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Mid-term nurse rostering considering cross-training effects

Andreas Fügener [a,*], Alexander Pahr [b], Jens O. Brunner [b]

[a] Department of Supply Chain Management, Faculty of Management, Economics and Social Sciences, University of Cologne, Albertus-Magnus-Platz, 50923 Cologne, Germany

[b] University Center of Health Care Sciences at Klinikum Augsburg (UNIKA-T), Department of Health Care Operations/Health Information Management, Faculty of Business and Economics, University of Augsburg, Universitätsstraße 16, 86159 Augsburg, Germany

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ABSTRACT

Hospitals experience challenging times in which both the economic pressure and the challenges of uncertain demand for care increase. One of the most prominent problems in health care operations is the nurse scheduling problem, where nurse rosters are created to cover demand. Cross-training, i.e. educating nurses to work in units other than their dedicated one, offers an opportunity to react to the issues mentioned above within the field of nurse scheduling. We contribute to the nurse cross-training literature in three ways: First, we propose a framework to define and visualize cross-training policies. Second, we introduce a new cross-training policy where each unit trains one dedicated nurse for each other unit. Third, we are the first who develop a mid-term model creating and applying cross-training policies in nurse rostering. Within this new mid-term model, we make use of parameters that allow to control the trade-off between flexibility of nurses and the continuity of care. In two computational studies with 6400 instances we compare our newly developed cross-training policy with three existing policies from the literature, demonstrate the superiority regarding demand coverage and overtime per number of cross-trainings, and compare the effects of cross-training intensity, i.e. the number of cross-trained nurses, with cross-training breadth, i.e. the number of departments a nurse is cross-trained for.

1. Introduction

By 2030, more than 400,000 nursing and nursing assistant jobs in German hospitals will remain vacant (Ostwald et al., 2010). An important parameter in this forecast is the demographic change as an aging society will call for more medical services. The forecasts are alarming, especially when considering two major problems of the nursing profession.

Hospitals face increasing cost pressure, e.g., 42.2% of German hospitals reported a net deficit in 2013 (Blum et al., 2014). In 2013, personnel costs accounted on average for 58.9% of total costs (Statistisches Bundesamt, 2014), showing the importance of staffing and scheduling decisions for nurses (Burke et al., 2004) and physicians (Erhard et al., 2016). In addition to that, vacant positions are difficult to fill. Around one third of all hospitals had problems with finding qualified nursing personnel in 2013 (Blum et al., 2013). According to a 2011 survey, 70% of the interviewed nurses stated that they cannot imagine being physically able to work beyond the age of 55 (Buxel, 2011). The most frequently mentioned issues are high stress (56%), lack of appreciation from supervisors (62%) and the number of colleagues attributed to one shift in the scheduling process (63%). Preferences and fairness in physician scheduling in addition to demand coverage are discussed in Fügener et al. (2015).

In order to address the future nursing shortage, the desirability of the profession may be increased by reducing the physical, mental and time pressure on nursing personnel. In this way, job dissatisfaction, high turnover and early retirements of nurses may be reduced. At the same time, costs have to be kept as low as possible. One method to reach these aims is to redesign the way nursing shifts are scheduled. In most hospitals, nurses are employed in just one department. By cross-training nurses in order to enable them to work in various units, the scheduling process gains flexibility and efficiency. Besides, cross training might also have positive effects related to job enrichment. The purpose of this work is to develop a mixed-integer problem (MIP) examining how the possibility to train nurses for more than one unit may reduce the stress and workload they are objected to. In this context, our approach minimizes staff shortages and overtime assignments. As cross-training leads to additional costs, we consider and compare different cross-training policies.

The main contribution of this paper is threefold. First, we develop a framework to define, illustrate, and compare cross-training policies. Second, we introduce a new policy *One-for-Each* that outperforms policies

* Corresponding author.
E-mail address: andreas.fuegener@uni-koeln.de (A. Fügener).

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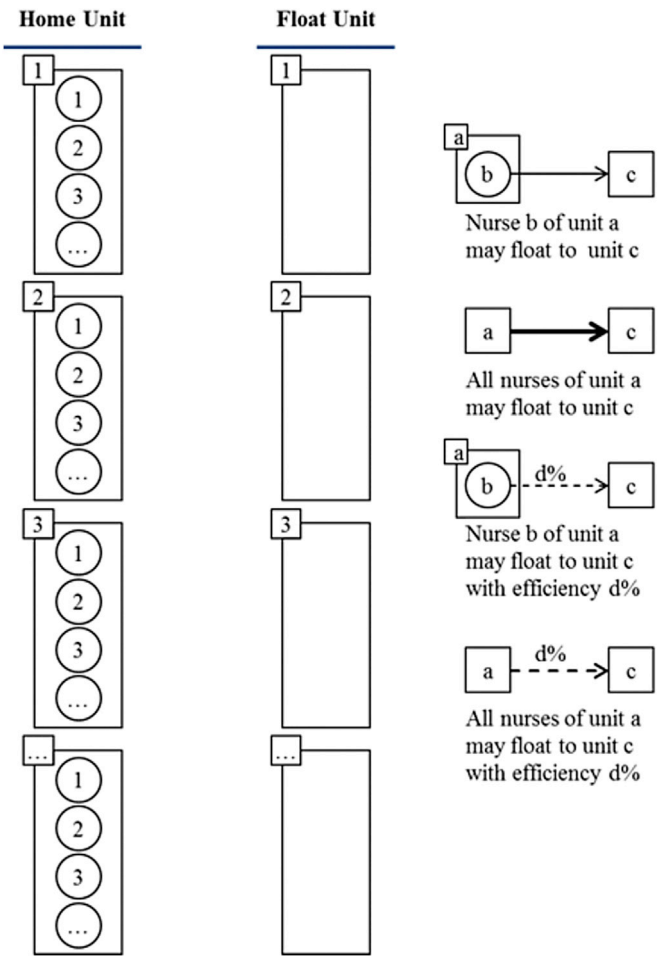

Fig. 1. Generic illustration of CT policies.

from the literature by achieving better schedules in terms of staff shortages and overtime assignments with the same number of cross-trainings. Even the policy *Chaining* (being dominant in the literature) is outperformed. Third, we introduce a new model to create mid-term nurse rosters allowing cross-training. Our approach is the first that integrates a parameter allowing to control the trade-off between flexibility of cross-training and continuity of care.

The remainder of the paper is structured as follows: In Section 2, basic concepts are presented, the literature on nurse scheduling considering cross-training is revised, and the contribution of our approach is described in detail. Thereafter, the scheduling model employed in this work (Section 3) and two numerical studies based on data from a large German hospital are presented (Section 4). Finally, Section 5 concludes the paper, summarizes our findings and proposes future research options.

2. Cross-training of nurses

The nurse scheduling problem is one of the most intensively investigated topics in the operations management literature. Beginning in the 1960's, researchers have been suggesting a large variety of approaches to optimize the nurse scheduling process in hospitals – for an extensive review on nurse scheduling we refer to Burke et al. (2004). For the methodological state of the art in solving nurse rostering problems we refer to the nurse rostering competitions (Ceschia et al., 2014; Haspeslagh et al., 2014). In awareness of the emerging nursing shortage several approaches to the nurse scheduling problem allow a higher degree of flexibility in personnel scheduling in order to deal with staff bottlenecks. In this section, we present basic definitions, discuss cross-training policies, and state our contribution.

2.1. Basic definitions

Summarizing the literature that concentrates on internal flexibility at first requires a classification of nurse flexibility. We distinguish between agency nurses, float pool nurses, and cross-trained nurses. Our approach considers cross-training of nurses.

Agency nurses: External nurses who may be temporary employed at short notice to cover demand peaks. Usually associated with high costs.

Float pool nurses: Highly trained internal nurses who are not dedicated to a specific ward. Typically they are trained to cover all wards connected with the pool. They are usually scheduled to a fixed shift pattern, whereas the unit they are assigned to is determined just at the beginning of their shift, dependent on which unit most urgently needs an additional nurse.

Cross-trained nurses: Internal nurses with a dedicated unit trained to cover one or more additional wards in case of demand peaks. We denote the dedicated unit as "home unit" and the additional units as "float units".

Three indicators are used to define the extent of cross-training (CT):

CT depth: The level of productivity and quality of care, which cross-trained nurses are able to provide when working in a float unit. It is often classified as a percentage of the productivity in the home unit.

CT breadth: The number of float units a cross-trained nurse is applicable to.

CT intensity: The number (absolute or percentage of total unit nurses) of cross-trained nurses within a unit.

We propose a generic framework for cross-training policies. A defined number of nurses in a unit may be cross-trained to be able to serve in additional units. We illustrate the generic scheme in Fig. 1. The large rectangles illustrate units (left: home units, right: float units), while the circles illustrate nurses. A bold connection between a home unit and a float unit indicates that all nurses of the home unit may work in the float unit, and a thin connection between a nurse and a float unit indicates that this specific nurse may work in the float unit. In case of CT depth of less than 100% the connections are illustrated as dashed lines with the CT depth noted on top of it. The number of connections between a nurse (and its home unit) and float units indicates the CT breadth, and the number of nurses connected to any float unit indicates the CT intensity.

Furthermore, we define cross-training policies according to Inman et al. (2005). The authors define the policy "All-to-All", where one nurse of each unit is cross-trained for all other units, and the policy "Total CT", where all nurses of each unit are cross-trained for all other units. We include both within a generic policy *n-to-All*, where n nurses are cross-trained for all other units. Exemplary illustrations of cross-training policies from the literature with J units are presented in Fig. 2. The exemplary values of CT breadth and CT intensity within the illustration are as follows: *Chaining*: CT breadth 1, CT intensity 1; *Reciprocal Pairs*: CT breadth 1, CT intensity 1; *n-to-All* ("All-to-All" in the literature): CT breadth: J-1, CT intensity 1; *n-to-All* ("Total CT" in the literature): CT breadth: J-1, CT intensity: J-1. The CT depth is assumed to be 1 for all nurses and units within the illustration.

Chaining: Each unit trains nurses for just one other unit which follows in a chain that connects all units.

Reciprocal pairs: Units are matched in pairs of two. Cross-training is allowed within the pairs only.

***n*-to-All:** Each unit provides n nurses that are cross-trained for all other units. In the literature, the case for $n = 1$ is denoted as "All-to-All", the case for $n = J$-1 is denoted as "Total CT".

2.2. Discussion of cross-training policies in the literature

In this section, we present the literature discussing cross-training of nurses. Simulations of Pinker and Shumsky (2000) indicate that