

A Review of Computational Solution Strategies for the Balanced Academic Curriculum Problem Optimization

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Abstract. The balanced academic curriculum problem (BACP) involves scheduling courses over academic periods to balance workloads and credits. This paper reviews existing research on optimization approaches for BACP. The review focuses on examining problem formulations and solution methods applied to balance curriculum plans. The aim is to summarize the progress in BACP optimization research. Different modeling techniques like integer programming and constraint programming have been employed for BACP optimization. On the other hand, a variety of metaheuristics, including genetic algorithms, tabu search, and ant colony optimization have been proposed to handle the curriculum balancing problem. One of the popular approaches to optimize BACP is hybrid algorithms that combine metaheuristics with local search methods. Based on the review, future BACP research should emphasize developing more flexible models that can accommodate individual student needs and choices. There is also scope for exploring the potential of new metaheuristics for handling the complexity of personalized curriculum optimization. In summary, this review synthesizes key findings on optimization approaches for BACP and identifies promising directions for further research.

Keywords: balanced academic load, academic load, student academic load, curriculum optimization.

1. Introduction

Balanced Academic Curriculum Problem (BACP) is a combinatorial problem that educational institutions face while attempting to design an efficient curriculum. In general, BACP deals with allocating academic courses in a curriculum to produce a balanced academic load throughout the study period. It involves the planning of offered courses every semester to satisfy students' needs and support institutional goals (Lambert et al., 2005). This problem has significant impacts on students, faculty, and administration performance.

The BACP remains an active research field in OM because it represents a critical instance of a large-scale, NP-hard combinatorial optimization problem central to educational resource planning and scheduling. The OM research focus has evolved from seeking optimal solutions for small instances via exact

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methods to developing highly efficient, scalable approximation methods such as metaheuristics and hybrid algorithms, that capable of handling the increasing complexity of real-world constraints. This review is envisioned as a valuable resource for teaching OM, as it illustrates a real-world scheduling problem and demonstrates the application and comparative value of exact methods versus various approximation techniques like metaheuristics and hybrids. The BACP provides an excellent case study for OM courses, highlighting how diverse algorithmic approaches can be applied to educational operations problems. It also underscores the evolution toward more flexible models that incorporate dynamism and personalization, preparing students for modern decision-making in service operations.

The BACP involves assigning required, elective, and prerequisite courses to academic terms, semesters, or quarters so that the student workload across terms will be balanced while satisfying curriculum constraints (Katal et al., 2023). In this context, a curriculum is defined as the complete set of courses, including required, elective, and prerequisite courses, needed to complete one specific academic program or major. More specifically, the BACP entails assigning a set of courses to terms such that all prerequisites are fulfilled, and the program requirements are all met in a predetermined time frame. At the same time, the total number of credits students must take is balanced evenly across terms.

While the basic BACP focuses on a single program, Generalized BACP (GBACP) or Multiple BACP (MBACP) considers many different programs simultaneously, where constraints like course staffing and shared course capacities often link the different programs. Standard BACP models typically do not assign specific faculty to courses, though advanced GBACP extensions often incorporate faculty preferences as soft constraints. The number of students primarily affects the model through course capacity limits (classroom size) and the complexity introduced by heterogeneous classes.

The BACP constitutes a highly complex combinatorial optimization problem. It can be formulated as an integer programming model with decision variables representing course-term assignments. The constraints include enforcement of prerequisite sequences, load limit policies per term, curriculum requirements, and limited classroom and teacher resources (Rubio et al., 2021). The objective function normally aims to minimize the imbalance in workloads across terms, measured by maximum total credits or deviation from the ideal average credits (Ferreira et al., 2024).

Solving the BACP effectively has profound impacts on students, faculty, and institutions (Thornby et al., 2023). For students, balanced curriculums prevent overload in any given term, enabling smooth progression through a program (Huntington-Klein & Gill, 2021). They promote satisfaction, retention, and improved learning outcomes from optimal workloads. For faculty, balanced schedules allow teaching assignments, preparations, and

student evaluations to be distributed evenly. Institutionally, solving the BACP allows schools to deliver optimized curriculums that maximize resource utilization and educational effectiveness.

However, the vast combinatorial search space, complex interdependencies, and competing constraints make the BACP extremely challenging to solve exactly. Real-world instances often contain hundreds of courses and thousands of students with different degree programs and personalized needs (Palma & Bornhardt, 2020). The curriculum balancing problem is a nonpolynomial hard (NP-hard), meaning no efficient algorithm exists to find perfect solutions. This requires approximation methods that can provide high-quality solutions in reasonable timeframes.

A number of existing research works have focused on applying advanced optimization techniques like metaheuristic algorithms, mathematical models, and artificial intelligence to produce near-optimal solutions to this educational scheduling problem. Solving the BACP remains an active research field requiring innovations in problem models and solution approaches.

This paper provides a comprehensive overview of the BACP literature, focusing on the optimization approaches proposed by existing studies. It examines the diverse methodologies employed to address BACP, offering insights into the strategies researchers have explored to optimize the problem. Despite the algorithmic advancements, a key gap persists: most existing BACP research focuses on institution-centered, fixed-curriculum planning for a single cohort, which is insufficient for modern, flexible educational systems, such as those with open registration, or for personalized curriculum advising. Additionally, the paper presents the problem formulation, elucidating the parameters and constraints investigated in the literature. Finally, the paper discusses the opportunities for researchers to make contributions to the study of BACP and presents the study limitations.

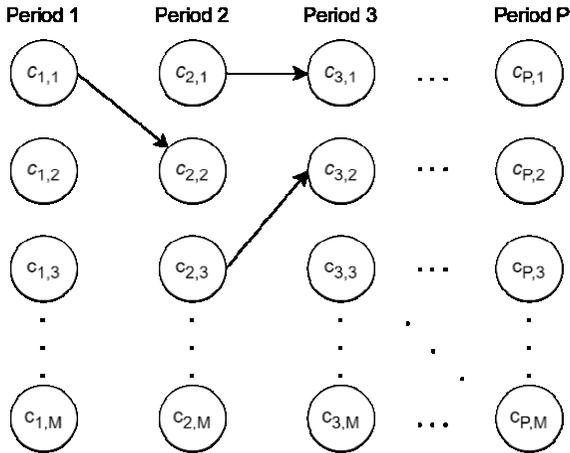
2. Balanced Academic Curriculum Problem Formulation

The BACP involves assigning courses to academic terms in a way that balances student workload across terms while satisfying prerequisites and curriculum constraints. The main objective is to ensure a balanced distribution of student workload across academic terms while adhering to various constraints such as prerequisites, curriculum requirements, load limits, and course capacities.

In the BACP, the inputs consist of several crucial components. These include a set C comprising all courses that need to be offered, with each course (c) being associated with a workload and learning hours denoted by r_c which is the key value used for load balancing. Additionally, there is a set P representing academic terms, which serves as the planning horizon. Minimum

(m) and maximum (M) allowable numbers of courses to be assigned to each term, following institutional policies, are also specified. Furthermore, prerequisite relationships are defined as a directed acyclic graph $D = (V, A)$, where nodes V represent courses and edges A signify prerequisites. In Fig. 1, the node represents the course, while the arrow shows the prerequisites relationship. The nodes $c_{i,p}$ represent the i^{th} course assigned to an academic period p . The arrows represent prerequisite relationships, which are inputs defining the order in which courses must be taken. Fig. 1 provides an illustrative directed acyclic graph representing prerequisite relationships in the BACP. The arrows show sample prerequisites. In practice, a prerequisite edge from one course implies it must precede all assignments of the dependent course, regardless of period.

Fig. 1: Illustrative directed acyclic graph representing the BACP (nodes represent courses in periods, arrows indicate prerequisite relationships).



In addition, the curriculum requirements include compulsory core courses, electives, and programs/majors with their own specified courses. The objective is to create an assignment of courses to terms that satisfy a set of constraints. Firstly, the prerequisite dependencies must be fulfilled, ensuring that courses are scheduled only after their prerequisites have been completed. This constraint normally is represented by the directed acyclic graph D .

Next, load limits must be strictly followed, with each academic term having an assignment of courses within the predefined limits. This helps maintain a balanced workload for students, and the number of courses assigned to each term should fall between m and M . The next constraint is curriculum rules, encompassing the fulfillment of compulsory core courses, elective policies, and program-specific course requirements. This constraint ensures