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Invited Review

State of the art in physician scheduling

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ABSTRACT

Over the last decades, hospitals have faced increasing financial pressure due to rising costs and changes in reimbursement policies. One of the reasons for this development is the rising number of qualified personnel required to handle the consistently growing demand for hospital services. In the U.S., on average more than 50% of hospital costs are workforce related. In order to reduce these expenses without sacrificing quality of care, a stream of research has focused on building more efficient personnel schedules for nurses and physicians.

We provide the first review that focuses on quantitative methods for physician scheduling in hospitals. We describe the relevant characteristics of various investigated physician scheduling problems, such as the problem type, i.e. Staffing, Rostering or Re-planning problems, personnel qualification and experience, and the utilized shift types. Furthermore, we analyze the existing literature with respect to additional modeling features including fairness aspects and underlying demand patterns, as well as employed solution approaches and real life applications. In total, we review 68 relevant publications in the OR/MS field. We use our presented framework to categorize the existing approaches and highlight gaps in the literature to initiate future research activities.

1. Introduction and motivation

In recent years, hospitals have faced shortages of medical personnel in most industrialized countries. For example, around half of the hospitals in Germany experienced difficulties to hire physicians in 2013, resulting in an average 2.5 vacant full time positions per hospital (Blum, Löffert, Offermanns, & Perner, 2013). The scarcity of available physicians on the job market forces managers to focus on finding efficient and effective ways to plan and schedule their workforce, which is compounded by the fact that more than half of the operating costs in hospitals are staff-related (Bölt, 2014).

Finding ways to reduce labor costs without generating negative effects for the health of their patients is an extremely important task for healthcare providers. Due to the uncertainty and high fluctuation in the daily requirements for care, the size of a scheduled workforce in hospitals is often inadequate to match actual demand, leading to under- or overstaffing. Understaffing has been shown to decrease quality of care (Aykin, 2000) and increase waiting times for patients (Kuo, 2014) as well as lengths of stay, which in turn can cause the workload for the assigned staff to further increase (Zeltyn et al., 2011). According to Aiken, Clarke, Sloane, Sochalski, and Silber (2002), dissatisfaction of the staff and an increase in absences due to illness and burnout are possible consequences. Moreover, turnover rates of qualified and experienced personnel may increase. In contrast, overstaffing leads to unsatisfactory personnel utilization levels, which unnecessarily drives up the costs of health care services (Villarreal & Keskinocak, 2014). Personnel rosters in practice may sometimes be designed to cope with demand peaks, leading to excessive capacity under normal workload (Aggarwal, 1982). Scheduling physicians in a more flexible manner can help to find a reasonable balance between overstaffing and understaffing.

While physician scheduling is part of the larger field of personnel scheduling, it exhibits a lot of properties that differentiate it from other topics within the realm of personnel scheduling. In Table 1, we illustrate physician-specific aspects derived from the literature, summarized features, and consequences for modeling concepts. Physicians represent one of the most valuable and expensive resources in hospitals and are considered a bottleneck in the care providing process (Santos & Eriksson, 2014). Having undergone extensive training, they are qualified and specialized em-

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Table 1
Specific features of the physician scheduling problem.

Aspects from literature	Special feature	Consequence for modeling
Cost-intense resource Physician shortage/Difficulty of replacement Contractual diversity Adherence to preference scheduling	Importance of physicians	Preferences, Fairness
Continued medical education Tasks diversity Composition of team qualifications Learning effects	Relevance of experience	Residents
24/7 operating hours Uneven workload distribution	Demand volatility	Flexibility, Break assignment
Stochasticity in emergencies and surgeries	Demand uncertainty	Stochastic demand

ployees that are usually difficult to replace (Bodenheimer & Smith, 2013). As a result, physicians usually do not only have collective labor contracts but also individually negotiated agreements with their employer (Charles et al., 2013). These aspects lead to a partial transfer of power from management to physicians, increasing the importance for the employer to adhere to the employees' schedule preferences and contractual agreements as well as to provide physicians with a high autonomy with respect to task performance and sequencing. Overall, this relative balance of power between the scheduler and the employees adds interesting implications to the physician scheduling problem. As a result, modeling of preferences and fairness issues is of great importance in physician scheduling.

Due to the nature of medical services, tasks and processes in health care can only be partially standardized. Serviced customers, here patients, are extremely heterogeneous with respect to their health conditions, the available status information, and the responsiveness to different forms of treatment (Chisholm, Weaver, Whenmouth, & Giles, 2011). This increases the importance of experience and continuing medical education for senior physicians, and cycles of task rehearsal during junior physicians' residency (Dorman & Miller, 2011), as physicians exhibit quality improvements by task repetition (Khan, Campbell, Wallington, & Gardam, 2006). Thus, education, learning, and team composition are often included in physician scheduling models, particularly when residents are considered.

Demand for care is highly volatile and occurs 24/7. Hospitals face uneven workload distributions over time (McManus et al., 2003) leading to difficulties in creating and applying appropriate shift designs. As a consequence, flexible modeling of shifts and breaks may create value in physician scheduling. Drivers of uncertain demand for medical services include emergencies (Venkat, Kekre, Hegde, Shang, & Campbell, 2015) and uncertain surgery durations (Fügener, Schiffels, & Kolisch, 2017). Thus, modeling stochastic demand for physicians is a relevant topic.

While all of the mentioned aspects make physician scheduling stand out from general (service) personnel scheduling problems, it is true that there are small subsets of service industries that have one or a few of the aspects in common with health care. However, the combination of all these aspects is very unique. It creates a complexity and diversity for physician scheduling problems that are outstanding in the field of service personnel scheduling. In our literature review, we put additional focus on the possible consequences for modeling derived from these specifics – i.e., modeling of preferences, fairness, resident specifics, flexible shifts and break assignments, and stochastic demand.

Even though the physician scheduling problem has received increasing attention over the last decades, there are still a lot of questions to be examined. Our work provides the first overview of the existing operations research and management science (OR/MS) literature in this field of research and identifies directions for future research. Up until the end of the year 2016, we identified 68 relevant papers on different types of the physician scheduling problem, which we classify as either *Staffing*, *Rostering*, or *Re-planning* problems. *Staffing* problems are considered in 14 papers, 53 publications handle *Rostering* problems, and only one manuscript deals with a *Re-planning* problem. Moreover, various facets such as worker categories, considered shift types, the implementation of breaks, fairness aspects such as evenly distributed workloads and granting individual scheduling requests, and the underlying demand patterns are examined. We find that there exists a lack of research that considers flexibility in the scheduling process. For example, only seven papers apply flexible shift types, and only three articles include break assignments. Fairness is considered in 37 papers. Demand is assumed to be deterministic in the major body of the current literature, i.e. 58 manuscripts, while the remaining articles do include some form of demand stochasticity. Mathematical Programming techniques are the most prominent choice of solution methodology, as 61 research articles employ methods related to Mathematical Programming. Moreover, we present various modeling objectives (*financial* or *non-financial* in nature) and discuss applied solution methodologies (exact and heuristic approaches). Based on our framework, we identify gaps in the literature and highlight promising areas for future research.

The remainder of this review is structured as follows: In the subsequent section, we discuss basic definitions of the physician scheduling problem, explain the scope of our review, and provide a meta-analysis. We offer a detailed review of the existing physician scheduling literature along our designed framework in Section 3. In Section 4, we summarize the key findings of our review.

2. Definitions, scope, and meta-analysis of the review

Personnel planning problems in general have been widely discussed in the literature. The following literature reviews deal with specific subsets of personnel planning problems: Scheduling problems for different types of services with a focus on modeling approaches and rostering algorithms are covered in Ernst, Jiang, Krishnamoorthy, Owens, and Sier (2004). For a detailed bibliography of personnel rostering publications, we refer to Van den Bergh, Beliën, De Bruecker, Demeulemeester, and De Boeck (2013). De Bruecker, Van den Bergh, Beliën, and Demeulemeester (2015), provide a literature review on workforce planning that incorporates different skill levels of personnel. All three reviews discuss staff scheduling issues in various industries, e.g., manufacturing and call centers. Focusing on the health care sector, a lot of research has concentrated on nurse scheduling, which has been reviewed in Burke, De Causmaecker, Canden Berghe, and Van Landeghem (2004) and Cheang, Li, Lim, and Rodrigues (2003) as well as in overviews focusing explicitly on nurse turnover (Hayes et al., 2012) and acute care staffing of nurses (Nosbusch, Weiss, & Bobay, 2011). Moreover, Cardoen, Demeulemeester, and Beliën (2010) con-

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