Constraint Programming for Curriculum-based High School Timetabling with Half-Blocks

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Abstract

In high school timetabling, some institutions adopt a university-like structure in which students follow different curricula and multiple sections are offered for each course, without pre-assigning students to specific sections. In such settings, student sectioning and timetabling are strongly interdependent.

In the case of universities, timetabling is usually carried out with integer linear programming or metaheuristics, before assigning students to sections on the fixed schedule. The goal for universities is most often to maximize the quality of the schedule defined by a set of weighted soft constraints. One of the soft constraints generally includes a course's well balanced meeting time slot distribution throughout the week. However, several Canadian high schools construct their schedule according to predefined block patterns, where a block corresponds to a set of meeting periods designed to ensure a balanced distribution of instructional time. These schools also pre-assign teacher workloads and rooms to courses. Instead of maximizing schedule quality already ensured by the block pattern, the goal is to balance the number of students across the groups. Indeed, aside from room capacities, government regulations impose a maximum limit on group sizes, over which schools have to pay penalties. Balancing group sizes is also fairer for teacher workloads and allows teachers to give equal attention to all students.

While the block structure eliminates many classical timetabling constraints, it introduces a specific challenge: courses occupying half-blocks must be paired to form full blocks. These courses require less meeting periods than the average, and are generally option courses, from which the variety in the curricula stems. Half-block courses also require resources shared with the whole school, such as gym rooms and art teachers. For these reasons, the half-blocks courses placed first in the schedule and are paired to form full blocks. This allows students to have the rest of their courses on well balanced, full blocks, thus easing student mixing between sections for improved student sectioning. The pairing of half-block courses is a critical step, as it directly impacts the balance of students across sections. Scheduling half-block courses is a clustering problem, as all courses use the same limited and fixed block pattern.

Dash Computer Solutions is a company responsible for the annual design of more than a hundred schedules in Quebec. These schedules are currently built manually, starting with a hand-crafted initial solution which is then iteratively improved through locally designed adjustments performed by human operators. Although this approach is capable of producing high-quality schedules, it is time-consuming: generating a schedule for half-block courses alone requires at minimum a day of work for one operator.

Based on this context, this paper introduces a constraint programming approach to generate a feasible half-block course schedule leading to good student balancing. The model relies on compatibility constraints between half-block courses and incorporates symmetry-breaking constraints to reduce equivalent solutions in the search space. The model is designed to enhance computational efficiency, accommodate additional practical constraints, and reduce the need for manual adjustments by scheduling operators. It uses a theoretical objective to search for solutions without assigning students to sections. The school's requirement on the minimum and maximum number of students

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per course are parameters taken into account to filter out solutions which could not lead to a balanced distribution of students. These parameters are also used post student assignation to determine whether a solution is acceptable or not.

The approach is evaluated on anonymized real-world data from Canadian high schools for the 2024-2025 academic year, provided by Dash Computer Solutions, a company responsible for the annual design of over 180 high school schedules in Quebec, and is integrated with their existing student sectioning algorithm. The four main instances tested have between 46 and 112 groups to schedule, and between 399 and 781 students to assign. All experiments were conducted on a laptop equipped with an Intel i7-1065G7 CPU (1.30 GHz) and 8 GB of RAM as it is closer to the standard operator's machine at Dash.

Our model allows to find in a matter of seconds a valid schedule for all students, which allows the confirmation of the workloads and room assignment choices. The symmetry breaking constraints identifying course clusters are critical as no solution can be found within the given time limit without them. Our results show that our approach provides solutions of moderate quality compared to a human-guided local search with a hand-crafted initial solution, but reduces the designing time from 10 hours of operator work to one hour in the best case, without supervision. The schools with a higher number of sections per course are solved significantly faster. Our method is also compared with the hand-crafted approach used by the industrial partner to find a first feasible solution. This algorithm provides a solution almost instantly, with a significantly better theoretical score. However, it generates many conflicts, i.e., students without a feasible schedule, whereas no conflicts are produced by our CP model. Moreover, our solution remains flexible to specific school demands which could be implemented through additional constraints, further improving the performance.

While the global correlation between the theoretical objective and the actual group balance is confirmed, the correspondence between values does not seem strong enough for our theoretical objective to be used in the search. Hence, further work includes defining a more realistic search objective or incorporating iterations with the student sectioning algorithm. Additionally, our constraint programming model could be generalized to rarer tripartite block patterns.

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Supplementary Material
Dataset: `https://github.com/corail-research/half-block-scheduling-instances`

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