Modelling and Solving the Generalised Balanced Academic Curriculum Problem with Heterogeneous Classes

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1 Introduction

The *Balanced Academic Curriculum Problem* (BACP) consists in assigning courses to teaching periods satisfying prerequisites and balancing students' load in terms of credits and number of courses. The BACP planning horizon is divided in *academic years*, and each academic year is divided into *terms*. Each term of a year is a *teaching period* in which courses can take place. The problem consists in finding an assignment of courses to periods that satisfies certain load limits and prerequisites.

The first formulation of BACP has been proposed by Castro and Manzano [2], and it has been included in CSPLib [5, prob. 30] along with three benchmark instances. BACP, in the CSPLib formulation, has been studied by Hnich *et al* [6], Castro *et al* [1], Lambert *et al* [7], and Monette *et al* [8]. However, BACP is a very simplified model of the real problem that universities have to solve in practice. In fact, in its formulation it is implicitly assumed that a student takes all delivered courses without personal choices; whereas in practice a student can select among alternatives.

To try to overcome such limitation and to deal with the real cases, the formulation has been extended by Di Gaspero and Schaerf [4]. The problem defined by Di Gaspero and Schaerf [4], called GBACP (G for Generalised), makes it possible to specify several *curricula*, with courses shared among them. A curriculum is a set of courses representing a possible complete selection of a student. In this new formulation, courses have to be balanced for each single curriculum. Moreover, GBACP includes professor's preferences for teaching in specific terms, which are often taken into account in real situations.

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Instance	Periods (Years × Terms)	Courses	Curricula	Courses per curr.	Courses per period	Prereq.	Pref.
csplib8	8 (4 × 2)	46	1	46	5.75	33	0
csplib10	10 (5 × 2)	42	1	42	4.2	33	0
csplib12	12 (6 × 2)	66	1	66	5.5	65	0
UD1	9 (3 × 3)	307	37	34.62	3.847	1383	270
UD2	6 (2 × 3)	268	20	27.8	4.633	174	158
UD3	9 (3 × 3)	236	31	29.81	3.312	1092	198
UD4	6 (2 × 3)	139	16	25.69	4.281	188	80
UD5	6 (3 × 2)	282	31	34.32	5.72	397	162
UD6	4 (2 × 2)	264	20	27.15	6.787	70	110
UD7	9 (3 × 3)	302	37	33.89	3.766	1550	249
UD8	6 (2 × 3)	208	19	22.58	3.763	149	120
UD9	9 (3 × 3)	303	37	34.08	3.787	1541	255
UD10	6 (2 × 3)	188	15	25.07	4.178	214	110

Table 1 Statistics on the GBACP instances.

Di Gaspero and Schaerf [4] introduce six instances, called UD1 – UD6, obtained from real data from University of Udine, which are much larger than the CSPLib ones. They also propose a solution based on local search (LS), that finds easily the optimal solution for the CSPLib instances and provides a solution for the instances UD1 – UD6. Such instances turn out to be much harder to solve than the CSPLib ones, and their optimal cost remains unknown.

The GBACP has been further investigated by Chiarandini et al. [3] who study two solution approaches, one based on integer programming and one on local search. This latter is an improved version of the approach by Di Gaspero and Schaerf [4]. In addition, four new instances, called UD7–UD10 (still from University of Udine), have been added to the repository. All data on GBACP is available on the web at `http://www.diegm.uniud.it/satt/projects/bacp/` together with a program that validates the solutions.

Table 1, taken from [3], summarises the main features of the available instances.

2 GBACP with Heterogeneous Classes

In this work, we address another feature of academic curriculum scheduling that may be of interest to university. In order to gain more flexibility in their planning, some universities may wish to have *heterogeneous classes*, that is, having students attending a course in different years of their curricula while still having the course taught only once per year. In the GBAC model previously studied we did not allow this because each course was assigned to a period, which corresponds to a pair term/year that has to be the same for all students attending the course. Here, we extend that model to include also the possibility of *heterogeneous classes*. We call the extended model, GBACP with heterogeneous classes (GBACP-HC).

There are different ways to approach the new feature that a course can be attended in different years by different curricula in GBACP-HC. The model we investigated in this preliminary work consists in pairing a course with the curricula in which it appears and scheduling each pair separately in the term and the year. Then, since a course is taught only once during the academic year, the terms for all pairs with the same course must be imposed to be equal. Instead, the assignment of the year can be different for each pair. However, it is generally not advisable to have classes with large discrepancies in the academic age of the students because for pedagogical reasons the level of academic maturity should not differ too much. Hence, excessive spread of year of the students taking a course must be penalized.

3 Local Search for GBACP-HC

We solved the model for GBACP-HC described in the previous section by local search methods. Let C be the number of courses, Q the number of curricula, Y the number of years, T the number of terms, and $P = Y \times Q$ the number of periods. In the LS procedure for GBACP [3], the *search space* consists of the assignment $A : C \to P$. The *neighbourhood relation* is defined by moves that either change the period p assigned to one course c or swap the periods p_1, p_2 of two courses c_1 and c_2.

For GBACP-HC, we designed the *search space* to be made of two separate assignments: courses to terms ($A_1 : C \to T$) and pairs course/curriculum to years ($A_2 : C \times Q \to Y$). This new search space leads us to the definition of two different *neighbourhood relations*. The first one is originated by the moves that either change the *term* of one course or swap the *term* of two courses. The second one is originated by the moves that either change the *year* of one pair course/curriculum or swap the *year* of two courses in one given curriculum.

The *objective function* is defined by the same components used in the GBACP [3], load balance and professors' preferences, plus a new component determined by the sum over the courses of the largest difference between the years in which students are assigned to take the course.

Experiments of various local search procedure with different combinations of the above given neighbourhoods on the instances UD1 – UD10 are currently ongoing and the results will be presented in the forthcoming full paper.

Two preliminary observations are worth mentioning. First, it is easy to see that a solution to GBACP is also a solution to GBACP-HC, in which the same year is assigned to all curricula. Therefore, one may wonder whether the best solutions obtained by LS for GBACP are also the best obtainable by LS for GBACP-HC. Unless an extremely high penalisation of year discrepancies is defined, this is not the case. Experimentally, we verified that all best known GBACP solutions provided as initial solutions for GBACP-HC are improved by the local search procedure that works on the space of the GBACP-HC solutions.

The second observation is that for solving a GBACP-HC instance it is helpful to solve first the GBACP model on the same instance and then refine the search on the GBACP-HC model. Indeed, at present the current best solutions for GBACP-HC is a two phase local search obtained by first executing the LS procedure for solving GBACP, and then executing the specific LS for GBACP-HC. This overall procedure obtains results that are much better than those obtained by executing directly the LS procedure for GBACP-HC.

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