Optimized automated university timetabling with Covid-19 social distancing restrictions

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Abstract. This extended abstract article describes the impact of the COVID-19 health restrictions in the teaching activities at the HEIG-VD university in Switzerland and the way that teaching activities could be maintained by using a custom timetabling algorithm incorporating the necessary social distancing health measures. The modified algorithm, using a mixed-integer program model, produced a new timetable and at the same time automatically selected the optimal mode of delivery for each lecture: remotely by video conference or physically in the classroom. The optimization model ensured that physical contact among students was minimized, while at the same time guaranteed that the courses or laboratories requiring physical presence were still able to take place.

Keywords: Educational timetabling, mixed integer programming.

1 Introduction

University timetabling is a well-studied optimization problem in the academic literature [3,12,6,5,9] and a large volume of research has looked at every aspect of academic timetable production. The COVID-19 health crisis added new challenges in timetable construction, one of which is presented here.

The onset of the COVID-19 crisis had an impact on all aspects of life where social interaction is required, including education. In particular, during the spring of 2020, schools and universities in Switzerland, including ours, were obliged to restrict the use of classrooms and lectures were delivered online using videoconferencing. The only exceptions were a limited number of classes requiring specialized equipment or laboratories as well as the final exams, which were allowed to take place in the classrooms with protective measures.

The planning for the following academic year 2020–21 was subject to a number of COVID-19 social distancing restrictions, which are summarized as follows: (i) any lectures requiring specialized equipment or laboratories must take place physically at the university buildings, (ii) the remaining lectures may be given either online or at the university, and (iii) students can only be physically present at the university for a maximum of three days a week. The idea was to allow students at the university for a limited number of days, whilst optimizing the mode of delivery of each course. To implement this, each lecture was assigned a weight, ranging from 3 for a lecture which must be given in the classroom, 2 for a lecture ideally given in a classroom and 1 for lectures best suited for online lecturing. Some courses could have lectures of two types, for example, for Physics the practical experiments (one lecture a week) required physical presence, whereas the theoretical lectures (twice a week) could be given online.

The requirements created a challenging timetabling problem. We had to place the lectures which must take place in the classroom during a maximum of three days a week for each student (noting that some courses are shared between diplomas or orientations, so these three days can be different for each student) while filling in the gaps in the timetable using other courses which can be delivered in either mode. Conversely, all courses planned during the two days (at a minimum) during which a student is not at the university must take place online.

Note that the mode of teaching for each course must be the same for all students who follow it, so it is not possible for the same lecture to be "in the classroom" for some students and "online" for others. However, we assigned rooms to online lectures also: these rooms were used by students as a space to connect to an online lecture if they had to be at the premises for other lectures, and also in case the health measures were abandoned, enabling a return to classrooms.

At the same time the student population had to be assigned by the algorithm to the different parallel classes, since most courses are given multiple times (up to eight times) in order to ensure that classes contain no more than 25 to 30 students. Students are assigned to parallel classes each semester at the time of creation of the timetable. Furthermore, the usual quality constraints had to be maintained: avoid having gaps in the student timetables, distribute lecture of the same course over a number of days and so on.

If we consider the recent literature, it is clear that we were not the only university facing such challenges. Various COVID-19 timetabling challenges are studied in [1,8,13,4,2,7] although in many cases the size of the timetable considered is much smaller that the problem described here.

2 Mathematical modeling

The timetable for undergraduate engineering degrees at the HEIG-VD university is produced with an in-house software which models the timetabling problem as a mixed-integer program, similar to [10]. In particular this model calculates three elements, modeled as binary 0-1 decision variables: the start time of each class, the rooms allocated for each class and the assignment of classes to each student.

In order to model the COVID-19 requirements we introduced a fourth element to be calculated by the optimization model: a variable D_l, shared by all students, denoting whether the class takes place in the classroom or via videoconferencing. For every lecture l to be placed on the timetable:

$$D_l = \begin{cases} 1 & \text{if the lecture } l \text{ takes place via videoconference (online),} \\ 0 & \text{if the lecture } l \text{ takes place in a university classroom.} \end{cases}$$

With regards to the additional constraints imposed on the student timetable, an additional variable per student and per day was added, denoting if a student is entirely online that day (all his courses on that particular day are "via videoconferencing") and therefore not present in any university building, or not (at least one course he has to follow takes place in a classroom). This is modeled as follows: for every student s and day j we define:

$$V_{sj} = \begin{cases} 1 & \text{if all the lectures followed by student } s \text{ during the day } j \text{ are online,} \\ 0 & \text{if at least one lecture followed by } s \text{ takes place at the university.} \end{cases}$$

The addition of these two types of decision variables allowed us to formulate all the necessary COVID-19 timetabling constraints and define the additional terms of the objective function. It is possible for a student to have lectures given in a classroom and online on the same day. In those cases the room assigned to the online lecture could be used by students (and sometimes lecturers) as a space to connect to the lecture online if desired.

The implementation was done by adding the additional variables and constraints to the existing timetabling mixed-integer programming model used by the university, which already includes over 40 types of timetabling constraints and solved with a two-stage algorithm very similar to [11]. The software is programmed in C++ using a commercial version of Cplex as the mixed-integer programming solver and typically takes several days to solve due to the sequential addition of the constraints and the need to remove some default constraints for some courses when infeasibility occurs.

The addition of the COVID-19 constraints did not have a big impact on the overall complexity or time needed to produce a solution of acceptable quality, however the final timetable produced placed lectures at very different locations to our standard timetable without any COVID-19 constraints. The characteristics of the timetabling problem are shown in Table 1. The number of courses denotes the total number of times the same subject is given (parallel courses), each student class is assigned to only one course for each subject it follows. The number of lectures is the number of events to be scheduled each week.

Table 1: Characteristics of the timetabling problem.

Number of students	962 (405 classes)
Number of different subjects	239
Number of different courses	377
Number of lectures (lessons) per week	709
Number of teaching staff	200
Number of rooms	87
Number of time slots	10 per day × 5 days
Duration of each lecture	2, 3 or 4 slots
Average size of each lecture	18.6 students

The results of this approach were very positive. Thanks to our ability to develop this mixed-integer timetabling model during the summer of 2020, we were able to construct a timetable for 2020–21 which reduced the number of students present at the university by 40% from an average of 840.6 students to 501.4 students present per day (Table 2). At the same time, we were able to place at least one lecture per week of every subject during the three days the students were present, a positive outcome, ensuring that contact between students and teachers was maintained, and activities such as tests could take place in the classroom during the semester.

Table 2: Number of students present and courses taking place in university buildings

Usual timetable	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	
Students physically present:	893	894	798	874	744	**840.6 (average)**
Lectures held in classrooms:	158	157	144	152	98	**709 (total)**
Modified Covid timetable	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	
Students physically present:	636	513	465	661	232	**501.4 (average)**
Lectures held in classrooms:	107	88	80	111	38	**424 (total)**

3 Conclusion

This paper presented the work carried out during the height of the COVID-19 crisis at the HEIG-VD university in Switzerland to guarantee the best teaching outcomes for the undergraduate engineering courses. Using a modification of the actual mixed-integer programming timetabling model we were able to incorporate the necessary social distancing health restrictions. This produced a timetable for the 2020–21 academic year which took into account the requirement to limit the number of days the students are present at the university buildings, while at the same time guaranteeing that courses requiring specialized laboratory equipment were able to take place in person.

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