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A SEQUENTIAL TWO-STAGE GOAL PROGRAMMING MODEL FOR FACULTY-COURSE-TIME SLOT ASSIGNMENTS

Key Words

Faculty Course Assignment; Goal Programming; Faculty Time; Solt Assignment; University Course Scheduling; Two-Stage Model

Abstract

Developing a model that could produce efficient and effective faculty-course schedules has been a challenging task in universities around the world. Different systems have been designed and built in an attempt to come up with the "optimal" schedule, yet every system has its limitations and drawbacks. This paper utilizes zero-one goal programming technique to assign faculty members to courses as a first stage and then to allocate courses-faculties to time-slots as the second stage. Through this two-stage optimization procedure, the model seeks to maximize the faculty course preferences in the first stage and maximize faculty time preference in the second stage. The method used in satisfying goals is the priority sequence approach, where goals are satisfied according to their order of importance based on some university, college, department, and major regulations and requirements. The model has been tested on different assignment scenarios. The first stage has proven to fulfill most goals completely to optimality, and then fulfill the faculty course teaching preferences up to 85.2%. The second stage fulfills the faculty-course-time slot teaching preferences up to 88.8%.

Introduction

The problem of assigning faculties to different courses, time-slots, and class rooms such that resources are fully utilized, faculties are completely satisfied, and students are efficiently progressed through their educational requirements has been a recurring problem in most universities around the world. In an attempt to solve this problem, different universities have adopted different ap-

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proaches ranging from manual scheduling, sophisticated mathematical models and computer programs, and decision support systems. Using either approaches, however, the problem of developing perfect schedules still persist.

Manual approaches have proven to cause an ineffective course scheduling. Problems such as offering required courses at the same time on the same day, assigning the wrong class size to the wrong class room, inevitable biased faculty-course assignment, and relatively long time to complete the schedule have all been conventional results of using such approaches. In an attempt to eliminate or at least minimize such problems, researches have been developing more sophisticated methods. Their attempts date back to the early 70s, where linear programming models, network models, large-scale integer programming models were developed to solve the faculty-course scheduling problem. Although such models have successfully produced satisfying faculty-course assignments, some of these models have failed to include the time component factor to their models. On the other hand, models that have addressed the time components, have failed to consider the classroom availability aspect (Dinkel and Mote, 1989). More recently, however, sophisticated mathematical programming models have been developed to solve the faculty-course scheduling problems, yet they have either failed again to include the room information, or could not been optimally solved (Al-Yakoob and Sherali, 2006; HinKin and Thompson, 2002; Badri *et al.*, 1998; Badri, 1996) due to its level of complexity. For example, Al-Yakoob and Sherali (2006, 2007) have proposed a two-stage approach for solving the faculty-course scheduling problem. In their first stage model (Al-yakoob and Sherali, 2007) an efficient class timetable that considers available facility resources such as classrooms was developed. Then, the output of their first-stage model was used as an input to their second stage model (Al-Yakoob and Sherali, 2006), which is concerned with assigning faculty members to classes for individual departments. Although in their model the faculty-course scheduling problem has been taken one step further, in specific, it addresses a gender related policies, further enhancements to their model had to be implemented before a solution could be reached. When they tried to solve the model, they encountered out-of memory difficulties before reaching any solution that was within 50% of optimality. To overcome these difficulties they developed a two-phase LP-based heuristic and the best performance they have obtained using this heuristic yielded a solution within 68% of optimality. The time needed to obtain this solution was still more than two days and in some other cases they encountered out-of memory problem. They developed another complicated heuristic procedure, but their solution's optimality ranged from 55% to 73%. The modeling efforts required, the complexity and time necessary to develop utility function of faculty preference, and the run time required for completing the heuristic based solution was far from optimality, which could limit their application when used on a practical case.

Another approach that has been utilized to overcome the complexity of solving the faculty-course scheduling problem to optimality is the use of decision support system. Their use has played a significant role in trying to come up with close to optimality solutions in relatively reasonable time. Thus, methods such as developing specialized computer programs to automate the scheduling process have been a rectifying alternative. Software such as ScheduleExpert (Hinkin and Thompson, 2002) has been developed at Cornell University School of Hotel Administration, which made course scheduling more efficient and more effective to both students and faculties. Their software can determines what classes should be taught, what time they should be taught, and in what location. If desired, the software can also determine who will teach each class. However, in order to find such a solution, a complex heuristic procedure had to be designed and run. The user then must pause the program, examine the generated schedules, and decide on the best solution. This takes us back to the same old dilemma of running into possible ineffective schedules.

Goal programming may be used in some decision processes to assure least possible deviation from goals (Anderson *et al.*, 2008), Lee (1972), Lee and Schniederjans (1983), Schniederjans *et al.* (1982). The natural conflict in the course-faculty-time assignment problem between competing individual faculty members (i.e. faculty members wanting to teach certain courses or sections at certain times), represents an ideal application of the goal conflicting resolution characteristics inherent in goal programming.

The models of Harwood and Lawless (1975) and Schniederjans and Kim (1987) though did use goal programming to examine the conflicting goals in the faculty-course assignment problem. The major drawback with the first model is that it may be very difficult to implement. They presented a multitude of criteria that are strict requirements rather than goals. As a result, these criteria add needless complication and data collection requirements to the model. On the other hand, the proposed model of Schniederjans and Kim (1987) sought to overcome the possible implementation limitations of the Harwood and

Lawless model. In addition to satisfying departmental goals on the number and types of course offerings required, as well as the faculty teaching load requirements, their proposed model also dealt with faculty course teaching preferences. The major drawback with this second model is that it considered only one dimension of the departmental course scheduling, the faculty-course assignment problem. The second dimension dealing with the course-time assignment problem was not dealt with.

Badri (1996) proposed two-stage goal programming model that overcame the possible implementation limitation of Harwood and Lawless model. The model maximizes faculty-course preferences in assigning faculty members to courses and then maximizes faculty time preferences in allocating sources to time blocks (slots).The results of the model application to the United Arab Emirates University demonstrate the model's capability to provide an assignment that satisfies departmental policies and procedures with regard to course offerings, as well as recognizing the personal preferences of the faculty for teaching particular courses and during certain time blocks.

Badri *et al.* (1998) proposed a goal programming model the can simultaneously consider faculty preferences of courses and times. The application of the model illustrated how the faculty assignment problem could be structured into relatively small model (i.e. relative to Badri (1996)). In this research paper Badri did not make a complete comparison between his two-stage model and the simultaneous one based on a unique application for both models regarding the same problem.

The focus of our research activity is to build a three-stage (sequential) goal programming model, inline with Badri (1996) but with different major, department, and college and university policies. Rules and priorities are integrated in a decision support system that would allow the person in charge of faculty-course scheduling to come up with the most efficient and effective schedule. Figure 1 shows a block diagram and information flow of the three-stage (sequential) goal programming model under investigation. In the first stage of the model, the faculty-course assignment stage, the inputs to this stage would be faculty course preferences input (as shown in Table 1), university, college and department assignment rules and regulations related to assigning courses to faculties. The output of this stage would be faculties with courses assigned. The second stage, the faculty-course-time slot (timetabling) stage, would take faculties time preferences for their assigned courses (as shown in Table 4), the university, college, and department timetabling requirements as inputs in order to generated the faculty-course-time slot assignment (timetabling). The third stage model, the room assignment stage would take the faculty-course-time slot assignment result from the second stage along with the university, college, and department room assignment requirements as inputs in order to generate a complete final schedule. The decomposition of scheduling problem into three distinct and interrelated stages, compared to a single (simultaneously) stage solution, leads to an ease of use and significant reduction in computation time.

Work is underway to build the three-stage model integrated within a decision support system. The implementation and the results of the experimentation with such system for multi major at the College of Business Administration in Kuwait University will be reported in a forthcoming paper. As a result, in this paper we report the result of the implementation of two stages of our three-stage model. In section 2 we present the two-stage mathematical model, namely faculty-course-time slot assignment. In section 3 we present the results of our experimentation with the model and section 4 we present our conclusion and future research.

The Mathematical Model

In this section, we describe the goal linear programming model that is applied to the first of the two stages of the model, namely the faculty-course assignment and the timetabling assignment. An overview of goal programming model formulation is given first, followed by a detailed description of the two-stage model.

General Goals Linear Programming (GLP) Model Formulation

A goal is a desired result. It may be underachieved, fully achieved, or over-

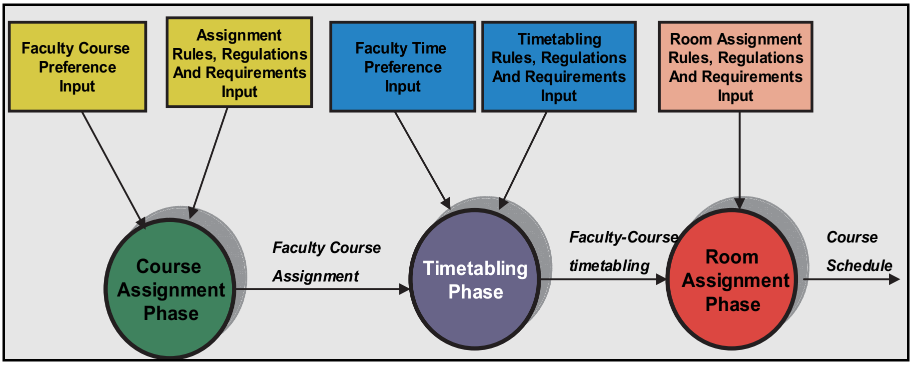

Figure 1: Faculty Course Schedule Block Diagram and Information Flow

achieved. Relative emphasis applied through managerial action contributes to the degree of goal achievement. Symbolically, 1 unit of effort applied to activity x_j might contribute an amount a_{ij} toward the achievement of the i^{th} goal.

The target level for the i^{th} goal, b_i, is fully achieved if

$$\sum_{j=1}^{n} a_{ij}x_j = b$$

To allow for underachievement or overachievement, let

d_i^- = negative deviation from the i^{th} goal (underachievement)

d_i^+ = positive deviation from the i^{th} goal (overachievement) From this, for the i^{th} can be stated in general terms as

$$\sum_{j=1}^{n} a_{ij}x_j = d_i^- + d_i^+ = b_i \quad i = 1, 2, ..., m$$

It is required that one or both of the deviational variables (d_i^-, d_i^+) be zero in the solution, since it is not possible for both underachievement and overachievement to occur at the same time.

The goal programming model must be able to incorporate goal attendant with both ranking and weighting as appropriate. Let

p_k = Ranking coefficient for all deviations having k^{th} priority of being avoided.

w_{ik}^- = Relative weight of the d_i^- in the k^{th} rank

w_{ik}^+ = Relative weight of the d_i^+ in the k^{th} rank

With m goals, the goal linear programming model may be formulated mathematically as requiring the minimization of the linear weighted ranking function

$$\sum_{j=1}^{n} \sum_{k} p_k (w_{ik}^- d_i^- + w_{ik}^- d_i^+)$$

Subject to the linear constraints

$$\sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = b_i \; i = 1, 2, ..., m$$

$$x_j, d_i^-, d_i^+ \geq 0 \; i = 1, 2, ...m, \; j = 1, 2, ..., n$$

Goal programming seeks satisfactory level of goal attainment that represents the best possible overall outcome. This aim can be realized if the several goal are stated and formulated mathematically in a manner that permit appropriate consideration in the goal programming model. Therefore, the decision maker must determine which goal are most important and assign an ordinal value (priority), P_k, to each goal or group of goals, Further, within a given goal, there may be sub goals of unequal importance which must be given different weights, w_{ik}^{-} w_{ik}^{+}.

Solving any goal programming model involves achieving highest priority goal, first, before any of the lower priority goals are considered. Once the highest priority goal is attained to fullest extent possible, the goal programming model proceeds to find a satisfactory level to next highest priority goal, and so on. However, it is not always possible to achieve every goal to the extent desired by the decision maker. But the advantage of goal linear programming over ordinary linear programming is that it seeks, within the given set of constraints, to minimize the deviation from the established goals targets, while the ordinary linear programming seeks to minimize or maximize certain goal directly.

Stage I: Faculty-Course Assignment Goal Linear Programming Model

In this section we formulate the goal programming model that represents the rules and regulations of Kuwait University, College of Business Administration, and the requirements of Management Science major at department of Quantitative Methods for assigning courses to faculty.

Suppose we have *m* faculty members and *n* courses. Each faculty member *i* has a specific maximum number of course sections load L_i (some faculty member has a maximum load of three course sections and some has maximum load of two) to teach, and each course *j* could have one or more different sections N_j that should be cover by faculty members.

Some of the courses are designated as College Level Courses (CLC) and others are designated as Major Level Courses (MLC) (core or elective courses).

Let X_{ij} be the number of sections for course *j* that will be assigned to faculty member *i* , and R_{ij} be the preference for faculty member *i* to teach course *j* . R_{ij} takes values 1, 2, 3, 4,and 5. Where 5 is the most favorite one course/section. If R_{ij} = 0 then X_{ij} = 0, which means that the faculty member *i* does not want to teach course *j* at all.

The required rules for this assignment can be represented by the following goals and priorities:

Goal 1:

Each faculty member *i* should take exactly his maximum load L_i. This goal has a priority *P1* and is represented by the following formula:

$$\sum_{j=1}^{n} X_{ij} + d_{1i}^{-} - d_{1i}^{+} = L_i \quad i = 1, 2, ..., m$$

the objective is to minimize both of $d_{1i}^{-}$and d_{1i}^{+} $\forall i$.

Goal 2:

The number of course sections N_j for course j should all be covered by faculty members. This goal has a priority P_1.This goal is represented by the following formula:

$$\sum_{j=1}^{n} X_{ij} + d_{2j}^{-} - d_{2j}^{+} = N_j \quad j = 1, 2, ..., n$$

the objective is to minimize both of d_{2i}^{-} and d_{2j}^{+} $\forall j$.

Goal 3:

Each faculty member should take at lease one of the CLC course sections. This goal is a department level requirement and is given a priority level P_2 . This goal is represented by the following formula:

$$\sum_{j \in CLC} X_{ij} + d_{3i}^{-} - d_{3i}^{+} = 1 \quad i = 1, 2, ..., m$$

the objective is to minimize d_{3i}^{-} $\forall i$.

Goal 4:

Each faculty member should take at lease one of the MLC course sections. This goal represent another department level requirement and is given a priority level P_3 . This goal is represent by the following formula:

$$\sum_{j \in CLC} X_{ij} + d_{4i}^{-} - d_{4i}^{+} = 1 \quad i = 1, 2, ..., m$$

the objective is to minimize d_{4i}^{-} $\forall i$.

Goal 5:

Maximize the total preference for each faculty member i that has a load L_i . This goal has a priority P_4 and is represented by the following formula:

$$\sum_{j}^{n} R_{ij} X_{ij} + d_{5i}^{-} - d_{5i}^{+} = 5L_i \quad i = 1, 2, ..., m$$

the objective is to minimize d_{5j}^{+} $\forall i$.

Finally we have one more hard constrain that does not allow any faculty member i to take more than two sections for the same course j . This constraint is represented by the following formula:

$$X_{ij} \leq 2 \quad i = 1, 2, ..., m \text{ and } j = 1, 2, ..., n$$

Satisfying the above goals with their priorities and the other requirements, the first stage GLP can be written as following:

First Stage GLP:

Minimize

$$P_1 w[\sum_{i=1}^{m} (d_{1i}^{-} + d_{1i}^{+}) +$$

$$\sum_{j=1}^{n} (d_{2j}^{-} + d_{2i}^{+})] +$$

$$P_2 \sum_{i}^{m} (d_{3i}^{-} + P_3 \sum_{i}^{m} d_{4i}^{-} +$$

$$P_4 + \sum_{i}^{m} d_{5i}^{-}$$

Subject to :

$$\sum_{j=1}^{n} X_{ij} + d_{1i}^{-} - d_{1i}^{+} = L_i \quad i = 1,2,...,m$$

$$\sum_{i=1}^{n} X_{ij} + d_{2j}^{-} - d_{2j}^{+} = N_j \quad j = 1,2,...,n$$

$$\sum_{j \in CLC}^{n} X_{ij} + d_{3i}^{-} - d_{3i}^{+} = 1 \quad i = 1,2,...,m$$

$$\sum_{j \in MLC}^{n} X_{ij} + d_{4i}^{-} - d_{4i}^{+} = 1 \quad i = 1,2,...,m$$

$$\sum_{j}^{n} R_{ij} X_{ij} + d_{5i}^{-} - d_{5i}^{+} = 5L_i \quad i = 1,2,...,m$$

$$X_{ij} = \begin{cases} 0 & \text{if } R_{ij} = 0 \\ \leq 2 & \text{otherwise} \end{cases},$$

$i = 1,2,...,m$ and $j = 1,2,...,n$

$d_{1i}^{+}, d_{1i}^{-}, d_{2j}^{+}, d_{2j}^{-}, d_{3i}^{+}, d_{3i}^{-}, d_{4i}^{+}, d_{4i}^{-}, d_{5i}^{+}, d_{5i}^{-}, \geq 0$

for $i = 1,2,....,m$ and $j = 1,2,....,n$

Where w is very big value to force the values of the deviations $d_{1i}^{+}, d_{1i}^{-}, d_{2j}^{+}, d_{2j}^{-}$ $\forall i$ and $\forall j$ to be zeros.

Stage II: Faculty-Course-Time Assignment Goal Linear Programming Model

In this section we formulate the goal programming model that represents the rules and regulation of Kuwait University, College of Business Administration requirements for assigning time slots to Faculty-Course assignment resulting from stage I. First, we define the following new notations:

Notations:

$t_{dp} = \{1,2\}$, Time slot number in a day d and period p , where

$d = \{1,2\}$, *days of the week. Such that* 1 $=\{$*Sunday*, *Tuesday*, *Thuresday*$\}$ and *2* $=\{$*Monday*, *Wednesday*$\}$

and p $=\{$*m*, *a*$\}$, *such that m* $=$ *morning* time *and a* $=$ *afternoon* time

$$X_{ijk_{ij}t_{dp}} = \begin{cases} 1 & \textit{if faculty i assigned to course j section } k_{ij} \textit{ during time slot t of day d in period p} \\ 0 & \text{Otherwise} \end{cases}$$

O_{tdp} $=$ Number of rooms available at time slot number t_{dp}.

The required rules for this assignment can be represented by the following goals and priorities:

Goal 1:

Total number of courses assigned in a specific time slot *cannot* exceed the number of rooms available for that time slot. This goal has a priority P_1 and is represented by the following formula:

$$\sum_{i} \sum_{j} \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dp}} - d_{1t_{dp}}^{+} + d_{1t_{dp}}^{-} = o_{t_{dp}} \quad \forall t_{dp}$$

the objective is to minimize $d_{1t_{dp}}^{+}$ $\forall t_{dp}$.

Goal 2:

Elimination of timing conflict of courses that can be taken at the same time for similar college level courses (CLC).

Total number of similar CLC assigned during a specific time slot in morning-time cannot exceed 2 sections for the same course. This goal has a priority P_2 and is represented by the following formula:

$$\sum_{i}\sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dm}} - d^{+}_{2jt_{dm}} + d^{-}_{2jt_{dm}} = 2$$

$$\forall j \in CLC \text{ and} t_{dm}$$

The objective is to minimize $d^{+}_{2jt_{dm}} \forall j \in CLC$ and t_{dm}.

Goal 3:

Total number of similar CLC assigned during a specific time slot in afternoon-time cannot exceed 1 section for the same course. This goal has a priority P_3 and is represented by the following formula:

$$\sum_{i}\sum_{k_{i}j} X_{i\,j\,k_{ij}\,t_{da}} - d^{+}_{3jt_{da}} + d^{-}_{3jt_{da}} = 1$$

$$\forall j \in CLC \text{ and} t_{dm}$$

The objective is to minimize $d^{+}_{3jt_{dm}} \forall j \in CLC$ and t_{da}.

Goal 4:

Reduce the gaps between ULC. The ULC courses should be 4 times more condensed during the morning-time than they are during the afternoon-time, where 4 is just any number that the department wishes to choose. This goal has a priority P_4 and is represented by the following formula:

$$\sum_{i}\sum_{j \in ULC}\sum_{k_{ij}}\sum_{t_{dm}} X_{i\,j\,k_{ij}\,t_{dm}} -$$

$$4\sum_{i}\sum_{j \in ULC}\sum_{k_{ij}}\sum_{t_{da}} X_{i\,j\,k_{ij}\,t_{da}} - d^{+}_{4} + d^{-}_{4} = 0$$

The objective is to minimize d^{-}_{4}.

Goal 5:

This is more like a guideline, where 60% of courses should preferably be offered during the odd days and 40% during the even days. This goal has a priority P_5 and is represented by the following formula:

$$\sum_{i}\sum_{j}\sum_{k_{ij}}\sum_{t_{1p}} X_{i\,j\,k_{ij}\,t_{1p}} -$$

$$1.5\left(\sum_{i}\sum_{j}\sum_{k_{ij}}\sum_{t_{2p}} X_{i\,j\,k_{ij}\,t_{2p}}\right) - d^{+}_{5} + d^{-}_{5} = 0$$

The objective is to minimize d^{-}_{5}.

Goal 6:

This is more like a guideline, where 70% of courses should preferably be offered during the morning-time and 30% during the afternoon-time. These goals have a priority P_6 and is represented by the following formula:

$$\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{m1}} X_{i\,j\,k_{ij}\,t_{1m}} -$$

$$2.3(\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{a1}} X_{i\,j\,k_{ij}\,t_{a1}}) - d_6^+ + d_6^- = 0$$

$$\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{m2}} X_{i\,j\,k_{ij}\,t_{2m}} -$$

$$2.3(\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{a2}} X_{i\,j\,k_{ij}\,t_{a2}}) - d_7^+ + d_7^- = 0$$

The objective is to minimize d_6 ، d_7

Goal 7:

Maximize the professor preferences on their class times. This goal has a priority P_7 and is represented by the following formula:

$$\sum_j \sum_{k_{ij}} \sum_{t_{dp}} R_{i\,j\,k_{ij}\,t_{dp}} .\ X_{i\,j\,k_{ij} t_{dp}} - d_{8i} + d_{8i}^- = M$$

$$\forall i, \textit{such that } M \textit{ is a large number}$$

The objective is to minimize d_{8i}^- $\forall i$

Hard Constrains

1 - Sum of sections taught for every professor in every specific time slot must be at most equal to 1.

$$\sum_j \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dp}} \le 1 \quad \forall i \in I,\ \forall t_{dp}$$

2 - Sum of ULC offered during a specific time slot during same day must equal at most 1.

$$\sum_i \sum_{j \in ULC} X_{i\,j\,1\,t_{dp}} \le 1 \quad \forall t_{dp}$$

3 - Sum of time slots for each section for every professor, every course, and every section must equal 1.

$$\sum_{t_{dp}} X_{i\,j\,k_{ij}\,t_{dp}} = 1 \quad \forall i, j,\ kl_{ij}$$

Satisfying the above goals with their priorities and the other requirements, the second stage GLP can be written as following:

Second Stage GLP:

$$\begin{aligned} &Minimize \\ &P_1 \sum_{t_{dp}} d_{1t_{dp}}^+ + P_2(\sum_j \sum_{t_{dm}} + d_{2jt_{dm}}^-) + \\ &P_3(\sum_j \sum_{t_{da}} d_{2jt_{da}}^+) + P_4 d_4^- + P_5 d_5^- + \\ &P_6(d_6^- + d_7^-) + P_7 \sum_i d_{8i}^- \end{aligned}$$

$$Subject\ to:$$

$$\sum_i \sum_j \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dp}} - d_{1t_{dp}}^+ + d_{1t_{dp}}^- = O_{t_{dp}} \qquad \forall t_{dp}$$

$$\sum_i \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dm}} - d_{2jt_{dm}}^+ + d_{2jt_{dm}}^- = 2 \qquad \forall j \in CLC \textit{ and } t_{dm}$$

$$\sum_i \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{da}} - d_{3jt_{dm}}^+ + d_{3jt_{da}}^- = 1 \qquad \forall j \in CLC \textit{ and } t_{da}$$

$$\sum_i \sum_{j \in ULC} \sum_{k_{ij}} \sum_{t_{dm}} X_{i\,j\,k_{ij}\,t_{dm}} -$$

$$4 \sum_i \sum_{j \in ULC} \sum_{k_{ij}} \sum_{t_{da}} X_{i\,j\,k_{ij}\,t_{da}} - d_4^+ + d_4^- = 0$$

$$\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{1p}} X_{i\,j\,k_{ij}\,t_{1p}} -$$

$$1.5(\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{2p}} X_{i\,j\,k_{ij}\,t_{2p}}) - d_5^+ + d_5^- = 0$$

$$\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{m1}} X_{i\,j\,k_{ij}\,t_{1m}} -$$
$$2.3(\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{a1}} X_{i\,j\,k_{ij}\,t_{1a}}) - d_6^+ + d_6^- = 0$$
$$\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{m2}} X_{i\,j\,k_{ij}\,t_{2m}} -$$
$$2.3(\sum_i \sum_j \sum_{k_{ij}} \sum_{t_{a2}} X_{i\,j\,k_{ij}\,t_{2a}}) - d_7^+ + d_7^- = 0$$
$$\sum_j \sum_{k_{ij}} \sum_{t_{dp}} R_{i\,j\,k_{ij}\,t_{dp}} \cdot X_{i\,j\,k_{ij}\,t_{dp}} - d_{8i}^+ + d_{8i}^- = M$$
$$\forall i, \text{ such that } M \text{ is a large number}$$

$$\sum_j \sum_{k_{ij}} X_{i\,j\,k_{ij}\,t_{dp}} \leq 1 \qquad \forall i \in I, \forall t_{dp}$$
$$\sum_i \sum_{j \in ULC} X_{i\,j\,1\,t_{dp}} \leq 1 \qquad \forall t_{dp}$$
$$\sum_{t_{dp}} X_{i\,j\,k_{ij}\,t_{dp}} = 1 \qquad \forall i, j, k_{ij}$$

all $X_{ijk_{ij}t_{dp}}$ are binary,and all $d's \geq 0$

Experimentation

The experimentation was performed in two parts reflecting the two-stage model under investigation as described earlier. Section 3.1 focuses on the faculty-course assignment stage: its collection date and its analysis and result. Section 3.2 focuses on the second, the faculty-course-time slot (timetabling) assignment stage: its collection date and its analysis and result. Section 3.3 presents and overall assessment.

Stage I: Faculty- Course Assignment

Data Collection

A form consisting of courses to be taught by the Department for the fall 2008 semester was presented to each faculty member as shown in Table 1. Faculty members were instructed to insert a value between 1 to 5 for each desired course section, where 1 and 5

Table 1
Faculty - Courses Preference Table

	Preferences Table (Fall 2008)												Faculty
	Courses												
Faculty	**205**	**210**	**310**	**316**	**318**	**415**	**410**	**412**	**493**	**428**	**473**	**532**	**Load**
Faculty 1	3	5	4	2	1	0	0	0	0	0	0	0	3
Faculty 2	2	5	1	0	3	4	0	0	0	0	0	0	3
Faculty 3	5	4	0	2	0	0	3	0	2	0	0	0	3
Faculty 4	5	4	0	0	0	1	0	3	0	0	0	3	3
Faculty 5	4	5	0	0	0	0	0	0	3	1	0	2	3
Faculty 6	5	4	2	3	1	0	0	0	0	0	0	0	3
Faculty 7	5	4	0	3	0	2	0	0	0	0	2	0	3
Faculty 8	4	5	3	2	1	0	0	0	0	0	0	0	3
Faculty 9	5	4	1	2	3	0	0	0	0	0	0	0	3
Course sections	9	8	1	1	1	1	1	1	1	1	1	1	

Table 2
Faculty - Courses Assignment Table

Assignment Table												
Courses												
Faculty	**205**	**210**	**310**	**316**	**318**	**415**	**410**	**412**	**493**	**428**	**473**	**532**
Faculty 1	0	2	1	0	0	0	0	0	0	0	0	0
Faculty 2	0	2	0	0	0	1	0	0	0	0	0	0
Faculty 3	1	0	0	0	0	0	1	0	1	0	0	0
Faculty 4	1	0	0	0	0	0	0	1	0	0	0	1
Faculty 5	0	2	0	0	0	0	0	0	0	1	0	0
Faculty 6	2	0	0	1	0	0	0	0	0	0	0	0
Faculty 7	2	0	0	0	0	0	0	0	0	0	1	0
Faculty 8	1	2	0	0	0	0	0	0	0	0	0	0
Faculty 9	2	0	0	0	1	0	0	0	0	0	0	0

represent the lowest and highest preferences respectively. A value of zero was also requested to be inserted to indicate no preference for that particular course and to force SOLVER not to assign the course for that faculty member. Other important input data such as number of faculties, the maximum load assigned to each faculty, number of courses and the numbers of sections for each course were also collected as part of the required data for the model. Upon the completion of the data collection, the model was run and results that indicate the course assignment for each faculty member was obtained as shown in Table 2.

Analysis and Assessment

The course assignment model was able to successfully distribute all faculty members to their courses according to the college level requirements (goals 1 and 2), department level requirements (goals 3 and 4), and faculties' preferences (goal 5). The percentages of achievement for each goal are shown in Table 3.

Case 1 represents the situation where the total faculties' load, generally 3 loads per faculty, equals to the total sections offered. Different scenarios of different preferences of input were tested for case 1, where total faculties' load were equal to the total load of courses offered, the model was able to satisfy goals 1 through 4 up to 100% in most scenarios. Depending on the level of competition over the courses being offered, however, the satisfying goal 5, that is giving each faculty exactly the courses of his first choice to teach, ranged from 73.3% up 85.2%. This indicates that the more competition there is over the same course the harder it is to satisfy every faculty's desire.

Cases 2 and 3 represent the situation where total faculties' load either greater than or less than the total sections offered. Different Scenarios that represent the percent increase or decrease between the faculties' loads and the sections offered by the department were tested for each case as shown in Table3.

In case 2, where faculties' load is greater than the total sections offered by the department, results indicate that the greater the difference between the two, the lower the percentage met of some goals such as 1, and 5. This

Table 3
Percentage of Goal Achievement for Different Cases and Scenarios

			Percentage Met				
Case	**Description**	**Scenario**	**Goal1**	**Goal2**	**Goal3**	**Goal4**	**Goal5**
1	Faculties' Load = Sections Offered	1	100	100	100	88.9	82.9
		2	100	100	100	100	85.2
		3	100	100	100	100	73.3
		4	100	100	100	100	84.4
		5	100	100	100	100	77
2	Faculties' Load > Sections Offered	8%	92.6	100	100	88.9	77
		17.4%	85.2	100	100	88.9	69.6
		19%	77.8	100	100	88.9	62.2
		21%	70.4	100	100	88.9	54.9
3	Faculties' Load < Sections Offered	8%	100	92.6	100	88.9	85
		12.5%	100	88.9	100	88.9	85.5
		17.4%	100	85.2	100	88.9	86
		22.7%	100	81.5	100	88.9	86.4

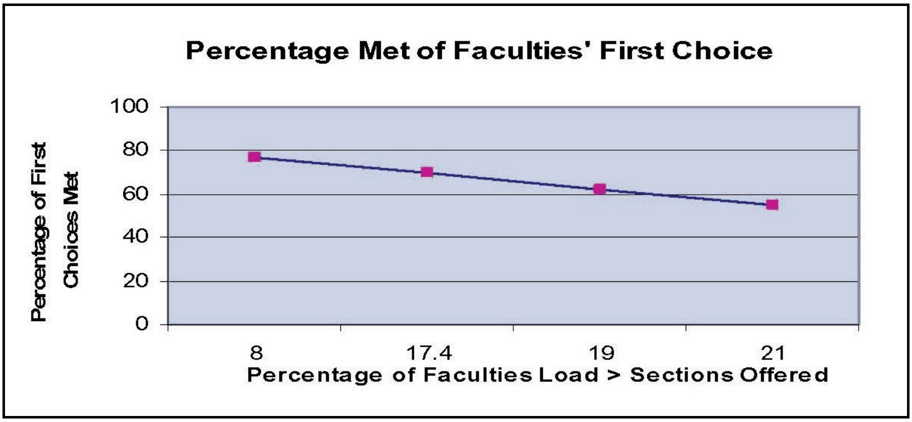

Figure 2: Percentage of Meeting Faculties' First Choice Case 2

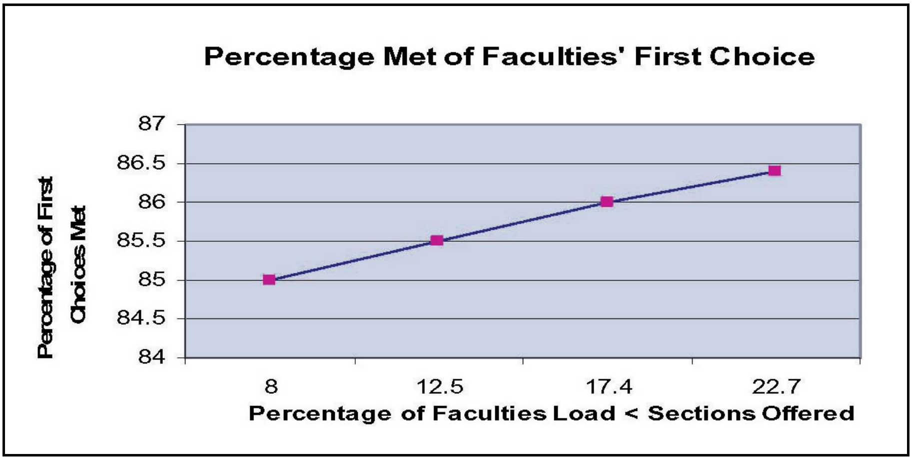

Figure 3: Percentage of Meeting Faculties' First Choice Case 3

means that the less sections there are to offer, the lower the chances that every faculty will be assigned his full load and the more the competition is over those course. Hence, the model's ability to meet the first choice of course to teach for the faculties is reduced. Figure 2 shows the decline in the percentage of satisfying every faculties' first choice.

Similarly, in case 3, where faculties' load is less than the total sections offered by the department, results indicate that the greater the difference between the two, the lower the percentage met of some goals such as 2, and 5. This means the less faculties there are to teach the courses in which the department is intend to offer, the less the chances that every course will be assigned a faculty to teach it and, based on the competition, there more chances for every faculty to get his first choice of courses. Figure 3 shows increase in the percentage of satisfying every faculty's first choice.

Stage II: Faculty-Course-Time Slot Assignment

Data Collection

After assigning faculties to their preferred courses as indicated in stage I, faculties were then asked to fill in their preferable time slots for their courses as shown in Table 4. Faculty members were instructed to insert a value between 1 to 4 for each desired time slot, where 1 and 4 represent the lowest and highest preferences respectively. Faculty members were also asked to insert the value of zero for absolutely undesirable time slot. Those undesirable time slots were translated to hard constraints in order to ensure that faculties will not be assigned any of their undesirable time slots. Other important input data such as the number of rooms assigned by the college to the department in every time slot, required number of sections for CLC in every time slot, the ratio of courses to be offered during morning sessions versus afternoon sessions, the ratio of courses to be offered during Day 1 (Sunday, Tuesday, and Thursday) versus Day 2 (Monday and Wednesday), and the amount of dispersion of ULC. Upon the completion of the data collection, the model was run and results that indicate schedule for each faculty member was obtained as shown in Table 5.

Analysis and Assessment

The faculty-Course-time slot assignment model was able to successfully distribute all faculty members to their preferred time slots based on the goals and rules explained in section 2.3 as shown in Table 6. Results show that most goals were met up to 100%. The only goal that was underachieved is goal 4, which is the goal that require ULC to be 4 times more condensed during the morning than they are during the afternoon in order to eliminate the dispersion of courses for students, were 4 is just any constant that the department sees appropriate. The sum of ULC offered during morning time came up to be 7 courses, where the number of ULC offered during afternoon time came up to be 3. This means the model was not able to condense the ULC during morning time as desired, which is what lead to the underachievement of goal 4 by 42%. Goal 8 indicates that about 90% of the faculties got the time slots they wished for of their first choice.

Overall Assessment

Since the model has been designed to find the local optima for every stage

Table 4
Faculty-Course-Time Slot Preference Table

			PREFERENCE TABLE											
			SUNDAY/ TUESDAY/ THURSDAY (D1)							MONDAY/ WEDNESDAY (D2)				
			Morning				Afternoon			Morning			Afternoon	
Faculty *i*	**Course** j	**Section** *kij*	**8:00 - 9:00**	**9:00 - 10:00**	**10:00 - 11:00**	**11:00 - 12:00**	**1:00 - 2:00**	**2:00 - 3:00**	**3:00 - 4:00**	**8:00 - 9:15**	**9:30 - 10:45**	**11:00 - 12:15**	**2:00 - 3:15**	**3:30 - 4:45**
Faculty 1	210	1	4	3	2	1	0	0	0	0	0	0	0	0
	210	2	0	4	3	2	1	0	0	0	0	0	0	0
	310	1	2	3	4	1	0	0	0	0	0	0	0	0
Faculty 2	210	3	4	3	2	1	0	0	0	0	0	0	0	0
	210	4	0	4	3	2	1	0	0	0	0	0	0	0
	415	1	0	0	4	3	2	1	0	0	0	0	0	0
Faculty 3	205	1	4	3	2	1	0	0	0	0	0	0	0	0
	410	1	0	4	3	2	1	0	0	0	0	0	0	0
	493	1	0	0	4	3	2	1	0	0	0	0	0	0
Faculty 4	205	2	0	0	0	0	0	0	0	4	3	2	1	0
	412	1	0	0	0	0	0	0	0	0	4	3	2	1
	532	1	0	0	0	0	0	0	0	1	2	4	3	0
Faculty 5	210	5	0	0	0	0	0	0	0	4	2	3	1	0
	210	6	0	0	0	0	0	0	0	3	4	2	1	0
	428	1	0	0	0	0	0	0	0	2	1	4	3	0
Faculty 6	205	3	3	4	2	1	0	0	0	0	0	0	0	0
	205	4	4	3	2	1	0	0	0	0	0	0	0	0
	316	1	1	2	4	3	0	0	0	0	0	0	0	0
Faculty 7	205	5	0	0	0	0	0	0	0	4	3	2	1	0
	205	6	0	0	0	0	0	0	0	0	4	3	2	1
	473	1	0	0	0	0	0	0	0	3	2	4	0	1
Faculty 8	205	7	0	4	3	2	1	0	0	0	0	0	0	0
	210	7	4	3	2	1	0	0	0	0	0	0	0	0
	210	8	3	2	4	1	0	0	0	0	0	0	0	0
Faculty 9	205	8	1	2	3	4	0	0	0	0	0	0	0	0
	205	9	2	3	4	1	0	0	0	0	0	0	0	0
	318	1	4	3	2	1	0	0	0	0	0	0	0	0

Table 5
Faculty-Course-Time Slot Assignment Output Table

			PREFERENCE TABLE											
			SUNDAY/ TUESDAY/ THURSDAY (D1)							MONDAY/ WEDNESDAY (D2)				
			Morning				Afternoon			Morning			Afternoon	
Faculty *i*	Course j	Section *kij*	8:00 - 9:00	9:00 - 10:00	10:00 - 11:00	11:00 - 12:00	1:00 - 2:00	2:00 - 3:00	3:00 - 4:00	8:00 - 9:15	9:30 - 10:45	11:00 - 12:15	2:00 - 3:15	3:30 - 4:45
Faculty 1	210	1	1	0	0	0	0	0	0	0	0	0	0	0
	210	2	0	1	0	0	0	0	0	0	0	0	0	0
	310	1	0	0	1	0	0	0	0	0	0	0	0	0
Faculty 2	210	3	0	0	1	0	0	0	0	0	0	0	0	0
	210	4	0	1	0	0	0	0	0	0	0	0	0	0
	415	1	0	0	0	0	1	0	0	0	0	0	0	0
Faculty 3	205	1	1	0	0	0	0	0	0	0	0	0	0	0
	410	1	0	1	0	0	0	0	0	0	0	0	0	0
	493	1	0	0	0	0	0	1	0	0	0	0	0	0
Faculty 4	205	2	0	0	0	0	0	0	0	1	0	0	0	0
	412	1	0	0	0	0	0	0	0	0	1	0	0	0
	532	1	0	0	0	0	0	0	0	0	0	0	1	0
Faculty 5	210	5	0	0	0	0	0	0	0	1	0	0	0	0
	210	6	0	0	0	0	0	0	0	0	1	0	0	0
	428	1	0	0	0	0	0	0	0	0	0	1	0	0
Faculty 6	205	3	0	1	0	0	0	0	0	0	0	0	0	0
	205	4	1	0	0	0	0	0	0	0	0	0	0	0
	316	1	0	0	0	1	0	0	0	0	0	0	0	0
Faculty 7	205	5	0	0	0	0	0	0	0	0	0	1	0	0
	205	6	0	0	0	0	0	0	0	0	1	0	0	0
	473	1	0	0	0	0	0	0	0	1	0	0	0	0
Faculty 8	205	7	0	1	0	0	0	0	0	0	0	0	0	0
	210	7	1	0	0	0	0	0	0	0	0	0	0	0
	210	8	0	0	1	0	0	0	0	0	0	0	0	0
Faculty 9	205	8	0	0	0	1	0	0	0	0	0	0	0	0
	205	9	0	0	1	0	0	0	0	0	0	0	0	0
	318	1	1	0	0	0	0	0	0	0	0	0	0	0

Table 6
Percentage of Goal Achievement for Faculty-Course-Time Slot Assignment Model

Goals	Percentage Met
Goal 1	100
Goal 2	100
Goal 3	100
Goal 4	58
Goal 5	100
Goal 6	100
Goal 7	100
Goal 8	88.8

separately, it is important to find overall all satisfaction level for faculties for the two stages combined. Taking Case 1/Scenario 1 into consideration, the overall faculty satisfaction level of the two stages combined was found to be 82.9% x88.8% = 73.6%. However, this result should not be miss interpreted for it measures the satisfaction level as far as faculties getting their first choices. Results indicate that the overall satisfaction level for faculties reached up to 100% when it came to getting at least their second choices of preferences. Moreover, the model's simplicity in formulation, its promptness when reaching local optimal solution, and its overall goals' fulfillment overwhelms the need for combining the two stages into one complex model and solving it at once (i.e., Simultaneously).

Conclusion and Future Research

Developing a model that could produce an effective faculty-course scheduling solution is no easy task. Different systems have been designed and built in different universities around the world in an attempt to come up with the "optimal" schedule, yet every system has its limitations and drawbacks. This paper utilizes the goal programming technique and the idea of breaking (decomposing) the problem into smaller sub problems in order to simplify formulation and swiftly reach a satisfying solution to the overall problem. The method used in satisfying goals is the priority sequence approach, where goals are satisfied according to their order of importance based on some university, college, and department regulations and requirements. The model has been tested on different scenarios and has proven to fulfill most goals completely. Moreover, faculties satisfaction level obtained were up to 85.2 and 88. 8 for the two stages models respectively. The overall satisfaction level when combining the two results reached up to 73.6% as far as faculties getting their first choices of preferences. Nonetheless, faculties' satisfaction level reached up to 100% when it came to getting at least their second choices of preferences. It is important to realize however, that faculties' satisfaction level is solely data dependent. This means that if most faculties prefer to teach the same course and only one faculty could teach it at a time, then not everybody who prefers to teach that course could do so. On the other hand, if it happens that different faculties prefer to teach different courses, then most faculties will be assigned to teach their preferred courses. Work is underway to build a three-stage model integrated within a decision support system. The implementation and the results of the experimentation with such system for all majors at the College of Business Administration will be reported in a forthcoming paper.

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الملخص

نموذج برمجة أهداف تتابعي ذو مرحلتين لمشكلة تخصيص أعضاء هيئة التدريس للمواد الدراسية وأوقات التدريس

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يعد تطوير نموذج يستطيع أن ينتج عنه جدولة تتصف بالكفاءة والفعالية لأعضاء هيئة التدريس للمواد الدراسية وأوقات التدريس، واحداً من أهم التحديات التي تواجه معظم الجامعات في جميع أنحاء العالم. وقد تم تصميم وبناء عدة أنظمة في هذا المجال للحصول على الجدول المثالي لذلك، ولكن معظم هذه الأنظمة كانت تعاني من بعض جوانب القصور والعجز.

في هذا البحث تم استخدام طريقة البرمجة الهدفية الثنائية (صفر –١) بحيث تم تخصيص أعضاء هيئة التدريس للمواد الدراسية في المرحلة الأولى، ثم تخصيص كل عضو هيئة تدريس مع المادة المخصصة له للفترات الزمنية المخصصة لكل يوم دراسي في المرحلة الثانية.

خلال هاتين المرحلتين يعمل النموذج على تعظيم أفضلية أعضاء هيئة التدريس للمواد الدراسية في المرحلة الأولى، ثم تعظيم أفضلية أعضاء هيئة التدريس للأوقات الزمنية لتدريس كل مادة تم تخصيصها له في المرحلة الأولى.

تقوم الطريقة المستخدمة في هذا البحث بتحقيق عدة أهداف حسب أولويات محددة، بحيث يتم تحقيق كل هدف حسب أهميته بالنسبة إلى القواعد والقوانين المطلوبة والخاصة بالجامعة والكلية والقسم والتخصص، وتم القيام بسيناريوهات مختلفة لاختبار صحة النموذج.

ولقد أثبتت المرحلة الأولى من النموذج قدرة على تحقيق معظم الأهداف كاملة، وتحقيق إجمالي أفضلية أعضاء هيئة التدريس إلى المواد التي يرغبون في تدريسها بنسبة ٨٥,٢٪ وفي المرحلة الثانية استطاع النموذج أن يحقق أفضلية أعضاء هيئة التدريس إلى الأوقات الزمنية لتدريس المواد المخصصة لهم بنسبة إجمالية تصل إلى ٨٨,٨٪.

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