2 and 3, it denotes intermediate and junior workers accordingly.

6. W indicates the total number of workers in the shift with a start time of t and a duration of h, whereas Wmth represents the total number of employees in the level m and the shift with a start time of t and h, respectively.

7. n stands for the matching ratio of senior and junior workers, e.g., when n is 3, it signifies that a senior employee may manage 3 junior employees at maximum.

8. The cost of an employee with a level of m is represented by Cm, whereas the cost of an employee with a level of m and a working length of h is represented by Cmh.

B. *First Stage: shift design*

The two-stage technique is used to this issue. In the first stage, the major goal is design the shifts, and constraints connected to shift need to be addressed, and the model may be constructed as follows:

$$\min \sum_{t,h} C_h W_{th} S_{th}$$
$$\sum_{t,h} S_{th} W_{th} \geq b_i \quad (i = 0,1,\ldots,23) \qquad (1)$$
$$S_{th} = \begin{cases} 1 & \text{when the shift } S_{th} \text{ includes the time period } i \\ 0 & \text{otherwise} \end{cases}$$

$$\sum_{th \in k} S_{th} \leq d_k (\forall k) \qquad (2)$$
$$d_k, W_{th}, b_i \geq 0 \text{ and all integer}$$

The goal of the first stage's integer programming model (IP1) is to reduce the overall cost of human resources. In this level, there is no hierarchy of workers, and the cost is merely connected to the shift length. (1) Requires that shift staffing be tailored to the specific needs of each time period. (2) Indicates that the total number of shift type corresponding to k cannot exceed dk.

C. *Algorithms*

Shift design begins with determining the start and end times of each shift, as well as how many employees will be working each shift. We utilize genetic algorithm to produce a matrix comprised of the start time and working hours of the shift, and each value in the matrix reflects the number of employees in the associated shift. In the iteration, first of all, we will produce random possible solutions and identify some better solutions, and then we randomly swap one component of the two feasible solutions; ultimately, we're going to choose a random value in the matrix that's not zero and make it zero. We will determine the value that differs the most from the demand for each time period after the exchange and replace the matrix element with the difference value if the demand for that time period cannot be supplied after the modification. To get at the best result, this process is performed several times.

In the second step, we analyze the restrictions of hierarchical personnel cooperation. For this scenario, we utilize certain guidelines to solve the issue. For example, the lower-cost collocation technique and the shift with the longer working hours should be prioritized when completing the requirements of each period.

For the issues in the two separate phases, we apply genetic algorithm and heuristic to answer them accordingly, then iterate between the two stages to increase the quality of the solutions.

IV. EXPERIMENT RESULTS

A. *Parameter Setting*

For the issues in this study, we specified certain parameters:

1. If the cost of one hour for an employee is 10, the cost of a worker with four hours (C4) is 40, and so on, the cost of worker with eight hours (C8) is 80.

2. We cannot have more than three people working in each shift type (morning/day/evening/night), which means dk = 3 in all cases. As you can see in Table 1, the particular timetable for each sort of shift is provided.

3. The cost of a senior employee is 100, an intermediate worker is 70 and a junior worker is 50, and the overall cost of an employee (Cmh) is equal to the cost of the shift length plus the cost of the employee level.

4. At maximum, a senior worker may oversee three juniors, therefore n is equal to three.

5. Each period's demand fluctuation (bi) circumstances are distinct.

TABLE I. EACH SHIFT TYPE'S TIME SCHEDULE

Shift type	Min-start	Max-start	Min-length	Max-length
Morning shift	04:00	06:00	02:00	06:00
Day shift	07:00	09:00	02:00	06:00
Afternoon shift	10:00	14:00	02:00	06:00
Night shift	20:00	00:00	02:00	06:00

The sensory information received by brain networks is likely to be temporally linked. To better understand how inputs influence the dynamics of the network and the encoding of memories in the brain, we use numerical simulations and mean-field analysis to investigate temporally asymmetric Hebbian learning rules in a recurrent network of rate-based neurons. We demonstrate that the network dynamics rely on the temporal correlations in the input stream the network receives. For inputs with short correlation timescale, the network displays sequential activity (Fig. 1 A left), whereas for longer correlations within the stream of input, the network settles into a fixed point attractor during retrieval (Fig. 1A right) (Fig. 1A right). An attractor state is reached when the network has completed a partial traversal of the input sequence at an intermediate value of correlations (Fig. 1 A middle). Correlations boost the network's capacity for sequential memory, according to our findings. The range of timescales of correlation for which networks represent memories as sequential activity in the network is expanded by non-linear learning rules (Fig. 1 B). Both in the succession of discrete patterns and in the continuum limit, we demonstrate that the network preserve a sequential representation (Fig. 1 C). Our result therefore implies that the correlation time scales of inputs at the time of learning have a considerable effect on the form of network dynamics during retrieval.

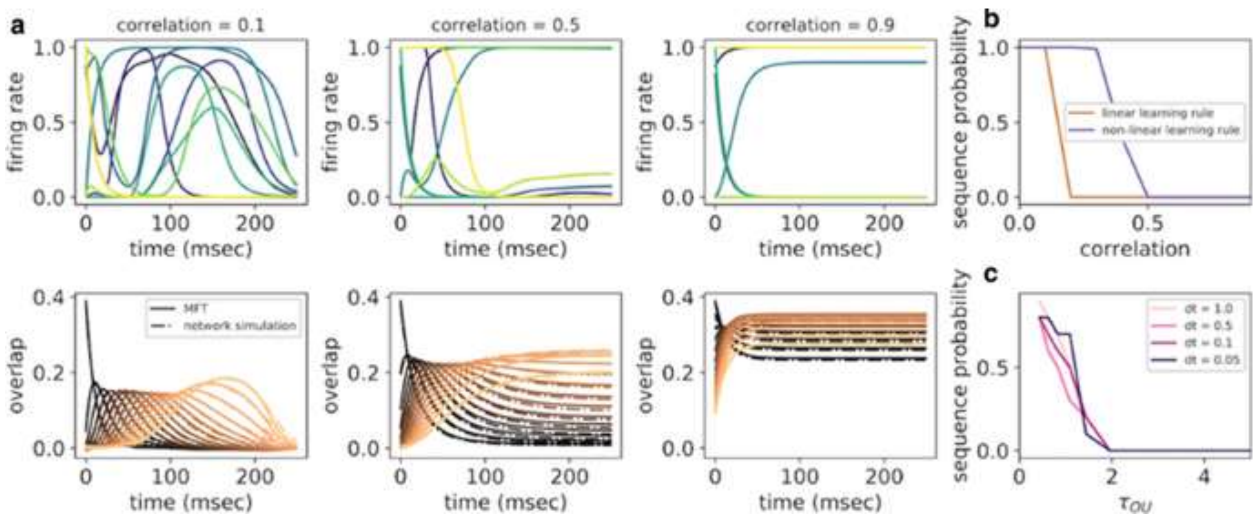

Figure 1. A Interactions between neuronal activity (top) and stored patterns from simulations and mean-field theory (bottom) (L to R). A linear and non-linear learning algorithm for retrieving sequences as functions of correlation B and tau OU, for alternative discretizations of a continuous OU process C

1) When the peak number of demand curve is calculated, the total number of people required for the ideal shift design schemes steadily grow as the ratio of high and low peaks increase. To make matters more complicated, under the unimodal scenario, a growth in the overall population rises and falls according to shifts in demand.

2) It is not necessary to raise or reduce the overall number of workers needed for 8 hours as much as the total number of individuals required for 4h-7h in the best shift design scheme as the ratio of high and low peaks grows progressively. 2.

3) When demand fluctuates more dramatically, fewer personnel are required for the ideal shift design scheme with an 8-hour shift duration for each of three distinct peak instances, in the same ratio of high and low peak demand.

4) According to the foregoing findings, it can be shown that when the demand varies in each period, the optimum shift design scheme and the overall cost are changed to a considerable amount, and the experiment results are significantly different from the usual condition of three shifts with 8h. The overall cost and the total number of personnel needed in the ideal shift design scheme would grow gradually with the increase of the ratio of high peak and low peak, although the increase is not linear. In addition, the demand scenario which has more peaks demands higher expense. In addition, the ideal solution requires fewer personnel with 8-hour shifts and lower overall costs when demand varies more sharply, and fluctuation circumstances have a greater influence when there are fewer peaks.

V. CONCLUSION

This research primarily covers the issues experienced by nursing homes owing to the features of nursing job, and a two-stage modelling technique was established based on these characteristics. Genetic algorithm and rules are respectively employed to tackle the issue of shift design in the first stage and the problem of hierarchical cooperation in the second stage. This article studied the issue from the following aspects: the number of peaks, the ratio of the number of persons in high and low peaks, and the variation of demand. Overall cost and best shift design are both impacted by variations in demand, and the experiment's findings vary significantly from the conventional model of three 8-hour shifts. Summarizing, this work proposes an effective approach to address issues in nursing homes, conducts a number of case studies, and draws conclusions from those studies, all of which have some relevance in solving real-world issues. However, further research into these issues is needed.

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