

A Branch-and-Price Procedure for Nurse Staffing Incorporating Roster Preferences

Broos Maenhout

Ghent University, Hoveniersberg 24, B-9000 Gent, Belgium, Broos.Maenhout@Ugent.be

Mario Vanhoucke

Ghent University, Hoveniersberg 24, B-9000 Gent, Belgium, Mario.Vanhoucke@Ugent.be

Vlerick Leuven Gent Management School, Reep 1, B-9000 Gent, Belgium, Mario.Vanhoucke@Vlerick.be

1. Introduction

Managing, recruiting, keeping the right staff, and deploying resources efficiently are key challenges for the healthcare industry in the coming decennia due to the increasing elder population and the corresponding increasing demand for care and caring personnel ([16]). Since the quality of care ultimately depends on the quality and motivation of health human resources, personnel problems should be appropriately addressed since staff shortages or unmotivated health workforce are likely to have adverse effects on the delivery of health services and outcome of care. A key factor is the organizational support to employees which is especially revealed in the personnel staffing policies and scheduling practices conducted by the health organizations. On the one hand, it is of critical importance to deploy efficiently the available personnel since this is a large determinant of service organization efficiency and customers' requirements satisfaction in providing the continuity of care. On the other hand, [7] identify unattractive schedules and high workloads as two important factors leading to discontentment and a high nursing turnover.

In order to optimize the organizational support to the largest extent, we integrate the staffing and scheduling phase of the nurse workforce management process ([1], [3], [13], and [14]). The staffing phase contains a strategic budgeting decision which boils down to determining the number of nurse labour hours required of each nursing skill class to meet the forecasted patient demand. Based on these authorized budgets for full-time equivalent nursing personnel and the allowable usage of supplemental staffing resources, the number of permanent nursing positions of each type (both full- and part-time) is established within budgetary constraints. The scheduling phase focuses on the assignment of nurses to work days and/or daily work shifts across a typical planning horizon of 1 to 8 weeks for each nursing unit in order to satisfy the minimal coverage requirements while meeting legal, union, hospital and personal constraints imposed on the nurses' individual schedules. An overview of the extensive literature on personnel scheduling can be found back in [4] and [10]. Personnel scheduling solution procedures are already applied to real-world problems (e.g., in [5]). Despite the wide impact of the staffing decisions on the alternatives in the scheduling phase, these two phases have been mainly investigated separately in the literature. Little research has been carried out that integrate staffing and scheduling decisions (e.g., [9], [13], and [15]).

2. Problem description

In hospitals nurses are typically assigned to a ward. This assignment is done rather arbitrarily by the department head based on the nurse's competencies and the nurse's ward preference. Next to being assigned to a specific ward, nurses can be assigned to float between different wards which is nowadays one of the most common staffing strategies ([11]). Advantages and disadvantages of this staffing policy are provided in the literature survey of [8]. The use of a float pool is typically a cost-saving and efficient staffing strategy which diminishes inadequate staffing levels, eliminates unneeded manpower and reduces the number of budgeted hours, overtime hours and/or the need for reliance on costly agency or per diem staff. However, this strategy is generally recognized as to be at the expense of the nurse (dissatisfaction, stress, poor group dynamics, etc) and the patient's

quality of care (i.e., floating staff needs to be competent and familiar with the patient care practices). Evidently, the health organization needs to offer something in exchange for this flexibility to compromise and motivate nurses to guarantee the provided quality of care. Typically, nurses need to be (socially) satisfied by catering for their individual roster preferences as much as possible. In this respect, the interaction between the staffing and the scheduling phase becomes interesting. Modelling, quantifying and parametrizing these considerations, nurses are assigned to one of the wards or to the float pool and rostered with a certain degree of nurse- and/or period-specificity. In this way, an ideal and well-balanced mix of employees is determined not only in terms of skills and employment but also in terms of roster preferences.

3. Solution Procedure

The formulation of this integrated problem based on the original assignment variables (i.e., a nurse is assigned to a certain shift, on a particular day, and to a department) has been decomposed based on the Dantzig-Wolfe decomposition. The problem is solved using an exact branch-and-price approach which simultaneously assigns the nurses to a particular department or to the float unit and constructs a roster over the planning horizon for each nurse. Branch-and-price relies on column generation to find the linear programming relaxation of the master problem. In order to check the optimality of an LP solution, a subproblem, called the pricing problem, is solved to try to identify columns (i.e., individual roster lines) to enter the basis. If such columns are found the LP is re-optimized. Branching occurs when no columns price out to enter the basis and the LP solution does not satisfy the integrality conditions ([2], [12]). Branching is done on the original assignment variables and not on the column variables.

The master problem formulation aims to optimize not only the hospital's objectives (i.e., the quality of care) but also the nurses' objectives. Moreover, the master problem ensures each nurse receives a roster and indicates the best option in case of personnel shortages (e.g., extra personnel, interim personnel, and overtime hours). A small modification in the formulation of the master problem, i.e., each nurse is assigned to at most one schedule, allows us to address nurse recruitment problems using the proposed approach.

The pricing step consists of generating an individual roster line for each nurse for each department (i.e., the involved ward and the float unit) incorporating the dual prices of the coverage requirements of the corresponding department. The pricing problem is a resource constrained shortest path problem which is typically solved using a dynamic programming approach ([6]). This shift assignment needs to be in conformity with all (hard) case-specific time related constraints (e.g., roster rules imposed by law) satisfying the nurses' preferences and contract stipulations and the (soft) regulations as much as possible. Moreover, since the scheduling practices and policies are typically different from ward to ward, this pricing problem is different for each unit. Moreover, this subproblem will even differ from employee to employee since the specific nurse preferences, contract stipulations, work regulations, skill competencies, etc vary largely among the nursing staff. When constructing an individual nurse schedule for a specific ward (and not the float unit), nurses cannot be assigned to shifts of another ward. This practice is only exercised in case of unanticipated variation (e.g., sickness) and is dealt with in the short-term adjustment phase ([1]).

4. Computational results

We test and validate our algorithm on a real-life situation in a Belgian university hospital. Three wards and one float unit are involved in the study. Based on a questionnaire, we reveal the characteristics of the nursing personnel (e.g., preferences, competencies) and the practices and policies of the head nurse. Based on this information gathering, different theoretical and practical insights are obtained on how to increase quality of care and preference satisfaction in case of recruitment of new personnel, re-organization of the existing structure and/or revision of the staffing process of the concerned wards.

References

- [1] W.J. Abernathy, N. Baloff, and J.C. Hershey (1971), The Nurse Staffing Problem: Issues and Prospects, *Sloan Management Review* **12**, 87–99.
- [2] C. Barnhart, E.L. Johnson, G.L. Nemhauser, M.W. Savelsbergh, and P.H. Vance (1998), Branch-and-Price: Column Generation for solving huge Integer Programs, *Operations Research* **46**, 316–329.
- [3] M.J. Brusco, and M.J. Showalter (1993), Constrained Nurse Staffing Analysis, *Omega* **21**, 175–186.
- [4] E.K. Burke, P. De Causmaecker, G. Vanden Berghe, and H. Van Landeghem (2004), The state of the art of nurse rostering, *Journal of Scheduling* **7**, 441–499.
- [5] E.K. Burke, P. De Causmaecker, and G. Vanden Berghe (2004), Novel Meta-heuristic Approaches to Nurse Rostering Problems in Belgian Hospitals, In: Leung, J., (ed.), *Handbook of Scheduling: Algorithms, Models and Performance Analysis*, CRC Press, 2004, 44.1–44.18.
- [6] A. Caprara, M. Monaci, and P. Toth (2003), Models and algorithms for a staff scheduling problem, *Mathematical Programming* **98**, 445–476.
- [7] D. Cline, C. Reilly, and J.F. Moore (2003), What’s behind RN turnover?, *Nursing Management* **34**, 50–53.
- [8] J. Dzubia-Ellis (2006), Float Pools and Resource Teams: A Review of Literature, *Journal of Nursing Care Quality* **21**, 352–359.
- [9] F.F. Easton, F. F., D. F. Rossin, and W. S. Borders (1992), Analysis of alternative scheduling policies for hospital nurses, *Production and Operations Management* **1**, 159–174.
- [10] A.T. Ernst, H. Jiang, M. Krishamoorthy, B. Owens, and D. Sier (2004), Staff scheduling and rostering: A review of applications, methods and models, *European Journal of Operational Research* **153**, 3–27.
- [11] W.M., Mercer, (2000), *Attracting and Retaining Registered Nurses – Survey Results*, Chicago IL, 1–8.
- [12] F. Vanderbeck (2000), On Dantzig-Wolfe Decomposition in Integer Programming and Ways to Perform Branching in a Branch-and-Price Algorithm, *Operations Research* **48**, 111–128.
- [13] R. Venkataraman and M.J. Brusco (1996), An Integrated Analysis of Nurse Staffing and Scheduling Policies, *Omega* **24**, 57–71.
- [14] H.W. Warner (1976), Scheduling Nursing Personnel According to Nursing Preference: A Mathematical Approach, *Operations Research* **24**, 842–856.
- [15] P.D. Wright, K.M. Bretthauer, and M.J. Côté (2006), Reexamining the Nurse Scheduling Problem: Staffing Ratios and Nursing Shortages, *Decision Sciences* **37**, 39–70.
- [16] P. Zurn, C. Dolea, and B. Stilwell (2005), Nurse retention and recruitment: developing a motivated workforce, *The global nursing review initiative (WHO)* **4**, 1–31.