Socio-Economic Planning Sciences 47 (2013) 220–237

Contents lists available at SciVerse ScienceDirect

Socio-Economic Planning Sciences

journal homepage: www.elsevier.com/locate/seps

Multi-period layout planning for hospital wards

Ines Verena Arnolds*, Stefan Nickel

Karlsruhe Institute of Technology, Institute of Operations Research, Kaiserstr. 12, 76131 Karlsruhe, Germany

ARTICLE INFO

Article history:
Available online 21 February 2013

Keywords:
Discrete optimization
Multi-period ward layout planning
Different-sized bed rooms
Decision support

ABSTRACT

Layout planning for hospitals is a long-term decision. Nevertheless, medical and organizational factors change over time. For example, demand for different-sized bed rooms varies based on medical requirements and patient preferences. In this paper, we consider the planning of ward layouts over multiple periods using different approaches. The fixed ward layout models aim at minimizing either the number of demand violations or costs for installing fixed patient rooms. In contrast, the variable ward layout model allows for layout adaptations to satisfy demand. Thus, additional costs for the movement of walls have to be considered. The application of the different approaches as a decision support tool for hospital planners is explained. Hence, it can be derived in which settings the costs for adapting a layout do not exceed the benefits of such a change. Computational experiments demonstrate the applicability of the models for realistic instances.

1. Introduction

In the framework for hospital planning and control the hospital layout planning problem is classified as a resource capacity planning problem [1]. The spatial organization within hospitals directly influences the quality and efficiency of healthcare and secondary services [2,3] as well as patient satisfaction [4]. In most applications the layout is considered as a long-term decision [5]. In such static layout problems all relevant parameters are assumed to remain constant during the entire planning horizon. Nevertheless, demand for different-sized bed rooms on hospital wards varies over time due to the reasons outlined in the following paragraphs [4].

First, the number of nosocomial infections due to highly contagious diseases where patients require isolation is continuously increasing [6]. This results in the need for different patient room sizes at short notice. Second, inpatients have service-related expectations which includes a preference for a desired (maximum) number of roommates. As a service provider, the hospital should try to satisfy this demand. Third, Hurst [7] points out that inflexible wards may artificially enforce non-occupied beds, e.g., due to the separation of patient rooms by gender. Finally, from a cost perspective the number of beds per square meter impacts the economic efficiency. On the one hand, single rooms usually have the same size as double rooms but, on the other hand, different reimbursement rates are charged.

Since it may not be obvious, we will outline some reasons why patients might ask for roommates instead of staying in a single room. First, there are social and personal issues. For example, patients who do not expect to receive visits may not want to stay all alone in a single room. Due to their personality some patients will prefer to have roommates with whom they can chat. This distraction potentially decreases the perceived waiting time for the patients to recover. Second, to some patients it gives a feeling of safety to know that the roommates will have a look after each other in between the visits of nurses and medical doctors. Third, there is a monetary reason: In Germany, patients have to pay supplements if they want to stay in a single room. Consequently, even though a person might prefer to have no roommates he or she might not be willing or able to pay for that. Finally, some patients, e.g., children or patients in a severe health status, will be accompanied by family members or other persons who want to stay in the same room.

In current practice, fixed ward layouts are planned by architects having expertise in designing healthcare facilities. Usually, logistics experts are not involved in the planning process. Architects know the appropriate legal regulations and follow the instructions and requirements of the invitation to tender. The latter defines the number of different-sized rooms for each ward. A varying demand during the lifetime of the hospital is not considered. As far as we know, there have not been any mathematical models developed that can be applied as a decision support tool to plan adaptable ward layouts in a multi-period context.

* Corresponding author. Englerstr. 11, Bldg. 11.40, 76131 Karlsruhe, Germany. Tel.: +49 721 608 43994; fax: +49 721 608 46874.
E-mail addresses: ines.arnolds@kit.edu (I.V. Arnolds), stefan.nickel@kit.edu (S. Nickel).

0038-0121/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.seps.2013.02.001

In order to overcome the disadvantages of a static layout planning we provide two different multi-period ward layout planning approaches. The fixed ward layout problem (FWLP) is to find a robust layout that cannot be adapted in later periods. This means, there is only made one single decision in order to find the best possible ward layout for all periods. In contrast, the variable ward layout problem (VWLP) is to generate a layout plan, i.e., an own layout for each period of the planning horizon. Here, demand will always be satisfied as walls can be moved along a system of rails in order to change room sizes. Nevertheless, if it is not enforced by the changing demand, movable walls do not necessarily have to be moved in each period. Comparing the results of both approaches provides a decision support tool to differentiate settings where layout adaptations are advantageous or not.

Fig. 1 depicts a sample solution of the VWLP. The planning horizon comprises three periods, there are three different room sizes and two rows where patient rooms can be located, e.g., to the left and right of a central corridor. Colored rectangles represent the different-sized patient rooms, dots and rhombi identify movable and non-moveable walls. Arrows indicate necessary wall movements to satisfy demand in the next period. The scale at the bottom corresponds to the length of the corridor. If more space is available than needed the surplus area is added to one or more of the rooms. In Fig. 1, this can be observed in period $t = 3$. The surplus area in row $r = 2$ between positions $p = 25$ and $p = 26$ is added to the room that is installed to its left.

To the best of our knowledge, there do not yet exist applications of movable walls on hospital wards. However, as we know from architects there have been experiments on using movable walls in the past [8]. The reasons why this idea has not become a success are twofold. First, the technical prerequisites for movable walls had not been fully developed for a usage in hospitals at that time. Nowadays, technically mature systems facilitate an easy handling and appropriate characteristics. For example, such walls are now available in sound absorbing designs and wall movements can be easily conducted by the hospital personnel themselves. There are many providers who offer solutions to install movable walls, more detailed information about the technology involved can be found, e.g., in Refs. [9–15]. Second, in the past there was missing a planning tool to decide when and which walls should be moved to which position. The VWLP answers exactly this question.

The remainder of this paper is structured as follows. In the next section we give a short review of the relevant literature in the field of layout planning. Afterward, in Section 3 we introduce our model assumptions before presenting the FWLP and VWLP models in Section 4. Section 5 explains how to use the presented models as a decision support tool. In Section 6, computational results are discussed. Finally, we give a summary and conclusion in Section 7.

2. Literature review

Classical layout problems arise in manufacturing environments and aim at minimizing traveling or material handling costs based on distances by deciding on the relative positions of machines. We refer the interested reader to the survey of Drira et al. [5] and the textbooks of Tompkins et al. [16] and Heragu [17]. In the following, we focus on two streams of literature: Dynamic layout problems and layout problems in healthcare settings.

2.1. Dynamic layout problems

Dynamic layout problems consider varying input data during the planning horizon. Two approaches have been developed to reflect this variability [5,18]: Developing a robust layout that is best in sum over all periods (see, e.g., Refs. [19–27]), or a layout plan for multiple periods where rearrangement costs are incurred for layout adaptations (see, e.g., Refs. [28–38]). Reviews on dynamic layout problems and solution approaches are given in Refs. [39,40]. All dynamic layout problems that we could find in the literature aim at minimizing the walking distances or transportation costs which are based on distances. This differentiates the modeling approach for dynamic layout problems from our multi-period ward layout problem (MWLP) since we are not concerned with any distances at all.

Furthermore, some authors developed approaches to measure robust layouts against layout plans. Braglia et al. [41] have introduced quantitative indices which are used to identify the strategy

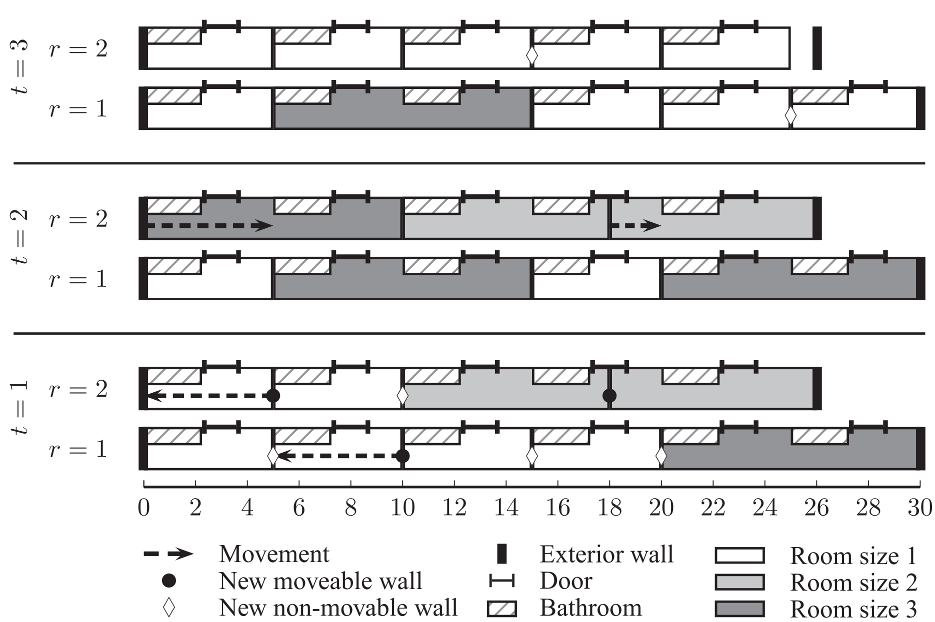

Fig. 1. Example for the VWLP.