CASE STUDY

An undergraduate uses O.R. to improve final exam schedules at her university

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Abstract

Final examination scheduling is typically a complex problem that impacts students, faculty, and administrators at every university. In this paper, we describe how an undergraduate student, for her senior project at Kutztown University, analysed the final exam schedules at Kutztown University to see if she could improve them. Specifically, she wanted to see if she could reduce student conflicts defined to be a student having three exams scheduled on the same day. The approach that she developed, based on a balanced bin packing algorithm, was very appealing because it could be implemented manually by a staff member of the Registrar's office, requiring at most 30 minutes to generate the schedule. Testing this approach using actual data from the Fall 2015 semester resulted in a 42% reduction in student conflicts. This approach, because of its simplicity and intuitive appeal, was widely accepted by the Kutztown University faculty and administrators and is being implemented for the Fall 2016 semester.

Keywords: Final examination scheduling, operational research applications, balanced bin packing algorithm, undergraduate student projects.

1. Introduction

Typically, Kutztown University (KU) posts a final exam schedule for both the fall and the spring semesters before knowing any of the students' class schedules. These final exam schedules are usually the same for both semesters. The current posting of the exam schedule does not take into account the number of students that take an exam on each day (There are three two-hour exams scheduled each day). If a student is scheduled for three exams in one day, this is considered a conflict and the student has the right to get one of these exams scheduled on a different day. This is obviously both a nuisance to the student as well as the instructor. In this paper, we will discuss how an undergraduate student, as her senior project, developed an approach for final exam schedules that tends to minimize student conflicts. Her approach could be manually (done in less than 30 minutes by a staff member of the Registrar's office) implemented using only readily available (at the beginning of each semester) knowledge of the number of students in each class meeting time.

In the next section, we will briefly mention some final exam scheduling approaches that appear in the literature. This will be followed by a discussion of KU's current exam schedules and constraints. After that we will remark on how a sample of student classes and exam times motivated the balanced bin packing algorithm for final exam scheduling. Subsequently, student data for the entire Fall 2015 semester will be used to compare the number of student conflicts caused using the actual fall final exam schedule versus the final exam schedule generated using

the student's balanced bin packing approach. Finally, implementation details of the balanced bin packing algorithm will be outlined.

2. Approaches in the Literature to Final Examination Scheduling

There is a vast literature of research dealing with the final examination scheduling problem. For background on the final examination scheduling problem, we suggest the reader consult the paper by Mohmad Kahar and Kendall (2015). This paper also contains an extensive list of references on the subject. In this section, we will simply give two examples of approaches used to attack this problem.

In their paper titled, Heuristics for the Exam Scheduling Problem, Zhaohui and Lim (2000) proposed a solution to scheduling exams for the National University of Singapore in which they attempted to maximize the amount of time each student has between each of their exams in order to have more time to study. In their paper, Zhaohui and Lim focused on this specific constraint to the exam-scheduling problem by applying a graph colouring technique, which they called "*Iterative Greedy.*" Each node represents an exam and the edges between the nodes represent the conflict between the exams so that the nodes cannot be coloured the same colour or else it would result in one student having two exams at one time. The authors also used a Tabu Search to find an even better solution when attempting to further optimize the spread of the schedule. A direct use of the value of Average Gap between exams is used to solve the exam problem with a Tabu Search.

Akhan Akbulut and Guray Yilmaz (2013) conducted their research on the exam scheduling problem and the implementation of a graph colouring algorithm as well. To begin their approach, Akbulut and Yilmaz created a ratio control that shows the common percentage of students between two exams. The ratio control is checked when placing two exams on one day. Like Zhaohui and Lim, each node in Akbulut and Yilmaz graph colouring algorithm is an exam, and the edges between the nodes represent the conflict between two exams. Each node is coloured differently for the time period that exam will take place so that two adjacent nodes cannot have the same colour. Once one colour is used, that colour will not be in the domain of usable colours for the other nodes. This process is continued until each node has a specific colour and there are no overlapping colours.

3. Current Final Examination Schedules at KU

Currently at KU, the final examination schedule has remained the same for a number of years. A primary consideration (constraint) in the schedule is that classes that meet on Mondays, Wednesdays, and Fridays (MWF) must have their final exams scheduled on either a Monday or a Wednesday or a Friday. The same situation holds for classes that meet on a Tuesday and Thursday (TTH). This constraint appears to be motivated, at least in part, by commuting students who, for logistical reasons, only schedule classes on Mondays, Wednesdays and Fridays or only on Tuesdays and Thursdays (With more online classes, students are more and more limiting their visits to campus). There are 15 final exams scheduled over five days (Monday through Friday) - one week. Classes that meet in the evenings or on Saturdays make up a very small percentage of the student body and are not considered in this study.

The student began her analysis by organizing the class times of both Monday, Wednesday, and Friday (MWF) classes and Tuesday and Thursday (TTH) classes into chronological order and assigning each class time to ordered periods shown below:

Table 1. Class Time Periods

Class start times	Periods
MWF 8:00AM	1
MWF 9:00AM	2
MWF 10:00AM	3
MWF 11:00AM	4
MWF 12:00PM	5
MWF 1:00PM	6
MWF 2:00PM	7
MWF 3:00PM	8
MWF 4:00PM	9
TTH 8:00AM	10
TTH 9:30AM	11
TTH 12:00PM	12
TTH 1:30PM	13
TTH 3:00PM	14
TTH 4:30PM	15

She did this to organize the data in order to effectively show the calculations and make the tables easy to understand.

As stated previously, KU keeps the exams for TTH classes on either Tuesday or Thursday and the same for MWF classes because of possible scheduling conflicts with the students who have other obligations. This can be seen in the current University's exam schedule shown below:

Table 2. Current Exam Schedule

Exam Days	Class Time Periods
Monday	2 3 5
Tuesday	11 12 14
Wednesday	4 6 7
Thursday	10 13 15
Friday	1 8 9

This table shows which class periods' exams are held on each day.

In terms of the objective of reducing student conflicts (a student having three exams on one day), the final exam scheduling for MWF classes can be handled separately from the final exam scheduling for TTH classes. In fact, for MWF classes, the problem reduces to looking at partitioning nine things into three sets of three items each. This number of partitions is $\frac{C(9,3)\times C(6,3)\times C(3,3)}{3!} = 280$. For TTH classes, the problem reduces to looking at partitioning six things into two sets of three items each. This number of partitions is $\frac{C(6,3)\times C(3,3)}{2!} = 10$. Remember that we are focused on reducing student conflicts. The Registrar's office has the flexibility to decide which exam time is scheduled 1st, 2nd and 3rd for a given day. Also, which day (MWF or TTH) the exams are given does not change the number of student conflicts. Hence, in theory, computer programs could be written to analyse all 280 possible partitions for exams for MWF classes and select the partition that minimizes student conflicts for those exams and the same approach could be used for the 10 possible partitions for the TTH classes. However, with approximately 9,000 students, the computing resources required to develop the programs, maintain them, and execute them each semester are non-trivial. The student decided to see if there was a more efficient way that would not require any computer programming and could be done manually by a member of the Registrar's staff in under 30 minutes (usually less) using existing class enrolment information.

4. A New Final Examination Scheduling Approach for KU and Its Experimental Results

To get some idea if student conflicts could be reduced in the final exam schedules at KU while still adhering to the constraints that final exams for MWF classes are scheduled on either Monday or Wednesday or Friday of the exam week and that final exams for TTH classes are scheduled on either Tuesday or Thursday of the exam week, the student decided to analyse the class and final exam schedules of 154 anonymous KU students from the Fall 2015 semester. She meticulously calculated the number of student conflicts for each of the final exam days. Without getting into specific numbers, what the student found was that there were an uneven total number of final exams scheduled on each day with more conflicts occurring on days when more final exams were scheduled. She wondered what would happen if the exams were spread out more evenly across the five days of exam week, but still obeying the MWF and TTH constraints. To this end she viewed the three days (MWF) as 'bins' and she developed a 'balanced' bin packing algorithm to 'fill' these bins in a balanced manner. She used the same approach for TTH classes, but only two bins are 'filled'.

Balanced Bin Packing Algorithm (BBPA) for MWF classes:

- Step 1: Calculate the number of students in each class time period for MWF classes (This information is available from existing computer systems);
- Step 2: Sort the class time periods in descending order by the number of students in each period;
- Step 3: Take the class period at the top of the list, schedule that period on the exam day with the fewest number of students already assigned to that day (bin);
- Step 4: Continue this until all MWF class time periods have been assigned. Make sure that exactly three exams are assigned to each day.

The BBPA for TTH is analogous. The second part of Step 4 is necessary if there are class times with very small enrolments. Amazingly, when this approach was used to schedule final exams for the 154 student test data set, the number of student conflicts (over the five exam days) dropped from 19 to only 8.

Based on these encouraging results, we requested assistance from KU's Institutional Research Department to analyse data for all students for Fall 2015 (approximately 9000 students). Institutional Research provided the class enrolment information needed for Step 1 of the BBPA. Also, they calculated all student conflicts (by exam day) for the actual Fall 2015 final exam schedule. Using this information the BBPA was applied to determine a new final exam schedule for Fall 2015. The schedule generated by the BBPA was then provided to Institutional Research. Institutional Research calculated the number of student conflicts for this schedule. A side-by-side comparison of the two schedules with the number of student conflicts for each schedule is given in the table below.

Table 3. Comparison of Two Exam Schedules

Exam Days	Actual Schedule	Number of student conflicts	Balanced Schedule	Number of student conflicts
Monday	2 3 5	483	3 8 7	150
Tuesday	11 12 14	395	11 14 10	145
Wednesday	4 6 7	244	2 6 1	194
Thursday	10 13 15	29	12 13 15	72
Friday	1 8 9	34	4 5 9	129
Total conflicts		1185		690

The final exam schedule generated manually (in a few minutes) based on the BBPA resulted in only 690 student conflicts versus 1185 student conflicts in the actual schedule. This is a 42% reduction in the number of student conflicts.

5. Implementation

These results and the Balanced Bin Packing Algorithm were initially presented to the Registrar and members of his staff in fall of 2015. Based on the intuitive appeal and ease of implementation of the BBPA, they immediately bought into having the Registrar's office use this approach. Next, the chairs of all the academic departments unanimously approved the BBPA approach for final exam scheduling (early spring semester 2016). The final step was the endorsement by the appropriate administrative departments (April 2016) to use this approach starting with the Fall 2016 semester.

6. Conclusions

In this paper, we discuss how a student, for her senior project, applied operational research techniques to develop an algorithm that significantly reduces student conflicts of three final exams scheduled in one day. This approach is actually being implemented at her university to generate final exam schedules starting with Fall 2016. Unfortunately, being a senior and having graduated in Spring 2016, she will not be able to enjoy the fruits of her labour.

7. Acknowledgements

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8. References

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