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udpSkeduler: A Web architecture based decision support system for course and classroom scheduling

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ABSTRACT

A key process for post-secondary educational institutions is the definition of course timetables and classroom assignments. Manual scheduling methods require enormous amounts of time and resources to deliver results of questionable quality, and multiple course and classroom conflicts usually occur. This article presents a scheduling system implemented in a Web environment. This system generates optimal schedules via an integer-programming model. Among its functionalities, this system enables direct interaction with instructors in order to gather data on their time availability for teaching courses. The results demonstrate that significant improvements over the typical fully manual process were obtained.

1. Introduction

For decades, higher educational institutions have relied on computer-based systems to support a wide range of administrative functions such as course registration, student record management and storage, and personnel and financial management. The use of such systems has significantly improved these institutions' organizational agilities, allowing them to achieve and maintain a considerable degree of administrative and operational efficiency.

A basic recurring process in colleges and university administration is the generation of timetables for course offerings. In its simplest form, this course scheduling process assigns each course to a time slot and a classroom subject to a series of requirements and constraints [28]. These conditions typically include the type and size of the required classroom, instructor time availability, and the avoidance of timetable conflicts for courses students are required to take in the same semester, in addition to any other conditions relating to specific objectives that have been defined by the institution administrators. The scheduling problem created by such a set of circumstances clearly poses an interesting intellectual challenge.

Given the combinatorial nature of the problem and its computational complexity, which has been categorized as NP-hard, manual solution approaches based on trial and error are naturally considered to be inefficient in scenarios with large numbers of courses and classrooms [19]. In real applications, the methods used must address not only the computational complexity but also a series of interconnected factors that vary over time, such as the instructors' time preferences, course prerequisites, and the creation of new courses and study programs.

The problem of generating course schedules and classroom assignments is by no means a new one, having been studied extensively in the literature and addressed through various solution approaches based on operations research [17,27]. In practice, however, only a small number of these studies have been implemented as decision support systems (DSS). A series of interconnected factors underlie this dearth of real-world applications, including organizational resistance to change and the adoption of new technologies [4], organizational attitudes and lack of commitment [11], negative perceptions of the systems' user-friendliness [25], the degree of problem difficulty supported by the DSS [12,13], the need for a multi-disciplinary work team to perform system-related tasks [1,11,26], as well as the required levels of users' experience [22,24], training [12] and participation in the development of the system [11,26].

The present article describes a scheduling decision support system that is based on a Web architecture called *udpSkeduler*. It was implemented in the Faculty of Engineering (hereafter referred to as “the

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Faculty") at Universidad Diego Portales (UDP) in Santiago, Chile, where it has generated a series of benefits that will be described in the following sections. The system uses an integer-programming model in order to define optimal schedules, which simultaneously incorporates all of the problem's requirements and constraints, as well as any additional objectives that are set by the Faculty Board of Directors. Further benefits of the *udpSkeduler* implementation include a reduction in the time that is required for scheduling due to process automation, improvement in schedule quality with fewer human errors and timetable conflicts, the ability to easily and quickly explore and analyze multiple scenarios through a user-friendly interface, and a reduction in work load for planning staff, which frees them for other tasks.

The structure of this article is as follows. Section 2 reviews the literature regarding the role of computer-based support systems in course schedule decision-making at educational institutions. Section 3 introduces the Faculty's timetabling problem and the various stages of the course scheduling process. Section 4 describes the *udpSkeduler* system and its constituent modules. Section 5 presents the results of the implementation, focusing on quantitative evidence of the improvements that are provided by the system. Finally, Sections 6 and 7 discuss the computational experiments that were conducted with the system and present our conclusions.

2. The importance of computer-based systems based on mathematical models in higher education course scheduling

Decision support systems based on mathematical programming models have been supporting course-scheduling processes for more than two decades [3]. The most commonly used solutions employ linear and integer programming techniques. The study by [7], a seminal work in this area, offers a theoretical analysis of a series of optimization problems that have inspired a variety of real-world problem applications. Solution approaches that are built around integer programming are presented in several studies such as [5,6,8,20,21]. Most of these works propose models in which the individual weekly sessions for each course are separately assigned, and the time slot configuration conditions are imposed by applying constraints. In the model to be presented here, the course sessions are assigned simultaneously to a single pattern made up of two components: a set of timeslots and a classroom.

Indeed, most of the above-mentioned studies concentrate on theoretical development and do not analyze an actual computer-based implementation; however, some researchers have integrated their solution approaches into practical applications by including decision support systems for the timetabling process. In 1989, [3] developed a computer-based system for a scheduling problem at an adult education institute that delivers initial solutions with relatively few course conflicts in a matter of minutes which can then be manually fine-tuned. They report that this iterative process produces a satisfactory schedule in no more than an hour.

In 1993, Johnson [16] implemented a computer-based scheduling system at the Loughborough University Business School that efficiently manages course information through a range of queries to a database. One of the principal benefits for the School has been the greater standardization of the process, which has been completely automated. Similar benefits are achieved in the system we propose here through partial structuring and automation of the process and the efficient management of information by means of database filters. These filters organize the information to fit the structure of the pattern assignment variable in the integer programming model, mapping the patterns within a reduced solution space and eliminating all a priori infeasible combinations.

A computer-based system that was implemented by Ferland and Leurent in 1994 [9], known as *SAPHIR*, adopts a heuristic approach to solve an integer-programming model, and provides an interactive optimization procedure that is similar to that in [3].

Stallaert [28] developed a computer-based course scheduling system for Anderson School of Management at the University of California at Los Angeles (UCLA) that generates schedules in two stages. The first stage exclusively deals with the core courses whereas the second schedules all of them. This allows the system to generate multiple versions of the core course schedule reflecting different criteria. A sensibility analysis can then be conducted and the best version can be chosen, with the end result being a better overall schedule. The method also integrates information management and report-generating functions that facilitate the process of fine-tuning the timetables.

Another decision support system for course scheduling, known as *SlotManager* [10], follows an approach that was originally designed by Liang et al. [18] by using a three-component structure that consists of interfaces, databases, and an optimization model. This system features a user-friendly interface and functionalities for obtaining information on course registrations, available classrooms, and course characteristics. The general structure of our *udpSkeduler* system is derived from this work but includes an additional module that supports direct interaction with the teaching staff, capturing instructors' time availability for giving classes and related preferences.

Dimopoulou and Miliotis [8] report on a computer-based system that was developed at the Athens University of Economics and Business that utilizes both a mathematical programming model and heuristic procedures in order to arrive at definitive course and examination schedules. The system is structured around five modules: a data module that manages information, a control system module that includes the user interface and generates data to be fed to the models, an optimization module that solves the mathematical programming model and executes the heuristics, a report generating module that reports on class timetables for use in decision-making, and an evaluation module that examines the quality of the generated schedules. According to the authors, this system provides better timetables for the students, a better use of classrooms, and a satisfaction of instructors' time preferences.

In 2002, Hinkin and Thompson [14] describe a computer-based system they developed, known as *SchedulExpert*, that uses an integer-programming model to generate course schedules for Cornell University's School of Hotel Administration. The principal benefits of this system are that it defines schedules that meet the objectives of the institution's governing body and reduces the time that is needed to produce them. In particular, it eliminates timetable conflicts between required core courses and certain sets of elective courses while, at the same time, minimizes conflicts between certain electives. Finally, this model also supports instructor course assignment decisions.

Miranda [19] presents a computer-based system named *eClasSkeduler* for courses that are given by the Executive Education Unit at the Universidad de Chile. Because of the way courses are taught by the Unit, with different course startup dates and varying course durations, the problem the system must solve requires that each week be individually and simultaneously scheduled. It therefore departs considerably from the problem addressed in the present work in which a single weekly schedule is replicated for an entire semester. Furthermore, although *eClasSkeduler* uses a course pattern assignment variable, the pattern structure differs from the one to be used here in that the former is defined by three components: a set of time slots, a classroom and a period of consecutive weeks over which the course is taught. As for the reported benefits of *eClasSkeduler*, they include a reduction in off-site classroom rental costs, fewer course conflicts, and efficient classroom use.

Finally, we note that all of the surveyed papers of Schaerf [27] and Lewis [17] clearly illustrate the significant benefits of incorporating computer-based systems into the decision-making process for course scheduling.