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A two-stage method to determine the allocation and scheduling of medical staff in uncertain environments

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ABSTRACT

Medical staff scheduling problems have received much attention from researchers. This research studies an integrated medical staff allocation and staff scheduling problem in uncertain environments. In order to solve the integrated problem, this research develops a two-stage algorithm based on goal programming to determine the smallest possible medical staff required and to create the best schedule for them. In the first stage, this study adopts a worst-case scenario approach to determine the minimum required medical staff. In the second stage, this study constructs hard and soft constraints for a monthly medical staff schedule and applies the analytic hierarchy process (AHP) to determine the penalty of soft constraints. By reducing the number of medical staff, this research determines the appropriate staff size based on the objective function of the constructed model. This research uses a medical image center and its radiological technologists as a case study. The results demonstrate that the proposed method can produce the appropriate number of radiological technologists based on different monthly workloads and can generate the least undesirable radiological technologist schedule. Hence, staff managers will have the ability and flexibility to assign different medical staff to each team/department for each scheduling planning period in order to overcome the uncertainty of both patient issues and medical staff issues.

1. Introduction

Due to the increase in medical demand and shortage of medical staff, the workload of medical staff has become heavier (Wright & Bretthauer, 2010); consequently, medical staff frequently work overtime (Campbell, 2012). This heavy workload and the longer workday have been the two main reasons for attrition among medical staff, especially nurses (Wright & Bretthauer, 2010). Emergency room staff are under great pressure because an emergency room requires medical professionals for three 8-h shifts a day, seven days a week, 365 days a year. Overwork can lead to malpractice lawsuits and high turnover (Jaber, Givi, & Neumann, 2013; Rogers, Hwang, Scott, Aiken, & Dinges, 2004). Wright and Bretthauer (2010) predicted that by 2020 there will be a 36% shortage of nurses in the American healthcare sector. Therefore, the importance of allocating medical staff appropriately is a critical issue for hospitals.

Allocating medical staff involves three issues (Abernathy, Baloff, Hershey, & Wandel, 1973): hospital policy, staff allocation, and scheduling. First, hospital managers should decide which departments (e.g., outpatient, inpatient, or emergency room) are to be included in the schedule. Second, hospital managers should determine how many medical staff members are to be assigned to each department (Defraeye & Van Nieuwenhuyse, 2016; Hernandez et al., 2015). Third, hospital managers should determine which medical staff member is going to work which shift(s). This is a staff scheduling issue (Defraeye & Van Nieuwenhuyse, 2016; Guo, Wu, Li, & Rong, 2014; Legrain, Bouarab, & Lahrichi, 2015; Van den Bergh, Beliën, De Bruecker, Demeulemeester, & De Boeck, 2013).

For the hospital staff policy and staff allocation issues, most hospitals make their staff assignments to each department either when creating a new department or when considering reallocations. For staff scheduling, this is usually the responsibility of a department chair or a team leader. As a schedule needs to comply with government regulations, hospital policies, and the medical staff's preferences, the schedulers need to negotiate with the staff. The scheduling staff usually schedule shifts according to their experience or the previous month's schedules. Furthermore, creating a monthly schedule takes time. As the size of the medical staff and fluctuations increase, so does the amount of time required to generate a monthly schedule. Because the department chairs or team leaders already have too much to do, they need a tool to help them design a better schedule. This is the practical motivation of this research.

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According to the literature review, most researchers have focused on either staff allocation or scheduling issues with a set number of medical staff. However, due to the uncertainty of patient issues (such as the varied number of patients and different levels of patients' severity), medical staff issues (such as cross-training, absence, or pregnancy), or operation issues (such as special requests from government projects), departments or task groups require different numbers of medical staff for certain planning periods (Tuna, Baykal, Turkmen, & Yildirim, 2015; Wang, Gupta, & Potthoff, 2009). Staff managers should forecast and determine the future staff size based on uncertainty (Tuna et al., 2015) to ensure that they have their ability and flexibility to assign extra staff to other departments/teams or request extra staff from other departments/teams, as necessary. Thus, a department chair needs to negotiate the size of the medical staff with each group leader prior to making the schedule. For example, the staff of an image center can be classified into emergency, X-ray, computed tomography, magnetic resonance imaging, ultrasound, healthcare, and special teams. These teams might have to adjust their staff size at the beginning of each month. If a team's expected workload is lower than the planned workload, the team leader may reduce the staff size at the beginning of the coming month. For instance, if there are not many appointments for ultrasounds, a radiological technologist could be transferred from the ultrasound team to the X-ray team for cross-training. Such transfers are commonplace for junior radiological technologists, who should be capable of operating multiple imaging scans when their workload is not heavy. Therefore, team leaders will need to engage in negotiations to determine staffing levels at the end of each month. In another scenario, a team's radiological technologist may sometimes be sent for special professional skills in an allied hospital for several weeks or months, temporarily decreasing the size of the team. In a third scenario, for an image center, the daily or weekly appointments fluctuate and patients' conditions vary. If such appointments (or required service capacities) are sometimes over the predetermined quota (or capacities), the director will need to decide when to allow overtime or when to add an extra radiological technologist to a certain shift in order to accommodate patients' service needs. All three of these conditions cause temporary changes in the size of the image center staff. Hence, the director of an image center must determine how large his or her staff will be before setting the schedule.

Based on the abovementioned practical motivation, the purpose of this research is to develop a method to evaluate the required staff and determine their schedule in an uncertain environment, thereby giving staff managers the flexibility to reallocate their staff to other departments or request staff from other departments in order to overcome the uncertainty of patient issues, medical staff issues, and operation issues. The research problem of this study integrates staff allocation and staff scheduling problems in an uncertain environment. A rigid academic methodology for dealing with such practical staff allocation and staff scheduling problems is lacking. This lack of methodology is the academic motivation of this research, which examines integrated staff allocation and scheduling problems. To the best of our knowledge, the studies by Maenhout and Vanhoucke (2013) and Wright and Mahar (2013) are the only two papers that have combined the staff allocation and staff scheduling issues to form an "integrated staff allocation and scheduling problem" (ISASP). This new ISASP consists of making two decisions: determining the size of the medical staff at the beginning of each period and using that information to create the schedule. The objective of this research is to design a two-stage method that combines the worst-case approach, goal programming, the analytic hierarchy process (AHP), and branch-and-bound method to resolve the ISASP. The proposed methodology will assist hospital managers in calculating the size range of the medical staff and its schedule for each period. Finally, the proposed methodology will determine the appropriate number of medical staff with the least undesirable schedule in an uncertain environment.

The rest of this article is organized as follows. Section 2 reviews the literature on medical staff scheduling problems and the AHP method. Section 3 constructs the associated mathematical models and describes their solution procedures. Section 4 uses a case study to illustrate the proposed two-stage procedures, analyzes the results of the case study, and summarizes the managerial implications. Finally, Section 5 concludes the study and suggests directions for future research.

2. Literature review

2.1. Medical staff scheduling problems

Researchers have studied medical staff scheduling problems (or nurse scheduling problems) since the 1950s. According to Ernst et al.'s (2004) research, it is difficult to construct a staff schedule that meets staff requirements. The medical staff scheduling problem is usually complicated by staff requirements and government/hospital regulations. The schedulers have to consider the number and conditions of patients; the skills, experiences, and preferences of the medical staff; government regulations; and hospital policies (Ernst, Jiang, Krishnamoorthy, & Sier, 2004). Since the medical staff scheduling problem has become an important research topic in healthcare, more research studies on the medical staff scheduling problem have been published during the past two decades. Several researchers have conducted a review or survey on the medical staff scheduling problem, including Cheang, Li, Lim, and Rodrigues (2003), Ernst et al. (2004), Rais and Viana (2011), Van den Bergh et al. (2013), and Defraeye and Van Nieuwenhuyse (2016), in order to summarize the characteristics, solution methodology, and future research trends of the medical staff scheduling problems. For example, Van den Bergh et al. (2013) surveyed 291 papers from 2004 to 2012 and categorized their solution methods as mathematical programming (including integer, linear, dynamic, and goal), constructive or improvement heuristics, simulation, constraint programming, queueing, and other.

Several recently published papers have used mathematical programming to solve staff scheduling problems. Maenhout and Vanhoucke (2013) considered the nurse staff allocation and applied the column-generation procedures. Dohn and Mason (2013) formulated a generalized staff scheduling problem as a generalized binary set partitioning problem, which contained two problems: master problem and subproblem. The master problem consisted of roster-lines of staff and needed to satisfy the demand constraints. The subproblem was to generate a feasible roster-line. Dohn and Mason (2013) applied the branch-and-price concept to a column-generation algorithm in order to solve the master problem and subproblem. Rocha, Oliveira, and Carravilla (2013) studied the cyclic staff scheduling for workers in a glass plant and in a continuous care unit. They constructed an integer programming mathematical model and applied the branch-and-bound method to search for optimal solutions. Guo et al. (2014) formulated a mixed integer programming (MIP) for a case operating room (OR) suite in order to minimize total regular and overtime cost of nurses. They adapted the branch-and-cut search to solve the proposed MIP OR problem and performed sensitivity analyses on the key parameters.

Although many researchers have studied uncertainty in terms of patient issues, medical staff issues, or operation issues, few researchers have studied uncertainty in terms of staff size when examining the medical staff scheduling problem. Wang et al.