A Hybrid Evolutionary Algorithm for the Generalized Surgery Scheduling Problem

Atle Riise • Edmund Burke • Carlo Mannino

1 Introduction

The term surgery scheduling is used about a variety of strategic, tactical and operational scheduling problems [1], many of which are critical to an efficient use of hospital resources. Our focus is on operational surgery scheduling, which may be informally described as the task of assigning times to surgery-related activities for each patient, while reserving capacity for these activities on a set of constrained renewable resources. Such resources may be, for example, operating rooms, operation teams, surgeons, equipment, or post-operative bed capacity. Objectives are typically overtime, hospitalization costs, intervention costs, operating room utilization, patient's waiting time, and patient or personnel preferences, among others. These scheduling problems are often NP-hard [2]. The exact problem formulation varies substantially between hospitals, or even hospital departments. In addition, the degree of detail vary between different planning situations; patient admission planning may consider only one or two kinds of resources, is mainly concerned with allocating a date of admission for each patient, and typically has a long time horizon. Closer to the day of surgery, such as when scheduling surgeries for the next day or week, the number of activities, resources and choices to make increase. This diversity presents a challenge for those who wish to create scheduling methods that are applicable to surgery scheduling problems in general.

2 The Generalized Surgery Scheduling Problem

In [3], we approached this challenge by generalisation, introducing the "Generalized Surgery Scheduling Problem" (GSSP). The GSSP can be seen as a rich extension to the Resource Constrained Project Scheduling problem (RCPSP) [4]. It has multiple projects (one per patient), multiple resources per project activity, multiple modes, and setup times. The GSSP also has time dependent resource capacity, block constraints, and maximum delay constraints. Furthermore, it contains some new constraints: The "mode compatibility constraint" limits the simultaneous choice of modes for sets of related activities. For example, if a surgery activity uses a certain operating room, other related activities must also use that same room. Another constraint is the "mode dependent precedence constraint", which means that depending on the chosen modes for two activities, there may or may not be a precedence constraint between them. Finally, the "project disjunction constraint" dictates that for some resources, all activities related to a given project must be performed before the resource can be used for any activity of any other project, even if the resource has available capacity. This comes from the fact that one wish to complete all tasks relating to one patient in the operating room before starting any tasks relating to another patient.

The problem is naturally modelled as a directed activity-on-node graph. This problem graph can be seen as a union of project graphs and resource graphs. Project graphs represent precedence-, time window-, and maximum delay constraints. Resource graphs contain a sequence of resource periods [3], each represented by a pair of artificial start and end nodes. A range of constraints and objectives can be calculated directly from the propagated earliest start time of the end nodes of these periods. Resource period capacities and activity demands are modelled by constraints on a flow of resource units in the resource graphs.

A solution can be constructed by inserting each activity into the resource graphs of the activity's selected mode. Such a solution is feasible with respect to time-related constraints if the resulting solution graph is positively acyclic.

3 Algorithmic approach

Perhaps reflecting the variety of real world surgery scheduling problems, the literature includes the use of a wide range of resolution methods, both exact and heuristic [5]. Many variants of the problem are NP-hard, and several authors conclude that a meta-heuristic approach is needed for problems of realistic size. This is also our conclusion for the GSPS [3]. In this paper, we present two meta-heuristic methods for the GSSP. As for many studies of the RCPSP, we use a random key list solution representation. A schedule generation scheme (SGS) is used to produce a schedule by inserting activities into the solution graph in the order given in such a list. Our SGS is a heavily modified version of the classical sequential SGS [6]. It handles maximum delay constraints, project disjunctions and resource periods. Furthermore, this SGS can perform a search in the possible modes for each activity that is inserted, taking mode consistency and mode-dependent precedence constraints into account. As a baseline meta-heuristic we create a random restart algorithm which uses the SGS to construct schedules based on randomly selected random key lists. We then go on to present an evolutionary algorithm whose combination operators work on the level of mode choices and random key representations. Child schedules are constructed by applying the SGS. Using realistic test data from three different planning situations ("admission planning", "weekly surgery scheduling", and "daily surgery scheduling") [3], we demonstrate that this algorithm performs better than the base-line algorithm. We also show that it produces good approximations to the optimal solutions, using computation times that are acceptable in real life planning situations.

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