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Fairness in examination timetabling: Student preferences and extended formulations

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ABSTRACT

Variations of the examination timetabling problem have been investigated by the research community for more than two decades. The common characteristic between all problems is the fact that the definitions and datasets used all originate from actual educational institutions, particularly universities, including specific examination criteria and the students involved. Although much has been achieved and published on the state-of-the-art problem modelling and optimisation, a lack of attention has been focussed on the students involved in the process. This work presents and utilises the results of an extensive survey seeking student preferences with regard to their individual examination timetables, with the aim of producing solutions which satisfy these preferences while still also satisfying all existing benchmark considerations. The study reveals one of the main concerns relates to fairness within the student's cohort; i.e. a student considers fairness with respect to the examination timetables of their immediate peers, as highly important. Considerations such as providing an equitable distribution of preparation time between all student cohort examinations, not just a majority, are used to form a measure of fairness. In order to satisfy this requirement, we propose an extension to the state-of-the-art examination timetabling problem models widely used in the scientific literature. Fairness is introduced as a new objective in addition to the standard objectives, creating a multi-objective problem. Several real-world examination data models are extended and the benchmarks for each are used in experimentation to determine the effectiveness of a multi-stage multi-objective approach based on weighted Tchebyceff scalarisation in improving fairness along with the other objectives. The results show that the proposed model and methods allow for the production of high quality timetable solutions while also providing a trade-off between the standard soft constraints and a desired fairness for each student.

1. Introduction

Examination timetabling is a well-known and challenging optimisation problem. In addition to requiring feasibility, the quality of an examination timetable is measured by the extent of the soft constraint violations. The formulations for standard examination timetabling problems [1–4] have penalties representing the violations of various soft constraints, including those which influence the spread of examinations across the overall examination time period, providing students with more time for preparation. Of particular interest here is the fact that standard examination timetabling formulations concentrate on minimising the average penalty per student. We believe that this model can lead to unfairness, in that a small but still significant percentage of students may receive much higher than average penalties with a reduced separation between examinations than others. Since students believe that poor timetables could adversely affect academic achievement (as we show later by our survey findings), we believe that overall student satisfaction could be improved by encouraging fairer solutions. In particular, by reducing the number of students that may feel they have been adversely affected for no obvious good reason.

In our prior work [5,6], we briefly introduced a preliminary extension of the examination timetabling problem formulation in order to encourage fairness among the entire student body (for a study of fairness in course timetabling see [7]). However, the

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notion of “fairness” in this context is also likely to be quite a complex concept, with no single generic measure appropriate. Hence, to determine student preferences we conducted a survey. This paper reports the main results of the survey and also suggests and analyses extensions to the current models used for optimisation e.g. algorithms are presented along with experimental results.

The contributions of this paper broadly include:

- Presentation of the results of a survey amongst undergraduate and taught-postgraduate students concerning their own preferences for particular properties of examination timetables. These served to confirm our expectation that fairness is indeed a concern for them. In particular, it was apparent that students are mainly concerned with fairness within their immediate cohort.
- An extension to the examination timetabling problem formulation including objectives for fairness. The new problem formulation is inherently multi objective, including both objectives for fairness between all students, and also fairness within specified cohorts.
- Initial work towards building a public repository that extends current benchmark instances with the information needed to build cohorts, thus allowing methods on our formulation to be studied by the community.
- A proposal of an algorithm that works to improve fairness, specifically a multi-stage approach with weighted Tchebycheff scalarisation technique.
- Initial results on the benchmarks. In particular, we observe that there is the potential to control the trade-off between fairness and other objectives.

The rest of this paper is structured as follows. Section 2 presents the description of the examination timetabling problem and surveys the related works. We then present the findings from the survey, investigating students preferences especially regarding fairness over examination schedules within their immediate cohorts. Section 4 discusses our proposed extension on the examination timetabling problem formulation. The proposed algorithms used within experimentation are introduced in Section 5. Finally the experimental results are discussed in Section 6, before the concluding remarks in Section 7.

2. Examination timetabling

2.1. Problem formulation

The examination timetabling problem is a subclass of educational timetabling problems. (For example, see the survey of Schaerf [8], where educational timetabling problems are placed within three sub-categories: school timetabling problems, course timetabling problems, and examination timetabling problems.) Examination timetabling problems are a combinatorial optimisation problem, in which a set of examinations $E=\{e_1, \ldots, e_N\}$ are required to be scheduled within a certain number of timeslots or periods $T=\{t_1, \ldots, t_M\}$ and rooms $R=\{r_1, \ldots, r_K\}$. The assignments are subject to a variety of hard constraints that must be satisfied and soft constraints that should be minimised [9]. The hard constraints and soft constraints can vary between institutions: examples and detailed explanations can be found in [9].

In order to provide a standard examination timetabling problem formulation as well as the problem datasets from real-world problems in examination timetabling research, some previous studies have shared public benchmark problem datasets. The two most intensively studied benchmark datasets in this research area are the Carter (also known as Toronto) dataset [1] and International Timetabling Competition 2007 (ITC 2007) dataset [10].

The Carter dataset consists of 13 real-world simplified examination timetabling problem instances. The only hard constraint taken into consideration in the Carter model is that whereby each examination has to be allocated a timeslot and be ‘clash-free’, meaning no student is required to sit more than one examination in the same timeslot. The period (maximum) duration of each timeslot and room capacity are ignored. In other words, it is assumed that each timeslot has a long enough period duration for all examinations and there is always a room with sufficient capacity to fit all students sitting an examination during each timeslot. A soft constraint violation penalty, called the ‘proximity cost’, is also introduced. This cost should be minimised in order to give enough period gaps between examinations so as to give students enough time for revision. Formally, the penalty, P, is defined by:

$$P = \frac{\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} C_{ij} W_{|t_j-t_i|}}{Q} \quad (1)$$

where

$$W_{|t_j-t_i|} = \begin{cases} 2^{5-|t_j-t_i|} & \text{iff} \quad 1 \le |t_j-t_i| \le 5 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Solutions are subject to the hard constraint which stipulates that no student has two or more exams at the same time:

$$\forall_{i \neq j}. \quad t_i \neq t_j \quad \text{when} \quad C_{ij} > 0 \quad (3)$$

In Eqs. (1) and (2), given N and Q as the total number of examinations and students respectively, C_{ij} is defined as the number of students taking both examinations i and j, $(i \neq j)$. Also t_i and t_j are the allocated timeslots for examinations i and j respectively, and the timeslots are defined as a time sequence starting from 1 to M, the total number of timeslots.

Furthermore, $W_{|t_j-t_i|}$ is the weight of the penalty produced whenever both examinations i and j are scheduled with $|t_j-t_i|$ timeslots gap between them. The formula is reasonable in that an increased gap reduces the penalty, but the details are somewhat an ad hoc choice; for example, if the gap between two examinations is greater than five timeslots, then there is no penalty cost.

In contrast with the problem formulation of the Carter dataset, the ITC 2007 dataset formulation allows for the representation of much more complex real-world examination timetabling problems. In addition to the ‘clash-free’ constraint as required in the Carter dataset, a feasible timetable also requires that each examination has to be allocated to a timeslot with a long enough period duration and at least one room with enough capacity to accommodate all students sitting the examination. One can also specify hard constraints related to period (i.e. examination x has to be timetabled after/same time as/different time to examination y) and hard constraints related to room (i.e. if a room r in a timeslot t is already allocated to examination x, a member of the specified exclusive examinations, X, then no other examinations can be allocated to room r and timeslot t).

Compared to the Carter dataset, the ITC 2007 examination timetabling formulation has a much richer set of potential soft constraints. Formally, subject to all hard constraints being satisfied, the objective function is to minimise the total penalty as the result of a weighted sum of soft constraint violations:

$$P = \sum_{s \in S} \left(w^{2R} C_s^{2R} + w^{2D} C_s^{2D} + w^{PS} C_s^{PS} \right) + w^{NMD} C^{NMD} + w^{FL} C^{FL} + C^{P} + C^{R} \quad (4)$$

Where, the first set is a sum over penalties directly associated to each student s: