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Innovative Applications of O.R.

A new mixed integer programming model for curriculum balancing: Application to a Turkish university

Yusuf Ziya Ünal *, Özgür Uysal [1]

Department of Industrial Engineering, Fatih University, 34500 Buyukcekmece, Istanbul, Turkey

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ABSTRACT

Curriculum design is a highly important activity for the academic institutions. It is discussed in literature as a balancing academic curriculum problem (BACP). The BACP schedules courses to different semesters, while balancing the total workload per period. BACP model involves precedence relations, but the related courses are not necessarily assigned to closest periods.

The Relevance Based Curriculum Balancing (RBCB) models presented in this paper are the first implementation of Generalized Quadratic Assignment Problem (GQAP) to curriculum design. RBCB aims at assigning relevant courses to closest possible periods in a way that academic load per semester is balanced and prerequisite conditions are met simultaneously. RBCB models are applied to Fatih University Industrial Engineering Department undergraduate curriculum and comparative performances of different RBCB and BACP models are examined in terms of relevance and balancing efficiency.

1. Introduction

Time scheduling is a popular research field in the academic environment. It covers many real life phenomena such as determination of departure time slots of vehicles, rostering and job scheduling. Among these, curriculum design, exam and course timetabling are very critical planning activities for academic institutions.

Design of academic curriculum, also known as curriculum planning or curriculum layout, aims at efficient utilization of student efforts by balancing total workload per semester. Workload of a course represents the total time an average student spends both in and outside class (i.e. lectures, projects, self-study, practical work and examinations, etc.) required to achieve the expected learning outcomes.

Balanced Academic Curriculum Problem (BACP), firstly introduced by Castro and Manzano (2001), is a special variation of curriculum planning. It aims at scheduling all the courses while meeting the prerequisite conditions and balancing the workloads of semesters (Monette, Schaus, Zampelli, Deville, & Dupont, 2007). BACP holds significance for course timetabling because it reduces the total weekly lecture hours of a student (Chiarandini, Di Gaspero, Gualandini, & Schaerf, 2012; Schaerf, 1999).

Hnich, Kızıltan, and Walsh (2002) and Castro and Manzano (2001) compared different BACP models based on constraint and integer programming in terms of performance and solution quality. Lambert, Castro, Monfroy, and Saubion (2006) developed hybrid techniques for BACP utilizing genetic algorithms and constraint programming.

Di Gaspero and Schaerf (2008) developed Generalized BACP (GBACP) extending the BACP models by adding lecturer preferences criterion. Chiarandini et al. (2012) introduced an integer programming model and heuristic solution method for GBACP based on hybrid local search techniques.

In undergraduate curricula of higher education institutions, there are generally 8 semesters and around 40 courses. A course establishing the fundamentals of a more advanced course is treated as the prerequisite and scheduled earlier in the curriculum.

In the previous studies, BACP is formulated as a variant of Generalized Assignment Problem (GAP) or bin-packing problem and the courses are assigned to semesters while meeting prerequisite conditions (Monette et al., 2007). But there is no special precaution for assigning a specific course and its prerequisite as close as possible. For instance, the prerequisite of a course in the 7th semester can be assigned to the 1st, 2nd or 3rd semesters. But of course, it would be much better to locate the prerequisite course just before its latter course (i.e. the 6th semester in this case). Furthermore, designating the pair to the "Semester 5–6" instead of "Semester 6–7" would still be another improvement, considering the long

* Corresponding author. Tel.: +90 212 866 33 00x5646; fax: +90 212 866 33 37.
E-mail addresses: yunal@fatih.edu.tr (Y.Z. Ünal), ouysal@fatih.edu.tr (Ö. Uysal).
[1] Tel.: +90 212 866 33 00x5610; fax: +90 212 866 33 37.

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summer vacation. To sum up, BACP satisfies the prerequisite conditions but it doesn't have an objective of assigning related courses as close as possible.

This study intends to design a curriculum that will better fit to real life situations by assigning relevant courses to closest possible periods while meeting all the constraints of BACP. To achieve this goal, curriculum balancing is modeled as a Generalized Quadratic Assignment Problem (GQAP), which is a totally new approach for curriculum design.

GQAP is a special type of Quadratic Assignment Problem (QAP). GQAP and QAP both aim at minimizing the total pair-wise transportation cost between facilities, also known as interaction or traffic cost (i.e. distance $*$ two-way flow). The difference is that, QAP assigns M facilities to M locations while GQAP assigns M facilities to N locations ($N < M$).

GQAP is not a linear model; it can be transformed into mixed integer programming using different linearization techniques. Since GQAP is strongly NP-Hard (Lee & Ma, 2004; Pessoa, Hahn, Guignard, & Zhu, 2010), obtaining an exact solution is impossible for big size problems. Heuristic methods are used for those problems, but they don't guarantee the optimal solution. For small size instances, exact algorithms such as cutting plane, branch and bound can give the optimal solution.

Lee and Ma (2004) introduced the first formulation of GQAP. They utilized it to locate multiple equipments to four manufacturing sites by minimizing the total transportation and installation costs. They proposed 3 different linearization techniques and a branch and bound algorithm to find the optimum solution of GQAP.

Hahn, Kim, Guignard, Smith, and Zhu (2008) presented a branch and bound algorithm based on a reformulation linearization technique (RLT) and dual ascent procedure to solve a Lagrange formulation of GQAP.

Pessoa et al. (2010) developed two hybrid branch and bound methods inspired from the study of Hahn et al. The methods calculate much stronger lower bounds for relaxed GQAP, one using the pure volume algorithm, the other using a combination of the volume algorithm and the transformational lower bounding procedure.

Cordeau, Gaudioso, Laporte, and Moccia (2007) considered the service allocation problem as a GQAP. They aimed at minimizing rehandling operation cost (yard to yard container transfers) and proposed a memetic heuristic that comprises genetic algorithm and tabu search.

McKendall Jr. (2008) denoted how the dynamic space allocation problem could be modeled as a GQAP. He developed 3 different tabu search heuristics that assign idle resources to storage locations in multiple periods by minimizing the sum of preparation and two-way transportation costs.

Hahn, Smith, and Zhu (2008) developed a multi-objective 3 dimensional GQAP model for multi-story assignment problem that assigns the departments to different floors of the building by minimizing inter-departmental traffic and evacuation cost simultaneously.

Yagiura et al. (2007) introduced a Multi-resource GQAP (MRGQAP) that aims at minimizing the pair-wise cost assignment of jobs to agents subject to cardinality and multi-resource constraints. They proposed a heuristic algorithm called path relinking with chained shift neighborhood.

The original GQAP aims at optimally assigning facilities to locations without violating the space limitation of each location. In this study, courses and semesters are taken as facilities and locations respectively, and relevant courses are assigned to closest possible semesters. However, GQAP does not have any objective for balancing the space utilization of each location. So, the balance violation is formulated as a cost and integrated into the GQAP model. Thus, we end up with a bi-objective (specialized GQAP) model that aims at assigning relevant courses to closest possible periods in a way that academic load per semester is balanced and prerequisite conditions are met.

The proposed model is quadratic but the problem at hand ($M = 46$ and $N = 9$) is not very big in size. So, it is transformed into mixed integer linear programming (MILP) by using an appropriate linearization technique by Frieze and Yadegar (1983). Then, the exact solution of the problem is obtained by using exact integer programming solver 'mmxprs' of FICO® Xpress Optimization Suite.

The outline of the paper is as follows: Section 2 is about problem definition. The common and distinct features of BACP and the proposed model are presented here. Section 3 explains the new model in detail, while different exact solution methodologies are handled in Section 4. Section 5 covers the application of the proposed model to Fatih University Industrial Engineering Department undergraduate curriculum. Section 6 gives experimental results and discussion on the new models. Finally, the article ends with a conclusion that compares the proposed model, BACP and GBACP, emphasizing the novel contributions. Some future work that can be accomplished to meet other real life requirements are also mentioned.

2. Problem definition

According to Castro and Manzano; the BACP should encapsulate the following regulations (Castro & Manzano, 2001):

- *Academic curriculum:* An academic curriculum is designed by a set of courses and a set of prerequisite relationships among them.
- *Number of periods:* Courses must be assigned within a maximum number of academic periods.
- *Academic load:* Each course has been associated with a number of credits or units that represent the academic effort required to successfully follow it.
- *Prerequisites:* Some courses can have other courses as prerequisites.
- *Minimum academic load:* A minimum amount of academic credits per period required to consider a student as full time.
- *Maximum academic load:* A maximum amount of academic credits per period allowed in order to avoid overload.
- *Minimum number of courses:* A minimum number of courses per period required to consider a student as full time.
- *Maximum number of courses:* A maximum number of courses per period allowed in order to avoid overload.

However, in real life, balancing the academic workload per period and satisfying prerequisite conditions are not the only criteria for curriculum design. Academic workload of lecturers per semester and the distance between specific courses are some other criteria that can be used (Chiarandini et al., 2012).

The proposed model in this paper, which is a customized version of GQAP, considers the following criteria distinct from other models in literature:

- *Relevance score:* It is a two dimensional (course $*$ course) matrix that defines the level of fundamental information a course includes for latter courses.
- *Closest layout for relevant courses:* Relevant courses should be assigned to the closest possible periods.
- *Workload of students:* It is taken as European Credit Transfer and Accumulation System (ECTS) credits.