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Case Article

Class Scheduling with Linear Programming

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This paper describes "Kelly's Class Scheduling" case that illustrates a real-life application that is understandable to undergraduate business students in an introductory management science course. Given available courses, their meeting times, and ratings of the course sections, we show how to use a simple integer program to find an optimal class schedule. The case analysis is followed by an optional "Make Your Own Schedule" assignment where students formulate their own class schedule using a similar approach. This case-and-assignment combination offers several benefits. It provides an interesting example that students can identify with and is simple enough for inexperienced students to grasp in a relatively short time. It helps students develop appreciation for optimization methods by applying them immediately in their own life and lets students experience the entire process of quantitative modeling including problem definition, data collection, model formulation, model solution, and implementation.

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1. Introduction

Class scheduling, from a university's perspective, is a difficult problem. Each course must be assigned an instructor, time slot(s), and a classroom. For any given time slot, only one course can be assigned to an instructor and a classroom. The requirements and preferences of instructors, estimated student enrollment, and course characteristics must also be taken into account. There is an extensive literature on the class scheduling, including Dinkel et al. (1989), Badri (1996), Schaerf (1999), Nakasuwan et al. (1999), Martin (2004), and Gunawan and Ng (2011).

From the student's perspective, class scheduling is not as complicated as creating an entire schedule of classes for a university or a department, but it involves balancing numerous desires and constraints. Students typically spend a significant amount of time choosing classes to take each term, poring over alternative schedules that may fit around their internship or work schedule, and discussing with their cohort the advantages and disadvantages of various courses and instructors.

In the case presented here, a student named Kelly has a set of courses she must schedule in the upcoming term, each course with a choice of meeting patterns. Some courses are mandatory, and some are electives she can choose from to meet certain curriculum requirements. Her goal is to maximize the "total value" of her class schedule. The analysis of this case demonstrates how a linear program can be used to build a student's class schedule. It is simple enough for an introductory undergraduate management science course. It is highly motivating and relevant to the students. After the case discussion, students are asked to formulate their own class schedule for the upcoming term. This follow-up assignment lets students see the benefit of using an optimization method in their own life. In addition, they experience all the usual steps of the quantitative decision-making process: problem definition, model development, data collection, model solution, and implementation.

Teaching cases and pedagogical articles that discuss the use of optimization models for scheduling exist in the management science literature. For example, Birge (2004) and Trick (2004) both address using integer programming in scheduling sports teams. Vanhoucke (2010) describes an in-class exercise that has the benefit of immediate real-life impact similar to this class scheduling case, where an integer program is used to assign students and exam cases to groups.

We know of two textbook exercises using integer programming for class scheduling. The first is problem 6 in Winston (2003, §9.2, p. 503), also appearing as problem 44 in chapter 6 of Winston and Albright (2011, pp. 341–342). This exercise asks to minimize the number of courses a student must take to satisfy a number of curriculum requirements. One must choose from a set of courses where each course satisfies one or two curriculum requirements and some courses have prerequisites. Here, the issue is not scheduling of courses in time slots as in Kelly's scheduling case, but choosing which courses to take.

The second exercise is problem 75 Winston and Albright (2011, Chapter 6, p. 345), a variation of problem 37 in Winston (2003, §9.2, pp. 508–509). Here, one is asked to schedule seven courses: five with enrollment of 50, one with enrollment of 100, and one with enrollment of 150 into five classrooms: two with 50 seats, one with 100 seats, and one with 150 seats. The courses meet at different times during a five-hour school day. The courses that cannot be scheduled in the five given classrooms will need to be taught at classrooms outside of the business school building. The goal is to minimize the number of hours students must take their class outside of the business building. In this exercise, in each hour of the five-hour day, there is a limited number of rooms available. This is somewhat similar to Kelly not being able to schedule more than one course in each time slot. However, the context is different in that Kelly needs to decide which courses to take and when to take them, whereas this exercise involves scheduling courses into classrooms.

In summary, to the best of our knowledge, class scheduling by students—as an application of optimization—has not been addressed in a teaching case, article, or textbook.

2. Case and Assignment Description

The case, titled "Kelly's Class Scheduling," is based on a common situation a student faces at a university, and the data in the case are loosely based on actual course offerings at Pace University. A student named Kelly needs to schedule five courses for the semester: Business Strategy (MGT 490), International Finance (FIN 358), either Intergenerational Computing (CIS 102T) or Web Design for Nonprofit Organizations (CIS 102W), and two additional finance courses. Each course has multiple sections. For example, FIN 358 has one section meeting Wednesday evenings and another meeting twice a week, two hours on Tuesdays and one hour on Thursdays. The case gives the list of course sections with their meeting times and ratings. The objective is to find the schedule with the maximum total rating while avoiding time conflicts. This problem can be formulated as a simple network optimization model and solved with Excel Solver. This is the basic case scenario. Students can be asked to explore various other scenarios, involving, for example, online courses, limiting the number of school days, and avoiding a morning and night class on the same day.

After the case has been solved, we ask students to complete a follow-up assignment, called "Make Your Own Schedule," which requires students to build their own schedule using a similar process in the case analysis. They are asked to determine their priorities and requirements, collect data from the online course schedule, assign ratings to classes based on their priorities, and find the optimal schedule.

3. Background and Teaching Objectives

The main objective of the "Kelly's Class Scheduling" case is to expose students to a realistic, but basic, optimization model that even weaker students can formulate and solve on their own. Formulating next semester's schedule is an important part of student life. Since class scheduling is a familiar situation to the students, the instructor does not need to spend time providing background information, and students do not need to read any background material to understand the case.

This case has been used successfully in MGT 355 at Pace University, a junior-level introductory management science course required of all undergraduate students in the business school. This course typically covers decision analysis, forecasting, linear programming (may include some network models), Monte Carlo simulation, inventory models, queueing models, and project scheduling. Excluding time for exams, there are approximately 33 hours of class time. Students are juniors and seniors who have taken a finite mathematics course (a freshman course covering probability, matrix algebra, and basic financial mathematics) and a statistics course before this course.

We face several challenges in teaching the introductory management science course. Many students have weak quantitative skills and only a rudimentary knowledge of Excel. Many students are not able to allocate substantial study time outside of classes because they have part-time jobs and internships, and some students work full-time while taking a full load of courses. Under tight time constraints in and out of class, it is difficult to bring the students to the level of proficiency where they could apply what they learned in a realistic setting. Hence, it is difficult to find a case that is appropriate for this group of students. Kelly's Class Scheduling case meets this need.

For two semesters, we used this case for class discussion. During that time, several students indicated they would like to try to build their own class schedule following the same method. In the third semester, we added a Make Your Own Schedule assignment as a follow up to the case. The addition of such an assignment has increased the value of the case. Specifically, it helped students retain the modeling concepts; see how the optimization model can be applied to their own life; and experience the whole process of problem definition, data collection, modeling, analysis, and the evaluation.

4. Case Analysis Process

The way we have integrated the case and the follow-up assignment is to show how to solve the case in class then have students work on their own schedule. The case is discussed after the students have been exposed to linear programming and simple transportation and assignment models. The case discussion is timed just before the class registration period, after the upcoming semester's course offerings become available online. Both the case and the assignment are handed out before the case discussion. The students are asked to read the case and to complete the first part of the assignment where they

—identify the important priorities and requirements for the next semester's schedule,

—make a list (using the online class schedule) of the course sections they would consider taking, and

—rate each course section based on their priorities.

Hence, when students come to the case discussion, they have defined their problem, have collected the relevant data, and are motivated to learn how to model the problem.

Of course, not all students will be registering for courses in the upcoming semester. Some may be graduating, and some may be planning to study abroad. In such cases, students are asked to create a hypothetical schedule of the courses they are taking currently, as if they were going to repeat their current semester during the upcoming semester.

The case discussion proceeds in the following steps:

1. Organize the data in a table with meeting time patterns as rows and courses as columns.
2. Solve the problem by a simple greedy heuristic of choosing the highest rated choice at each step.
3. Express the problem as a linear program.
4. Formulate the model in Excel and solve with Excel Solver.
5. Discuss variations to the model such as limiting the number of school days and adding the option of online courses.

These steps are described in detail in the accompanying case teaching note (available as restricted instructor material at http://dx.doi.org/ited.2014.0128ca). The entire process takes a little over an hour. The key step is to organize the data in a way that is understandable and manageable. The course section ratings are placed in a table with rows representing distinct meeting patterns and columns representing courses. The rows are allowed to overlap in time. For example, one row might represent the meeting pattern of Mondays 1:25–2:20 P.M. and Wednesdays 1:25–3:15 P.M. and another row might represent the meeting pattern of Wednesdays 2:30–5:10 P.M. The possibility of a student choosing courses in the overlapping time patterns is eliminated by adding an appropriate constraint. This approach is simpler than having rows represent all of the nonoverlapping time periods throughout the week (for example, 8 rows for Monday, 8 rows for Tuesday, etc.), which can quickly become unwieldy when courses have a variety of meeting patterns.

In general, we have found it helpful in our introductory course to experiment and explore hypothetical solutions before formally modeling the problem. This helps students develop intuition and understand the model when it is presented. For this purpose, the second step is important. We have borrowed a version of the minimum-cost method from the transportation model algorithm for this, choosing the highest-rated cell each time instead of the minimum-cost cell. This greedy heuristic makes intuitive sense, and the crossing out of rows and columns visually drives home the point that each choice eliminates many other potential choices. Even if students do not retain all the optimization modeling concepts in the long run, the first two steps, organizing the data in a table and using intuitive logic to make choices, are valuable lessons in themselves.

The optimization model is a variant of the transportation/assignment problem, and extensions to the basic scenario can be modeled with additional variables and logical constraints. The level of the students can dictate how much guidance is given in the modeling process.

The case discussion encourages student participation since the students recognize the familiar setting and are motivated by the need to eventually create their own schedule. Students identify in the case the requirements that are similar to their own and are eager to discuss their own requirements that are not apparently covered in the case. The discussion can become lively with some asides into discussion of teacher ratings such as www.ratemyprofessors.com and trading stories on different courses students have taken. There are a lot of opportunities for student participation even from the students who have weak quantitative background.

5. Experience

During the three semesters we included the "Make Your Own Schedule" assignment, the assignment was collected from 127 individual students. (The results from the first semester were reported in Winch and Yurkiewicz (2013).) Approximately 75% of the students were proficient with the basics: building a table from the list of their course sections, taking no more than one class per time slot, taking no more than one section of the same course, using Excel SUM and SUMPRODUCT formulas, and solving with Excel Solver. Seventeen percent solved the problem using only the heuristic and skipped the optimization model, and 10% of the students turned in a nonsensical solution. Among those who understood the basics, a common error was forgetting a constraint for overlapping time slots. Grading of the assignment took more time than usual since it was individualized. However, it was not overly burdensome as everyone had formulated the same type of model.

The size and complexity of the problem can vary depending on the student's course requirement and time constraints. Students who work during the day and take evening classes have fewer options and may feel using an optimization method is an overkill. Students who have complex requirements—such as having to choose a lab section and corequisites—will have more complicated models to build. A student may choose to ignore more complex requirements instead of spending the time necessary to build a realistic model. We assure the students they will receive full credit as long as they correctly implement the basic requirements and that they will not be penalized if they make errors in their attempt to account for more advanced requirements.

As for the size of the problems the students solved, the average number of course sections considered was approximately 11 and the maximum was 21. The maximum number of distinct courses students considered was 12 and the maximum number of distinct time slots considered was 13. For comparison, the problem size in Kelly's case was between 20 and 26 course sections with 10–11 time slots and 8–12 courses.

As a part of the assignment submission, students were asked "Do you plan to use the schedule you came up with from this method? Why or why not?" Seventy-one percent of the students said yes, 8% said no, 9% were unsure, and 12% did not answer. Among the students who said no, the majority were graduating students (so they will not be registering for classes).

Some of the stated reasons for using the optimal schedule were as follows:

"Solver did the thinking for me when it comes to figuring out what time to take each class and that was very cool."

"This model fits in my considerations, such as rating of classes and required classes, with scientific analysis. This is an amazing tool to schedule classes."

"Usually when making my schedule, I would make chart after chart with all the alternatives. This saved me a lot of time!"

"I do plan to use this schedule because it incorporates all my constraints and solver's optimal solution is my own optimal solution. Additionally, it allows me to put in more hours at work."

The following are some reasons for being unsure:

"If I find a job, I might want to come to school fewer days of the week."

"I would like to use this method I came up with, but I would prefer to make my own schedule myself. This takes too much time to choose classes."

"I plan to use the schedule as a guideline because my work schedule can change and I need to get more information on the professors before deciding on the final schedule."

"Although it was a useful tool for future schedules, I'm just old-fashioned. I'd rather have a schedule I don't like than to punch everything into Excel and have a solver decide for me."

Of course, the situation can change between the completion of this assignment and the actual registration. To follow up, one semester, students were asked on an anonymous end-of-semester survey whether they ended up using the optimal schedule they obtained from this assignment. Approximately 40 % chose the response "yes," 30% chose the response "yes with some changes," and the remaining 30% responded "no." The reasons for not using the optimal schedule were: a desired class filled up, changed mind about what courses to take or what days to take courses, found out new requirements or new prerequisites after talking to the adviser, work schedule changed, forgot to account for some constraints in the model, and made mistakes in the assignment.

It is not clear whether this assignment helped students save time in building their class schedule. There were mixed opinions as seen in the comments above. The assignment forced students to collect and systematically organize all their options and use a new method to make the decision. For some, this may have taken more time than their usual trial-and-error method. However, most students felt this method improved the quality of their decision. On the end-of-the-semester student course evaluation, the optional section contains the question "What aspects of this course did you like the most?" In the semesters the scheduling assignment was used, many students responded along the lines of "practical applications to everyday life/real world."

6. Alternative Approaches

In our experience, the assignment of having students make their own schedules allowed students to apply what they learned immediately in their own life and increased their enthusiasm about the subject. The case discussion was viewed as a means to completing the assignment. However, assigning such an individualized assignment may not be practical or feasible for many instructors. Some of the possible problems are grading burden, difficulty of coordinating with the registration schedule, and insufficient number of class choices to make an interesting model.

In this case, instructors may want to focus on the case and omit the follow-up assignment. Regardless of the approach used, instructors may find it worthwhile to modify the case data based on the courses and meeting times offered at their institution. It helps increase students' interest when they recognize the familiar setting.

The case discussion in class will involve the instructor guiding the students in developing the model in class, then students solving the problem and submitting the case write-up. The suggested steps for the case discussion are described in the teaching note. In a course with more time or a higher level of students, it would be valuable to let students engage more creatively, perhaps discussing modeling ideas in small groups. In a larger class, groups of students can be assigned the case, perhaps with slightly different data, and the case write-ups can be collected from the groups.

Another approach is to discuss the initial case solution in class, then give students an assignment of modifying the case model to account for various situations as discussed in the teaching note.

7. Conclusions

This case-and-assignment combination of class scheduling lets students apply linear programming in their own life, and gives them an opportunity to collect their own data and experience the entire process of quantitative modeling. It is easily understood and can be implemented by novice students using only Microsoft Excel Solver. The case analysis can accommodate advanced students with extensions that call for binary variables with logical constraints.

The scheduling assignment has been used successfully for several semesters. The undergraduate business students enrolled in our course appreciate the usefulness of optimization and gain an understanding of the quantitative modeling steps. We believe other instructors will find the class scheduling case a useful addition to their management science or quantitative modeling course.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/ited.2014.0128ca.

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