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Discrete Optimization

Finding robust timetables for project presentations of student teams

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ABSTRACT

This article describes a methodology developed to find robust solutions to a novel timetabling problem encountered during a course. The problem requires grouping student teams according to diversity/homogeneity criteria and assigning the groups to time-slots for presenting their project results. In this article, we develop a mixed integer programming (MIP) formulation of the problem and then solve it with CPLEX. Rather than simply using the optimal solution reported, we obtain a set of solutions provided by the *solution pool* feature of the solution engine. We then map these solutions to a network, in which each solution is a node and an edge represents the distance between a pair of solutions (as measured by the number of teams assigned to a different time slot in those solutions). Using a scenario-based exact robustness measure, we test a set of metrics to determine which ones can be used to heuristically rank the solutions in terms of their robustness measure. Using seven semesters' worth of actual data, we analyze performances of the solution approach and the metrics. The results show that by using the solution pool feature, analysts can quickly obtain a set of Pareto-optimal solutions (with objective function value and the robustness measure as the two criteria). Furthermore, two of the heuristic metrics have strong rank correlation with the robustness measure (mostly above 0.80) making them quite suitable for use in the development of new heuristic search algorithms that can improve the solution pool.

1. Introduction

In practice, analysts are often more interested in finding a robust solution rather than an optimal solution to a discrete optimization model of a problem, especially when a model has plenty of good solutions (including several optimal or close-to-optimal solutions). Because models are simplified representations of actual problems, analysts are usually forced to leave out some characteristics or quality criteria of the problems they are addressing. Robustness is one such criterion that is not straightforwardly integrated into a mathematical model. In this research, we propose an approach in which first a solution engine is used to generate a set of solutions (in this case, CPLEX with its solution pool feature) and then the set of solutions is represented by a network. Next, after a robustness measure is calculated using this network, Pareto-optimal solutions are identified (using the objective function values and the robustness measures of the solutions as the two criteria). Because robustness is calculated after a set of solutions has been found, the network-based approach is applicable not only to timetabling but also to scheduling and possibly other discrete optimization problems, with any solution engine that produces a set of alternative solutions (e.g. meta-heuristics).

The timetabling problem we address herein is one that one of the authors faced in an undergraduate-level *Introduction to Management* course. The characteristics of the course, which we describe in detail subsequently, led to the need to assign student teams to time slots according to diversity and homogeneity criteria. To the best of our knowledge, the literature has not addressed combining grouping decisions with diversity objectives and timetabling in a single model. Furthermore, rather than simply finding an optimal solution, we were interested in discovering a robust solution that was easy to modify (typically by assigning one team to a different time slot) without significantly deteriorating the solution quality (i.e. objective function value). Although scheduling literature has addressed robustness concerns, we have not come across any research on robustness for academic timetabling problems.

The term project of the *Introduction to Management* course is the preparation of a business plan. For this, teams of three or four students prepare their business plans, which they present at the end of the semester. The course consists of approximately 150 students per semester, resulting in approximately 40 teams. For pedagogical reasons, three or four teams present in a time slot and all members of the teams in a time slot must be in the audience when other teams

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present their business plans. Each team has 25 minutes to setup, present, and answer questions and, thus the length of each time slot is 100 minutes. This is equivalent to two consecutive lecture hours at the university. Each time slot has two judges; one is the instructor of the course and the other is usually a teaching assistant.

Diversity of the teams assigned to the time slot is an important concern. The university's undergraduate curriculum does not require students to declare their major until the end of their second (sophomore) year. Although students enter one of the three colleges (called Faculty or School) as freshmen, their choice of major can be in any one of the Faculties (Engineering, Arts & Social Sciences and Management). All students, regardless of the Faculty they enter, take the same set of core courses in their first year. During their sophomore year, students choose a set of courses from different majors, to help them make an informed choice. The *Introduction to Management* course is one such course; thus, many students with different backgrounds and interests take it. Many juniors and seniors (mainly studying engineering or economics) also take this course, resulting in significant diversity in the academic characteristics of the students.

Thus, two pedagogic concerns are taken into account when grouping teams. First, because judges inevitably grade presentations relative to one another, the instructor wanted each group of teams to reflect the academic diversity present in the course (with respect to enrolled Faculty, GPA, and class). Second, teams with the same type of business plan (e.g. retail, manufacturing, services) should be assigned to the same time slot, with the goal of sparking livelier question-and-answer periods because all the teams would have faced similar challenges in preparing their business plans and could cross-check others' assumptions, make recommendations, and so on. Therefore, ideally teams in a time slot would have different Faculty, class, and GPA characteristics (referred to as "academic diversity") but have the same business plan type (referred to as "business plan homogeneity").

With approximately 40–50 teams, 10–13 time slots were required in a week (the last week of the semester) for the presentations. The course instructor wanted the number of days spanning the time from the first to the last presentation (referred to as the time-span of the timetable) to be as small as possible. From the students' perspective, this creates a sense of fairness; everyone presents on the same two or three days (around final exams).

The instructor wanted a robust solution for cases when a team, for one reason or another, could not present during its assigned time slot. That is, having announced the timetable to the entire class, the instructor needed to quickly devise an alternative timetable that not only is feasible for each team but also was roughly similar to the initial timetable.

The article is organized as follows: Section 2 provides a review of relevant literature. Section 3 details how the mixed integer programming (MIP) model is formulated (including the data model used, pre-processing of data) and solved (including a heuristic for an initial upper bound). Section 4 discusses the methodology used to identify robust solutions. Section 5 demonstrates the entire approach with an example. Section 6 presents the results of seven semesters' worth of actual data, and Section 7 concludes.

2. Literature review

2.1. Problem domain

The problem we analyze in this article is related to two problem domains: forming groups of individual entities (people in general, teams in our case) and timetabling of events. A review of the literature on group formation reveals that most articles deal with the problem of grouping students into teams that have diversity within but similarity across teams. For example, Reeves and Hickman (1992) assign MBA students to their preferred projects while maintaining some control of the quality and foreign student mix of the teams. They use a MIP model that puts student preferences and team quality into its objective function. Team quality is measured by the sum of class ranks of the team members, the maximum of which is minimized across all teams.

Baker and Powell (2002) review previous literature on forming work groups that have diverse members within and a minimum difference among groups. They examine alternative formulations and objective functions and recommend a composite measure for solving large problem instances. In our study, the objective function we use builds on the results in this paper, which we discuss in detail in the next section.

In a related study, Baker and Benn (2001) develop a model for assigning incoming students to tutor groups, with the objective of having evenly balanced groups and solve it using a heuristic algorithm. The balance of teams is measured by multiple criteria such as gender, ethnicity, ability level, and so on. The heuristic is a simple neighborhood search implemented in a spreadsheet environment. Weitz and Jelassi (1992), Mingers and O'Brien (1995) and O'Brien and Mingers (1997) all address an almost identical problem.

Grouping and timetabling problems are also common in manufacturing in which operators or workers are grouped into manufacturing cells and/or assigned to shifts. Slomp and Suresh (2005) address the problem of assigning operators in a manufacturing plant to teams that work in a shift system. The formulation of the model includes multiple objectives related to worker cross-training, labor flexibility, and labor costs and uses an interactive goal-programming approach for solution. Although their model contains similar characteristics to ours in terms of team formation and timing, many other manufacturing-related features included in the model are irrelevant for our purposes.

The model we develop in this article has a timetabling aspect, and therefore the timetabling and personnel scheduling problems constitute the second domain of problems in our study. In a recent review of staff scheduling (rostering), Van den Bergh, Beliën, De Bruecker, Demeulemeester, and De Boeck (2013) argue that unique requirements of different industries and organizations require context-specific models (e.g. airline crew rostering, bus crew rostering, call-center rostering). Similarly, each timetabling problem such as exam timetabling, course timetabling, crew scheduling, nurse scheduling has its extensive literature (e.g. see Lewis, 2007; Qu, Burke, McCollum, Merlot, & Lee, 2008; Schaerf, 1999). These timetabling problems are fundamentally different from ours however: the entities (e.g. students, nurses) assigned to time slots must take part in multiple events (e.g. exams, classes, shifts).

Certain timetabling problems do have some similarities to our model. One example is the study by Potthoff and Munger (2003), in which speakers are assigned to sessions of a conference by a conference organizer (grouping dimension), and the sessions are assigned to time slots (timetabling dimension) such that sessions of a subject area are evenly distributed throughout the duration of the conference. The authors solve a problem with 10 time slots and 96 sessions using a MIP formulation, because parallel sessions occur in each time slot. In another study on conference timetabling, Sampson and Weiss (1995) assign presentations to sessions and time slots in such a way that specific requests of session participants are also taken into account. This model is also different from ours, because participants can and do attend multiple sessions, and this is included in the objective function. The problem of student sectioning involves assigning students to sections of the same course, and it can be solved simultaneously with the timetabling of courses, as Müller and Murray (2010) discuss.

2.2. Robustness in scheduling

Finding robust solutions to optimization problems is a primary goal of many studies. Gabrel, Murat, and Thiele (2014) provide a re-