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A multilevel integrative approach to hospital case mix and capacity planning

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ABSTRACT

Hospital case mix and capacity planning involves the decision making both on patient volumes that can be taken care of at a hospital and on resource requirements and capacity management. In this research, to advance both the hospital resource efficiency and the health care service level, a multilevel integrative approach to the planning problem is proposed on the basis of mathematical programming modeling and simulation analysis. It consists of three stages, namely the case mix planning phase, the master surgery scheduling phase and the operational performance evaluation phase. At the case mix planning phase, a hospital is assumed to choose the optimal patient mix and volume that can bring the maximum overall financial contribution under the given resource capacity. Then, in order to improve the patient service level potentially, the total expected bed shortage due to the variable length of stay of patients is minimized through reallocating the bed capacity and building balanced master surgery schedules at the master surgery scheduling phase. After that, the performance evaluation is carried out at the operational stage through simulation analysis, and a few effective operational policies are suggested and analyzed to enhance the trade-offs between resource efficiency and service level. The three stages are interacting and are combined in an iterative way to make sound decisions both on the patient case mix and on the resource allocation.

1. Introduction

In Belgium, the total health expenditures increase year after year and may expand potentially in the future. Actually, 15.38 billion Euro was spent in the health care sector in 2003, whereas this number was increased to 20.70 billion Euro in 2008 (RIZIV [1]). This represents an increase from 9.6% of the gross domestic product in 2003 to 10.2% in 2008 (OECD [2]). On the one hand, this increment attributes to an aging population growth combined with new and more expensive treatments, but on the other hand it is also the result of the incapability of the hospital to handle the decision making at strategic, tactical and operational levels in an integrative way, resulting in inefficiencies of the hospital operations.

Moreover, an inefficient hospital management will not only bring huge economic pressures to a hospital, but also result in the waste of precious resources and the inefficiency of the patient flow, as exemplified by long waiting lists, surgery cancellations or patient misplacements, which will directly impact the health care service level. Particularly, under the limited resource capacity in a given hospital, the inevitable variability within health systems, both from the hospital supply side (e.g., a machine breakdown, surgeons called away for emergency) and from the patient demand side (e.g., random patient arrivals, stochastic surgery durations), will undoubtedly further add to this inefficiency. Therefore, it becomes important for the health care sector to improve both the hospital resource efficiency and the health service level, and it becomes increasingly necessary for hospitals to investigate the production management problem in a systematic way.

First, in order to mitigate the increasing economic pressures, hospitals are prone to advance the financial contribution of their resources through an efficient capacity allocation and management. Naturally, it is expected that the available resource capacity may match the stochastic patient demand as perfectly as possible and the utilizations of multifold resources (i.e., hospital beds, operating rooms (ORs), nursing staff, etc.) may be coordinated as best as possible. Nevertheless, due to the scarcity of resources and the variability (e.g., the random patient arrivals, the variable length of stays (LOSs), etc.) within the patient flow, the capacity management problem seems to be quite complicated. But it is fortunate that, as pointed out by Carter [3], these complex problems within health care systems could benefit from operational research methods, such as mathematical programming, discrete-event simulation, and so on.

To implement target patient throughputs, Vissers [4] combines hospital production management and resource capacity planning

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together, and proposes a formalized method to allot the resource capacity within a whole hospital. Two mathematical models are built to calculate the resource requirements of each specialty. One supports long-term decisions about the resources required to match the future patient demand, and another supports decision making at the medium-term level for balancing the resource requirements of various types. Similarly, for the financial purpose, it is also beneficial for a hospital to integrate the production management and the capacity planning. Here, a hospital pursues to choose the patient mix and volume of different pathology types that can bring maximum profits and to determine the corresponding hospital-wide resource allocation. The mix and volume of different types of patients are referred to as the patient case mix [5] in this context, and the production management problem is referred to as the hospital case mix and capacity planning problem. Clearly, this hospital planning problem involves the decision making both on patient volumes and on resource requirements and allocation, and thus concerns both the patient volumes planning and control level and the resources planning and control level within the health care production control framework of Vissers et al. [6].

Hospitals are classified into two categories: constrained profit satisfiers and profit maximizers [7], according to the different profit targets of health care providers. Constrained profit satisfiers are motivated by professional interests rather than economic returns. A profit satisfier hospital seeks for the preferred case mix pattern or other preset objectives on condition that it can manage to break even without violating the capacity constraints [8]. On the other hand, profit maximizer hospitals are assumed to be positioned in a competitive business environment and thus they are willing to choose the patient cases that will bring the maximum rewards (e.g., [9–11]). In these papers, the mathematical programming models (i.e., linear programming, integer programming, goal programming) are deployed to solve the intended patient case mix. Moreover, in previous research [11], an efficient solution method for huge integer programs, branch-and-price [12], is presented and applied to solve the case mix problem optimally. In addition, to reflect and contain the variability in the system (e.g., the variable LOS of patients) into the planning model, both Utley et al. [13] and Adan et al. [14] successfully translate the stochastic resource requirements into the mathematical modeling by replacing the expected LOS with its probability distribution, and receive a better result from these stochastic models when solving the patient case mix and/or the allocation of resources in real configurations.

Second, as mentioned above, the inevitable variability in the health care system will not only influence the resource utilization [15–17], but also affect the service level of health care delivery [18–21]. Specifically, both the unpredictable patient demand (e.g., emergency admissions [15]) and the variable length of stay of patients (e.g., [13,14,16]) have a considerable impact on the fluctuation of bed capacity requirements. Moreover, Green [17] points out that the bed capacity planning should not be based on the target occupancy level only, but be connected with measures of patient delays, such as patient refused admission rate [18], patient waiting time [19], surgery cancellation [20], and patient misplacement [21]. To assess the operational performance and to examine the health care service level, a queueing model is adopted in [18] and simulation models are applied in [19–21]. In addition, besides the variability, changes in a cyclic master surgery schedule itself also affect bed consumptions. For instance, Beliën et al. [22] present a software system that visualizes the impact of the master surgery schedule on the demand for other various resources throughout the rest of the hospital.

Apparently, the balanced use of various resources will not only increase the resource efficiency but also advance the patient service level. Hence, it is significant to harmonize the utilization of, e.g., operating rooms and beds, in order to acquire an efficient patient flow in the health care system. Beliën and Demeulemeester [23] take into account the resulting daily bed occupancy levels when building cyclic master surgery schedules. The variable LOS of patients will bring fluctuations in the bed capacity requirement and deviations of the real bed demand from the assigned capacity, which causes the bed shortage phenomenon. Then, the bed shortage will lower the patient service level, since it either makes the scheduled surgery to be canceled [20] or it makes the operated patient to be misplaced [21]. Hence, it is meaningful to seek for a balanced cyclic master surgery schedule through minimizing the total expected bed shortages [23]. Besides, van Oostrum et al. [24] also incorporate maximizing OR utilizations and leveling bed requirements together when scheduling the surgery procedures into operating rooms.

In addition, there also exist a number of articles [25–27] applying an integrative approach to the hospital planning problems. Bretthauer and Côté [25] develop an optimization/queueing network model to determine resource requirements, which minimizes the capacity costs while controlling the customer service by enforcing a set of performance constraints. The queueing network model allows to involve the stochastic property of health care systems and to estimate the service levels within an optimization framework. Butler et al. [26] propose a two-phase model-based approach to the hospital layout problem. A quadratic integer goal programming model is built to determine a hospital configuration and the allocation of beds to health services in the first phase. Then, the detailed ramification of the suggested layout is assessed in the second phase through a simulation model. Oddoye et al. [27] also combine simulation analysis with goal programming modeling for the healthcare planning in order to achieve an optimal clinical workflow.

In this research, to overcome the increasing economic pressures on hospitals and the inefficiency in patient flows, the case mix and capacity planning problem is studied comprehensively, which on the one hand maximizes the financial contribution of the given resources at a hospital, and on the other hand improves the health care service level under the variability condition. To achieve the efficient trade-offs between resource efficiency and service level, an integrative three-phased solution approach is proposed, in which the first phase aims at maximizing the overall profits, the second phase is focused on reducing the total expected bed shortages, and the third phase works on assessing the operations performance and on analyzing the suggested effective policies. Each phase has its own emphasis and merits, and their solutions complement each other and complete the sound decision making for the hospital planning problem.

The remainder of this paper is structured as follows. Section 2 describes the hospital case mix and capacity planning problem briefly and addresses some concerned matters being valuable to the planning process. Section 3 specifies the proposed solution methodology for the planning problem, which is a multilevel model-based integrative approach on the basis of operational research methods, i.e., mathematical (integer linear) programming and discrete-event simulation. The methodology framework is formulated and explained in detail, and each phase is elaborated, respectively. Afterwards, an example is applied to demonstrate the efficiency and the importance of the designed integrative method in Section 4. Final, in Section 5 we draw the conclusions of this paper and mention some ideas for further developments.

2. Problem description

As discussed above, the hospital case mix and capacity planning problem concerns the decision making both at the patient volumes planning and control level and at the resources planning and