

# Chapter 21

## Mathematical Programming and Heuristics for Patient Scheduling in Hospitals: A Survey

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### ABSTRACT

*The effective and efficient treatment of individual patients subject to scarce hospital resources is an increasingly important and challenging problem for decision makers to address. A recent study by the U.S. Bureau of Labor Statistics listed Registered Nursing among the top occupations in terms of job growth until the year 2022 (American Association of Colleges of Nursing (2015)). This growing demand can be explained in part by the large number of aging baby boomers with multi-morbid health conditions who typically require more treatments and longer length of stay in a variety of healthcare delivery settings (Vetrano et al. (2014)). Given the projected demand growth and reduced mobility of elderly patients, efficient operational research methods have to be developed and deployed for optimizing the process of scheduling the treatment of individual patients in highly resource constrained environments. We will henceforth denote this process as ‘patient scheduling’ and provide a problem definition and a review of current approaches in the course of this chapter.*

### PREVIOUS REVIEWS AND AIM OF THIS REVIEW

Over the past few decades, a significant literature has been accumulated on resource allocation problems in health care. Textbooks include, among others, Brandeau et al. (2004), Hall (2006), Hall (2011), Kaplan et al. (2015), Kolker (2012), Langabeer (2008), Ozcan (2008), Ozcan (2009), Shiver and Eitel (2010), Vissers and Beech (2005) and Yih (2011). In the review paper by Hulshof et al. (2012), the au-

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thors provide a valuable taxonomic classification of planning decisions in health care for the Operations Research and Management Science community. Focusing on hospitals, Vanberkel et al. (2010) provide a literature review on the planning of multiple hospital departments while Cardoen et al. (2010) and Guerriero and Guido (2011) offer reviews on planning the operating theater. Methodological reviews that focus on specific techniques are also available. Jun et al. (1999) provides a survey on simulation techniques applied to health care. Teixeira et al. (2015) and Cayirli and Veral (2003) focus on admission systems and admission planning. The difference between these reviews and the one we provide is twofold: From a methodological point of view, this review focuses exclusively on mathematical programming and heuristic approaches that have been successfully applied to the patient scheduling problem in hospitals. Selection criteria will be defined in order to identify journal articles which will be categorized into different health care services, resources considered, modeling and solution approaches, modeling and evaluation of uncertainty as well as patient and resource-related objectives. The second major difference as compared to previous reviews is that we provide a recent literature review that closes the gap between i) Hulshof et al. (2012)'s broad and exhaustive review on planning problems in Operations Research and the Management Science, ii) Cardoen et al. (2010)'s detailed classification of operating room (OR) planning problems, and, iii) literature that is available in the Medical Informatics/Artificial Intelligence in Medicine domain.

## **DEFINITION AND CHARACTERISTICS OF PATIENT SCHEDULING**

A search for definitions for the term 'patient scheduling' revealed that there is lack of precision in its definition. An excellent starting point, however, is provided by Hulshof et al. (2012) who state the following: "Based on the appointment scheduling blueprint developed on the tactical level, patient scheduling comprises scheduling of an appointment in a particular time slot for a particular patient. A patient may require multiple appointments on one or more days. Therefore, we distinguish scheduling a single appointment, combination appointments and appointment series."

Below is a definition of the term 'patient scheduling', followed by some examples.

**Definition 1:** *Patient scheduling is the process of assigning individual patients and/or patients' activities to time and/or healthcare resources.*

- **Scheduling Individual Patients or Patients' Activities:** Individual patients can be, for example, elective patients, urgent patients, and so on. Patients' activities can be, for example, a surgery or diagnostics activity. Table 1a provides sample activities.
- **Temporal Assignment of Patients or Patients' Activities:** When assigning patients and patients' activities to time, researchers usually consider a finite planning horizon, such as one week (Conforti et al. (2011)) or one month (Gartner and Kolisch (2014)). The planning horizon can be divided into time points, for example starting time points of each hour within a day. Each patient's activity may have a time window within which it has to be scheduled. The activity's time window, which is a subset of the planning horizon, does not necessarily have to contain consecutive time points. For example, the start of a surgery for an elective patient may be scheduled between 8a.m. through 11a.m., or 1p.m. through 4p.m., but not between 11a.m. and 1p.m.

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