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Automating Nurse Self-Rostering: A Multiagent Systems Model

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Abstract—**This paper presents a multiagent systems model for constructing nurse rosters. Over the past decade self-rostering has become more favorable in nursing personnel scheduling, due to its empowerment and motivational benefits. However, the labor intensive negotiation procedure among participants has limited its application to medium sized and large wards. To overcome this limitation, we propose an automated negotiation tool utilizing economic-based negotiation mechanisms. We model the environment as a multiagent system. Nurses can indicate their preferences by configuring the preference profiles of the Nurse Agents, and the Nurse Agents collectively construct rosters through the negotiation with the management agents and among themselves. To support the design and implementation of automated self-rostering systems, we present a multiagent systems architecture, a structure of preference information, and a negotiation mechanism.**

I. INTRODUCTION

Nurse scheduling is a decision making process which assigns a work pattern to nurses in the form of a duty roster, while satisfying legal and policy constraints, and simultaneously attempting to accommodate individual preferences. Unlike many other service industries where standard shifts and days off are the rule, hospitals operate 24 hours a day, 7 days a week and face widely fluctuating demand. In addition to the demanding everyday workload, many nursing tasks are mundane and unrewarding[1]. In light of the growing nursing shortage, to help reduce occupational stress and to improve retention, management must now take into account individual preferences and requests for work pattern and days off and to provide more flexible arrangement in nurse rostering.

They are three commonly used methods in nurse rostering, namely departmental rostering, team rostering, and self-rostering [2]. Departmental rostering is a centralized scheduling approach, which is conducted by a single manager who can be the charge nurse, a staff nurse or an administrative staff. Team rostering is a mediated scheduling approach, where nurses are divided into teams and a nominated member of each team has the responsibility for rostering, in consultation with team members. Alternatively, self-rostering is constructed in a decentralized way through the negotiation among nurses. For a specific planning horizon, the management first determines the number of nurses required for each period, nurses are asked to sign up for any shifts that they want to work. To avoid an over-supply in any given period, an upper limit is placed on the number permitted to sign up in each block of time. When conflicts occur, further adjustments are made through negotiation among affected nurses.

From the perspective of catering individual preferences self-rostering has been instrumental because nurses have direct inputs in the roster generating process. Self-rostering is also advocated in health management literature due to its empowerment and motivational benefits [3-5]. Although the approach is appealing, because of the administrative burden in organizing the negotiation process among nurses, it is quite difficult to implement in medium sized and large wards. For example, in a large ward, it is a very labor intensive procedure in which the nurses indicate their preferences and negotiate to reach a common schedule. Another difficulty is conflict solving. In many cases, resolving a preference conflict in self-rostering involves multilateral negotiation and there could be many inter-related conflicts within the process of generating one roster. Even there are formal negotiation protocols in place, the complexity and cost of implementing them could be a daunting task. Moreover, the results may not necessarily be perceived as fair. Those who are savvy enough to game the system will always have an advantage over the procrastinators[6].

The purpose of this paper is to develop an automated negotiation framework aiming at overcoming the implementation complexities arising in self-rostering. To this end, we propose a multiagent systems model for automating the negotiation process among nurses. We focus on three important aspects of the model, namely system architecture, structure of preference information, and negotiation mechanisms. The rest of the paper is organized as follows: Section 2 review typical nurse scheduling literature which considers individual preferences. Sections 3 presents the multi-agent systems model for automating self-rostering process, which includes a multi-agent-systems architecture, a structure of preference information, and an automated negotiation mechanism. Section 4 concludes the paper and discusses future research directions.

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II. PREFERENCE SCHEDULING

Nursing personnel scheduling has been an active research topic in operations research and industrial engineering literature [7-9]. Many proposed approaches can be seen as a combination of departmental rostering and self-rostering. This type of approaches, such as those in [10-13], are known as preference scheduling [6]. The general idea is to take individual preferences into consideration when generating schedules. The primary goal is to provide the nursing staff with high-quality schedules subject to demand requirements and cost considerations.

In preference scheduling, many individual preferences, such as requests to work specific shifts or to be given specific days off, the exclusion of undesirable work patterns, and the number of working hours can be modeled. Nurses are asked to submit their preferences to the management prior to the beginning of the planning horizon. Critical to the success of the procedure is the idea of fairness of the resultant schedules. If some nurses feel that their preferences and requests are continually being ignored the approach is likely to fail. To avoid this situation, the model must be driven to select schedules that are in balance, i.e., have about the same number and severity of preference violations per nurse across the board[6]. From purely operational research perspective, this is achievable through carefully designed preference scheduling algorithms and rules if nurses submit the severity level for each of their preferences. However, preference scheduling approach does not prevent nurses from manipulating (gaming) the system. A nurse may not choose to truthfully report the severity of his/her preferences if he/she will benefit from doing it. In preference scheduling, the quality of a schedule is highly dependent on the truthfulness of the severity levels reported by nurses. If nurses try to exploit the system to their advantage, that is, they speculate and don't report severity levels truthfully, the final schedule computed by the preference scheduling algorithm can be arbitrarily far from the optimal solution. The challenge in this setting is how to design scheduling mechanisms that provide incentive which motivates nurses to report severity levels of preferences truthfully.

In economics, incentive is defined as a motivational force that stimulates economic agents to greater activity or increased efficiency. Mechanism design is the economic theory dealing with incentive by stimulating agents from inside under the assumption that agents are rational. To deal with incentive issue in the self-rostering automation problem, we design an auction-based automated negotiation system which can be seen as an application of the mechanism design theory. The rest of the paper briefly describes how this auction-based automated negotiation system is designed in the context of self-rostering using a multi-agent systems model.

III. MULTIAGENT SYSTEMS MODEL

We consider agent-based automated negotiation as an approach to improve the applicability of self-rostering to medium sized and large wards. In this paper we propose a multi-agent systems model concerning three aspects of the automated negotiation system, namely system architecture, structure of preference information, and negotiation mechanisms.

A. Multiagent Systems Architecture

As shown in Fig. 1, the system consists of five types of agents: Nurse Agent, Agency Manager, Director Facilitator, Scheduler, and Ward Manager. These agents work collaboratively to achieve the overall rostering task. The functionalities of the agents are briefly described as following:

Nurse Agent A Nurse Agent acts as a personal scheduling assistant of the nurse it represents. A Nurse Agent can represent both full-time nurses managed and paid directly by a hospital and a part-time nurse managed by an external nursing agency. Nurses indicate their individual preferences to their agents by updating the agents' scheduling preference profiles. A Nurse Agent is aware of the nurse's availability for a certain period of time. It maintains an up-to-date work schedule of this nurse, which has already been committed. It can automatically negotiate the work shifts allocations with Scheduler, Ward Manager, and other Nurse agents. If they like, nurses are able to involve into the negotiation process through a user interface.

Ward Manager A Ward Manager is an agent that is used to represent the management and coordination role in a ward. The main responsibility of a Ward Manager is to update service requirements and rules to the Scheduler such that they are satisfied by the final schedule. In cases that a feasible schedule cannot be achieved, Ward Manager needs to relax some requirements based on service policy and the unfeasibility feedback provided by the Scheduler.

Agency Manager An Agency Manager is an agent that is used to represent the management and coordination role in an external nursing agency. The main responsibility of an Agency Manager is to update contractual bounds of part-time nurses to the Scheduler such that those requirements are respected by the Scheduler.

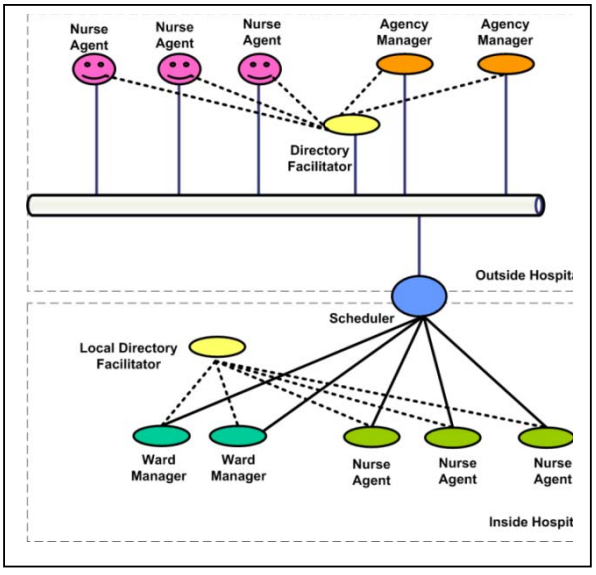

Figure 1. Multiagent Systems Architecture for Self-Rostering Automation

Scheduler The Scheduler is an agent that is used to coordinate the negotiation process among participants including nurses and managers. The Scheduler can be equipped with multiple negotiation protocols. It handles nurse rostering across multiple wards in the hospital. Both managers and nurses interact with Scheduler during negotiation processes.

Directory Facilitator A Directory Facilitator is an agent which provides registration and lookup services for other agents. All Nurse Agents and Managers need to register with a Directory Facilitator when they enter the system.

B. Structure of Preference Information

During a negotiation process, agents communicate through sending messages. In the context of automated self-rostering, A Nurse Agent needs to send the nurse's skill profile and preference profile to the Scheduler. Nursing skills are typically divided into at least four different categories: registered nurses (RN), licensed practical nurses (LPN), nurse aides, and technical nurses. Registered nurses are the most versatile and generally preferred because they can provide the widest range of care. LPNs are less flexible, while nurse aids have only limited training and skills. A technical nurse is usually needed to operate certain medical instruments specific to a unit, such as cardiology. For purposes of matching skills with requirements, those information needs to be presented to the Scheduler. In addition, nurses may want some specific days off or prefer a specific work pattern. This preference information needs also be communicated to the Scheduler. A Nurse Agent can also associate each preference requirement with preference points to indicate how much it weights the preference. We represent a nurse's skill and preference profiles information using the structure of Abstract Syntax Notation as follows:

```
PREFERENCE-BID    DEFINITIONS ::= BEGIN
Bid ::= SEQUENCE{
record                  PersonnelRecord
preference      Preference }
PersonnelRecord ::= SET {
name            Name
    category            Category
    number              EmployeeNumber
    fullTime            BOOLEAN
    restrictions        ContractualRestrictions }
Name ::= SEQUENCE {
    givenName           VisibleString
    initial             VisibleString
    familyName          VisibleString
Category::= CHOICE {
    registered          RegisteredNurse
    licensed            LicensedPracticalNurse
    aid                 NurseAid
    technicalTechnicalNurse }
EmployeeNumber ::= INTEGER
ContractualRestrictions ::=SET { data ANY}
Preference ::= SET {
    dayOffs             PreferredDayOffs
    wards               PreferredWards
pattern                 WorkPattern }
PreferredDayOffs ::= SET OF {
    dayOffBbid          DayOffBid }
PreferredWards ::= SET OF {
    wardBid             WardBid }
DayOffBid ::= SEQUENCE {
    date                Date
    shift               Shift
    points              PreferencePoints }
WardBid ::= SEQUENCE {
    wardName            VisibleString
points                  PreferencePoints}
Shift ::= CHOICE {
    earlier             VisibleString
    late                VisibleString
    night               VisibleString }
END
```

C. Automated Negotiation

In the multiagent systems model, the negotiation mechanisms adopted between agents are economically inspired negotiation protocols, such as Contract Nets and various forms of auctions. Agents exchange information in the framework of these protocols. This section presents an iterative bidding protocol as the negotiation mechanism for automated self-rostering.

1) Bidding

Each Nurse Agent has a valuation function which is a mapping from the set of preferences to a range of amount of preference points. Here, preference points are used as a monetary measure expressing how much the agent is willing to pay for a preference to be satisfied. We assume that a Nurse Agent has been assigned a certain amount of preference points before it participates the bidding. The amount assigned could be based on the nurse's seniority and other factors at the discretion of the management. The goal is to align the distribution of preference points with the contribution that a nurse has to the service objectives. Before the auction starts, an agent calculates the value for each of its preferences in terms of preference points. It then constructs its bid using the

PREFERENCE-BID structure. At the first round of bidding, the agent may bid with a preference points lower than its value on a preference. If the preference is not awarded by the Scheduler, the agent may consider gradually increasing its preference points up to its value in future bidding rounds. At round t, if each of an agent's preferences is either awarded or the bidding preference points associated to the reference is equal to the preference's value, the agent will repeat its current bid in round t+1. Otherwise, the agent will increase its preference points for unawarded preferences.

2) Winner Determination

After receiving bids from agents, the auctioneer (Scheduler) solves the winner determination problem, computing a schedule that maximizes the sum of preference points from all awarded preferences, and at the same time, satisfies the service requirements imposed by the management. The computed schedule is sent back to agents, so an agent knows which of its preferences have not been awarded and it can increase preference points on those preferences in the next round. To speed up the bidding process, the Scheduler can impose a minimal preference points increment ε on the bidding agents. In this case, if the preference points increment for an unawarded preference is smaller than ε, that preference will be ignored. In our setting, the winner determination problems are represented using the structure of PREFERENCE-BIDs. Therefore, the winner determination algorithms need to be designed to accommodate this structure. Specially designed auction-based scheduling algorithms, such as that in [14], normally achieve higher efficiency.

3) Termination

The auction terminates when all agents submit the same bids in two consecutive rounds.

IV. Conclusion and Future Directions

Self-rostering has been advocated by both academia and practitioners due to its empowerment and motivational benefits brought by allowing direct preference inputs from nurses. However, its application to medium sized and large wards has been limited by the implementation complexities, such as time consuming negotiation among nurses, lacking of formal conflict solving procedures and fairness in rosters. To overcome these limitations, we have proposed to use an agent-based scheduling system to facilitate the negotiation process among nurses and to provide a mechanism for conflict solving. The core of the approach is the iterative auction designed for automating the rostering negotiation process among Nurse Agents. To support the implementation of the automated negotiation mechanism, we also presented a multi-agent systems architecture, and the structure of preference information based on which the nurses' preferences are represented. We have also introduced a concept: preference points which is used to quantify nurses' value on each preferences. As a contribution of this paper, we model the self-rostering problem in an economic context. In addition to the modeling and algorithmic issues, which have been studied in the operations research literature, we are trying to address incentive issues by applying mechanism design theory to the domain of nurse scheduling.

This is the first step towards the design and implementation of a practical decentralized self-rostering system. As for future directions, we need to develop an ontology which captures a wide variety of scheduling preferences from nurses as well as from the management. We also plan to design other negotiation mechanisms to be used in various self-rostering environments.

References

[1] P. Hingley, "The humane face of nursing," Nursing mirror, vol. 159, p. 19, 1984.

[2] R. Silvestro and C. Silvestro, "An evaluation of nurse rostering practices in the National Health Service," Journal of Advanced Nursing, vol. 32, pp. 525-535, 2000.

[3] M. L. Miller and M. S. Bsn, "Implmenting Self-Scheduling," JONA: The Journal of Nursing Administration, vol. 14, p. 33, 1984.

[4] K. K. Ringl and L. Dotson, "Self-scheduling for professional nurses," Nursing management, vol. 20, p. 42, 1989.

[5] H. Griesmer, "Self-scheduling turned us into a winning team," Management Decisions, vol. 56, pp. 21-23, 1993.

[6] J. F. Bard and H. W. Purnomo, "Preference scheduling for nurses using column generation," European Journal of Operational Research, vol. 164, pp. 510-534, 2005.

[7] E. K. Burke, P. De Causmaecker, G. V. Berghe, and H. Van Landeghem, "The State of the Art of Nurse Rostering," Journal of Scheduling, vol. 7, pp. 441-499, 2004.

[8] B. Cheang, H. Li, A. Lim, and B. Rodrigues, "Nurse rostering problems––a bibliographic survey," European Journal of Operational Research, vol. 151, pp. 447-460, 2003.

[9] A. T. Ernst, H. Jiang, M. Krishnamoorthy, and D. Sier, "Staff scheduling and rostering: A review of applications, methods and models," European Journal of Operational Research, vol. 153, pp. 3-27, 2004.

[10] D. M. Warner, "Scheduling nursing personnel according to nursing preference: A mathematical programming approach," Operations Research, pp. 842-856, 1976.

[11] B. Jaumard, F. Semet, and T. Vovor, "A generalized linear programming model for nurse scheduling," European Journal of Operational Research, vol. 107, pp. 1-18, 1998.

[12] H. E. Miller, W. P. Pierskalla, and G. J. Rath, "Nurse scheduling using mathematical programming," Operations Research, pp. 857-870, 1976.

[13] K. A. Dowsland, "Nurse scheduling with tabu search and strategic oscillation," European Journal of Operational Research, vol. 106, pp. 393-407, 1998.

[14] C. Wang, H. H. Ghenniwa, and W. Shen, "Constraint-Based Winner Determination for Auction-Based Scheduling," IEEE Transactions on Systems Man and Cybernetics Part A Systems and Humans, in press, 2008.