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Solving Faculty-Course Allocation Problem Using Integer Programming Model

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One of the most challenging tasks performed by the department chair every semester is the assignment of faculty members to courses. This task, when done manually, is tedious to accomplish because of the numerous faculty-course combinations, the policies to be considered, faculty retirements, faculty resignations, and the hiring of faculty members. Satisfying the needs of employees has been increasingly significant in the scheduling decisions of different companies. In this study, a binary integer programming model that considers the preferences of faculty members was proposed to solve the faculty-course allocation problem. Constraints that permit the faculty members to perform other duties aside from instruction were included in the model. The model was applied to the faculty-course assignment of a department. Schedules that considered both policies in educational institutions and the preferences of faculty members were obtained.

Keywords: assignment, binary integer programming model, faculty members to courses allocation, preferences of faculty members

INTRODUCTION

The assignment of faculty members plays a part in the optimal use of human resources, which is – in turn – vital for the efficient delivery of services of higher educational institutions. Educational institutions commonly accomplish the faculty members' teaching load manually, which is tedious and inefficient since the teaching assignment to be given to a faculty member is not solely determined by the predicted demand but also by several considerations, policies, and restrictions. Moreover, due to varied preferences of faculty members concerning courses and time slots (Ismayilova *et al*. 2007), allowable teaching load credits, research load credits, administrative load credits, study load credits, allowable leaves, in-service teacher training, high faculty turnover, and other policies about the faculty, allocation of teachers to courses becomes a challenge. Besides, the complexity and size of this type of problem are furthered by faculty retirements, faculty resignations, and the hiring of faculty members. As a result, the manually generated schedules are usually biased and inefficient in terms of resources management (Al-Yakoob and Sherali 2006).

Faculty scheduling is an example of an assignment problem in operations research. Here, a cost is given in assigning worker i to job j. The goal of the typical assignment problem is to provide an optimal allocation of agents to tasks with the assurance of assigning them only once (Taha 2017). Applications of the assignment problem in modeling can be seen in different fields such as the assignment of shifts or jobs to workers, players to a game, landing slots to airlines, and many more (Budish 2011).

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Satisfying employee needs has been progressively significant in scheduling decisions (Topaloglu and Ozkarahan 2004; van den Bergh *et al.* 2013). In crafting work schedules, companies consider the preferences of the employees such as working together with someone, choice in the type of work shift, and days off (van den Bergh *et al.* 2013). Some studies on employee scheduling that considered the preferences of personnel include the works of Topaloglu and Ozkarahan (2004), Sabar and co-authors (2008), Akbari and co-authors (2013), and Ruiz-Torres and co-authors (2017). In creating a faculty schedule, while it is significant to satisfy students' demands, it is also crucial to consider the needs of faculty members since considering their preferences would also affect the academic performance of students. This may then improve the educational system (Ismayilova *et al*. 2007). Other than that, the faculty members are usually involved in other academic-related responsibilities such as research, administration, and committee work, which also heavily consume their time. For these reasons, the preferences of the faculty members in courses must also be considered in creating teaching loads, besides ensuring that the policies and other considerations are satisfied.

There have been studies about faculty-course allocation in the past. Ismayilova and co-authors (2007) considered both the preferences of the administration and instructors in a faculty-course-time slot assignment problem. They developed a multiobjective 0-1 linear programming model and used AHP (analytic hierarchy process) and ANP (analytic network process) to weigh the different and conflicting objectives. Mathematical programming models were developed in the paper of Al-Yakoob and Sherali (2006) for assigning faculty members to classes at the Department of Mathematics and Computer Science at Kuwait University. They developed an integer programming model that minimizes the individual and collective dissatisfaction of faculty members. This model was improved to further enhance the satisfaction of faculty members by allowing classes to be offered during timeslots other than those already identified. Hsu and Chao (2009) proposed a two-stage heuristic-based class-course-faculty assigning model to solve the academic scheduling at the Electronic Engineering department of Kao Yuan University. Stage I was concerned with creating a student-oriented class-course timetabling model and Stage II was concerned with assigning faculty members to classes. Both stages include three steps: representing all necessary data sets and constraints, designing fitness functions, and iterative mutations. Other studies which used heuristic algorithms to solve scheduling problems are Mooney and Rardin (1993), Costa (1994), and Tam and Ting (2003). These algorithms are based on local search methods which are effective in an extensive range of problems and are easy to implement (Mooney and Rardin 1993).

Studies that also considered faculty members' preferences in assigning them to courses include the works of Al-Yakoob and Sherali (2006) and Ismayilova and co-authors (2007). Higher priorities to the tenured instructors were set in the paper of Ismayilova and co-authors (2007). In the paper of Al-Yakoob and Sherali (2006), constraints specific to the university were included such as gender-related policies and other restrictions regarding teaching different classes. Despite the similarity in the objective, *i.e.* the preferences of the faculty, different models have been proposed since there are different policies among universities or even among departments of the same institution. The goal of this paper is to propose a general model that can be applied to other departments that offer several degree programs. Note that this often limits the faculty members to teach some courses offered in their department. Moreover, a set of constraints was included in a typical model such that faculty members may have some time for other duties apart from instruction.

In this study, a binary integer programming model was formulated such that the preferences of the faculty members were maximized since as mentioned, the needs of employees are also an important factor to consider in improving the educational system. Moreover, a teaching day was partitioned into four time blocks. Other responsibilities such as research, administrative, and committee duties also consume plenty of time. Hence, a set of constraints was included such that every faculty member will handle a class either on the first three time blocks or the last three time blocks. This will give the teachers time to complete other duties in the academy.

MATERIALS AND METHODS

A binary integer programming model was proposed to solve faculty-course allocation such that the preferences of the faculty members were maximized while satisfying educational system requirements.

Model Assumptions

The following assumptions were incorporated in formulating the constraints:

a. The course schedules are already available.

b. All courses offered must be assigned.
c. Each faculty member must have a load within the minimum load and the maximum load set by the department.

Parameters

Faculty members can be classified according to the courses they can teach depending on the years of service or their specializations. Broadly speaking, those with less experience shall be classified as instructors whereas those with more experience will be referred to as professors. So, we denote:

$I = \{i_j : j = 1,2,3, \dots, n_1\}$ be the set of instructors, where n_1 is the total number of instructors,

$P = \{p_k : k = 1,2,3, \dots, n_2\}$ be the set of professors, where n_2 is the total number of professors.

Courses were classified into types depending on the different types of classes offered, *e.g.* graduate classes, laboratory classes, *etc.* The reason for this is first, the department may offer several degree programs and, hence, some classes can only be handled by a certain group of teachers. The reasons include faculty members' rank, highest educational attainment, specialization, and faculty members' number of years in service. Second, different types of courses have a varied number of workload units.

Let:

$S = \{s_l : l = 1,2, \dots c_1, c_1 + 1, \dots, c_1 + c_2, c_1 + c_2 + 1, \dots, T\}$ be the set of classes,

where parameters involving classes are as follows:

$T = c_1 + c_2 + \cdots + c_a$ is the total number of classes,

$s_1, s_2, \dots, s_{c_1}$ are the classes in the first type of courses,

$s_{c_1+1}, s_{c_1+2}, \dots, s_{c_1+c_2}$ are the classes in the second type of courses,

$s_{c_1+c_2+1}, s_{c_1+c_2+2}, \dots, s_{c_1+c_2+c_3}$ are the classes in the third type of courses,

$\vdots$

$s_{c_1+c_2+\cdots+c_{a-1}+1}, \dots, s_{c_1+c_2+\cdots+c_a}$ are the classes in the last type of courses,

where, c_i is the total number of classes in courses of type i, $\forall i = 1,2, \dots, a$.

Decision Variables

Each faculty member will be assigned to at least one class per semester. This can be modeled as a binary integer program. An integer programming model is a linear programming model with a restriction that variables must have integer values. Moreover, a type of integer programming in which the variables are restricted to 0 or 1 is binary integer programming. The decision variables are as follows:

$$x_{i_j s_l} = \begin{cases} 1, \text{if instructor } i_j \text{ is assigned to class } s_l \\ 0, \text{otherwise} \end{cases},$$

$$y_{p_k s_l} = \begin{cases} 1, \text{if professor } p_k \text{ is assigned to class } s_l \\ 0, \text{otherwise.} \end{cases}$$

Objective Function

As mentioned earlier, the objective of this study is to obtain an optimal allocation of faculty members to courses such that the preferences of the faculty members are maximized while satisfying necessary constraints. These weights, which can be defined for some scale, can be obtained by conducting a survey on the preferences of the teachers to courses and schedules. For instance, the teaching staff can assign 0, 0.1, 0.2, …,1 to classes, where 1 is the most preferred case. Thus, we have the following objective:

Maximize

$$Z = \sum_{k=1}^{n_2} \sum_{l=1}^{T} \underline{v}_{p_k s_l} y_{p_k s_l} + \sum_{j=1}^{n_1} \sum_{l=1}^{T} \underline{w}_{i_j s_l} x_{i s_l}, \tag{1}$$

where $\underline{v}_{p_k s_l}$ represents the preference weight given by professor p_k to course s_l and $\underline{w}_{i_j s_l}$ represents the preference weight given by instructor i_j to course s_l.

Constraints

1. Time constraints
   1.1 Assume that courses $u_1, u_2, u_3, \dots, u_t$ where $u_1 \neq u_2 \neq u_3 \neq \cdots \neq u_t$, are courses with the same timeslot and day. Hence, each teacher must be assigned to at most one of these courses. Thus, we have for instructors:
   $$x_{i_j u_1} + x_{i_j u_2} + \cdots + x_{i_j u_t} \leq 1 \quad \forall i_j, \tag{2}$$
   for professors:
   $$y_{p_k u_1} + y_{p_k u_2} + \cdots + y_{p_k u_t} \leq 1 \quad \forall p_k. \tag{3}$$
   1.2 The total number of classes assigned to all faculty members must be equal to the total number of classes offered by the department since each class must be assigned to a faculty member. Thus,
   $$\sum_{j=1}^{n_1} \sum_{l=1}^{T} x_{i_j s_l} + \sum_{k=1}^{n_2} \sum_{l=1}^{T} y_{p_k s_l} = T. \tag{4}$$
   1.3 Courses that will be team-taught can already be indicated in the model and are usually predetermined by the department. Each remaining unassigned course can then be handled by one faculty member. A set of constraints was included such that each class must be handled by only one faculty member. This corresponds to the following constraints.
   $$\sum_{j=1}^{n_1} x_{i_j s_l} + \sum_{k=1}^{n_2} y_{p_k s_l} = 1 \quad \forall s_l \tag{5}$$
2. As explained earlier, some departments provide numerous degree programs, and hence, other teachers might not be allowed to teach courses that are not covered by their specializations. Moreover, there are cases when the number of years in the profession is also considered before a teacher can handle other courses. To be certain that these teachers will not be assigned to these courses, the following constraints are included in the model.

   If instructor i_{r1} is not allowed to handle course s_{m1},
   $$x_{i_{r1} s_{m1}} = 0. \tag{6}$$
   If professor p_{q1} is not allowed to handle course s_{h1},
   $$y_{p_{q1} s_{h1}} = 0. \tag{7}$$
3. Departments have policies for the minimum and the maximum workloads. Thus, we have the following constraints:
   For instructors:

$$L_{min1} \leq \left(l_1^m \sum_{l=c_1+1}^{c_1+c_2} x_{i_j s_l} \right) + \left(l_2^m \sum_{l=c_1+c_2+1}^{c_1+c_2+c_3} x_{i_j s_l} \right) + \cdots + \left(l_a^m \sum_{l=c_1+c_2+\cdots+c_{a-1}+1}^{l=c_1+c_2+\cdots+c_a} x_{i_j s_l} \right) + L_{O_{i_j}} \leq L_{max1} \quad \forall i_j \tag{8}$$

For professors:

$$L_{min2} \leq \left(l_1^m \sum_{l=c_1+1}^{c_1+c_2} y_{p_k s_l} \right) + \left(l_2^m \sum_{l=c_1+c_2+1}^{c_1+c_2+c_3} y_{p_k s_l} \right) + \cdots + \left(l_a^m \sum_{l=c_1+c_2+\cdots+c_{a-1}+1}^{l=c_1+c_2+\cdots+c_a} y_{p_k s_l} \right) + L_{O_{p_k}} \leq L_{max2} \quad \forall p_k \tag{9}$$

where:

a is the number of types of courses,
l_1^m is the number of units per class of the first type of courses,
l_2^m is the number of units per class of the second type of courses,
⋮
l_a^m is the number of units per class of the last type of courses,
L_{min1} is the minimum load of each instructor,
L_{min2} is the minimum load of each professor,
L_{max1} is the maximum load of each instructor,
L_{max2} is the maximum load of each professor,
$L_{O_{i_j}}$ is the total load other than the teaching load of instructor i_j,
$L_{O_{p_k}}$ is the total load other than the teaching load of professor p_k.

4. The courses are grouped by time blocks. This is done because faculty members have other duties such as administrative, research, and committee works. In this study, a set of constraints are added so teachers may devote some time to these responsibilities. In this set of constraints, if a faculty member has a class in the first block, the schedule of the faculty member will be vacant in the last block. In this paper, a teaching day is divided into four blocks. For instance, if the classes in a department start at 7:00 AM and end at 7:00 PM, the blocks will be 7:00 AM–10:00 AM, 10:00 AM–1:00 PM, 1:00 PM–4:00 PM, and 4:00 PM–7:00 PM. Thus, if a faculty member has a 7:00 AM–10:00 AM class, the faculty member will not handle a 4:00 PM–7:00 PM class on that same day and *vice versa*. Thus, the following inequalities are included.

For instructors:

$$x_{i_j m_{1h}} + x_{i_j m_{2l}} \leq 1 \quad \forall i_j, \forall m_{1h}, \forall m_{2l}, \tag{10}$$

$$x_{i_j t_{1h}} + x_{i_j t_{2l}} \leq 1 \quad \forall i_j, \forall t_{1h}, \forall t_{2l}, \tag{11}$$

$$x_{i_j w_{1h}} + x_{i_j w_{2l}} \leq 1 \quad \forall i_j, \forall w_{1h}, \forall w_{2l}, \tag{12}$$

$$x_{i_j th_{1h}} + x_{i_j th_{2l}} \leq 1 \quad \forall i_j, \forall th_{1h}, \forall th_{2l}, \tag{13}$$

$$x_{i_j f_{1h}} + x_{i_j f_{2l}} \leq 1 \quad \forall i_j, \forall f_{1h}, \forall f_{2l}, \tag{14}$$

$$x_{i_j s_{1h}} + x_{i_j s_{2l}} \leq 1 \quad \forall i_j, \forall s_{1h}, \forall s_{2l}. \tag{15}$$

For professors:

$$y_{p_k m_{1h}} + y_{p_k m_{2l}} \leq 1 \quad \forall p_k, \forall m_{1h}, \forall m_{2l}, \tag{16}$$

$$y_{p_k t_{1h}} + y_{p_k t_{2l}} \leq 1 \quad \forall p_k, \forall t_{1h}, \forall t_{2l}, \tag{17}$$

$$y_{p_k w_{1h}} + y_{p_k w_{2l}} \leq 1 \quad \forall p_k, \forall w_{1h}, \forall w_{2l}, \tag{18}$$

$$y_{p_k th_{1h}} + y_{p_k th_{2l}} \leq 1 \quad \forall p_k, \forall th_{1h}, \forall th_{2l}, \tag{19}$$

$$y_{p_k f_{1h}} + y_{p_k f_{2l}} \leq 1 \quad \forall p_k, \forall f_{1h}, \forall f_{2l}, \tag{20}$$

$$y_{p_k s_{1h}} + y_{p_k s_{2l}} \leq 1 \quad \forall p_k, \forall s_{1h}, \forall s_{2l}, \tag{21}$$

where:

M_1 is the number of classes on the first time block during Mondays,

M_2 is the number of classes on the last time block during Mondays,

T_1 is the number of classes on the first time block during Tuesdays,

T_2 is the number of classes on the last time block during Tuesdays,

W_1 is the number of classes on the first time block during Wednesdays,

W_2 is the number of classes on the last time block during Wednesdays,

TH_1 is the number of classes on the first time block during Thursdays,

TH_2 is the number of classes on the last time block during Thursdays,

F_1 is the number of classes on the first time block during Fridays,

F_2 is the number of classes on the last time block during Fridays,

SA_1 is the number of classes on the first time block during Saturdays,

SA_2 is the number of classes on the last time block during Saturdays,

$Mon_1 = \{m_{1h}: h = 1,2, \dots, M_1\}$ is the set of classes on the first block during Mondays,

$Mon_2 = \{m_{2l}: l = 1,2, \dots, M_2\}$ is the set of classes on the last block during Mondays,

$Tues_1 = \{t_{1h}: h = 1,2, \dots, T_1\}$ is the set of classes on the first block during Tuesdays,

$Tues_2 = \{t_{2l}: l = 1,2, \dots, T_2\}$ is the set of classes on the last block during Tuesdays,

$Wed_1 = \{w_{1h}: h = 1,2, \dots, W_1\}$ is the set of classes on the first block during Wednesdays,

$Wed_2 = \{w_{2l}: l = 1,2,\dots,W_2\}$ is the set of classes on the last block during Wednesdays,

$Thurs_1 = \{th_{1h}: h = 1,2,\dots,TH_1\}$ is the set of classes on the first block during Thursdays,

$Thurs_2 = \{th_{2l}: l = 1,2,\dots,TH_2\}$ is the set of classes on the last block during Thursdays,

$Fri_1 = \{f_{1h}: h = 1,2,\dots,F_1\}$ is the set of classes on the first block during Fridays,

$Fri_2 = \{f_{2l}: l = 1,2,\dots,F_2\}$ is the set of classes on the last block during Fridays,

$Sat_1 = \{s_{1h}: h = 1,2,\dots,SA_1\}$ is the set of classes on the first block during Saturdays,

$Sat_2 = \{s_{2l}: l = 1,2,\dots,SA_2\}$ is the set of classes on the last block during Saturdays.

RESULTS AND DISCUSSION

Problem

To test the model, it was applied to the faculty scheduling problem of a department for one semester. For that semester, 259 classes must be assigned to 24 instructors and 24 professors. This was done manually in the department. This department offers several degree programs and so creating the schedules of the faculty manually is very time-consuming. Several restrictions must be considered such as certain courses can only be handled by a certain group of faculty members because of the expertise of the teachers in certain fields of study. Furthermore, the number of years in service and the highest educational attainment of the faculty members are also factors that affect their teaching load. Given the complexity of the problem, the goal is to come up with a feasible schedule that maximizes the preferences of the teachers. Feasible in the sense that it does not only satisfy the usual constraints of a scheduling problem, but it must also give a useful schedule, *i.e.* the teachers must not be given classes that are not in their line of expertise.

Instructors and Professors

In this problem, the instructors are grouped into i) those who have been teaching in the department for less than two years and ii) those who have been teaching for at least two years. Moreover, the newly hired professors were also separated from those who are not. This was done because new instructors and professors are restricted to handle some courses in the department.

Preference (Weights)

In this study, the weight given by a faculty member to courses ranges from 0–1 based on the schedule that was determined manually, *i.e.* if a faculty member handled a class s_d during that semester, the assigned preference weight is 0.9. If a faculty member was not assigned to a class but is not restricted to handle the class, a weight of 0.1 or 0 is assigned. Lastly, if the teacher is not allowed to teach the course, the assigned weight is 0.

Numerical results

The model was programmed and solved in GUSEK, a standalone executable that merges the SciTE (SCIntilla based Text Editor) and the linear/integer programming solver GLPK (GNU Linear Programming Kit). An optimal solution was found with a total computation time of 18.5 s. The code was run in an 8th Gen. Intel Core i5 2400 MHz. Please see the link in the Supplementary File section for the code used in this study.

Implementing the model, the usual constraints of a scheduling problem were satisfied. Furthermore, the teachers were only assigned to the classes that they are allowed to teach. Please see Figures 1–3 for sample tabular schedules of faculty members obtained from solving the model. Moreover, the workload that must be given to each faculty member in a semester falls within the minimum and the maximum loads set by the department. Aside from considering the preferences of all the faculty members, constraints that restrict each faculty member to handle a 4:00–7:00 PM class if the faculty member has a 7:00–10:00 AM class and *vice versa* were also included. Some teachers were not allocated to their most preferred subjects because constraints 10–21 must be met. For instance, if faculty member i_α prefers both subjects s_β and s_γ , and s_β belongs to the first block of classes during Mondays while s_γ belongs to the last block of classes on the same day, teacher i_α will not handle one of these classes due to the time block constraints. However, it is worth noting that all faculty members were assigned to the classes that they can teach, *i.e.* no faculty member has been assigned to courses not covered by the teacher's major, and no new instructor or professor has been allocated to courses they could not yet teach.

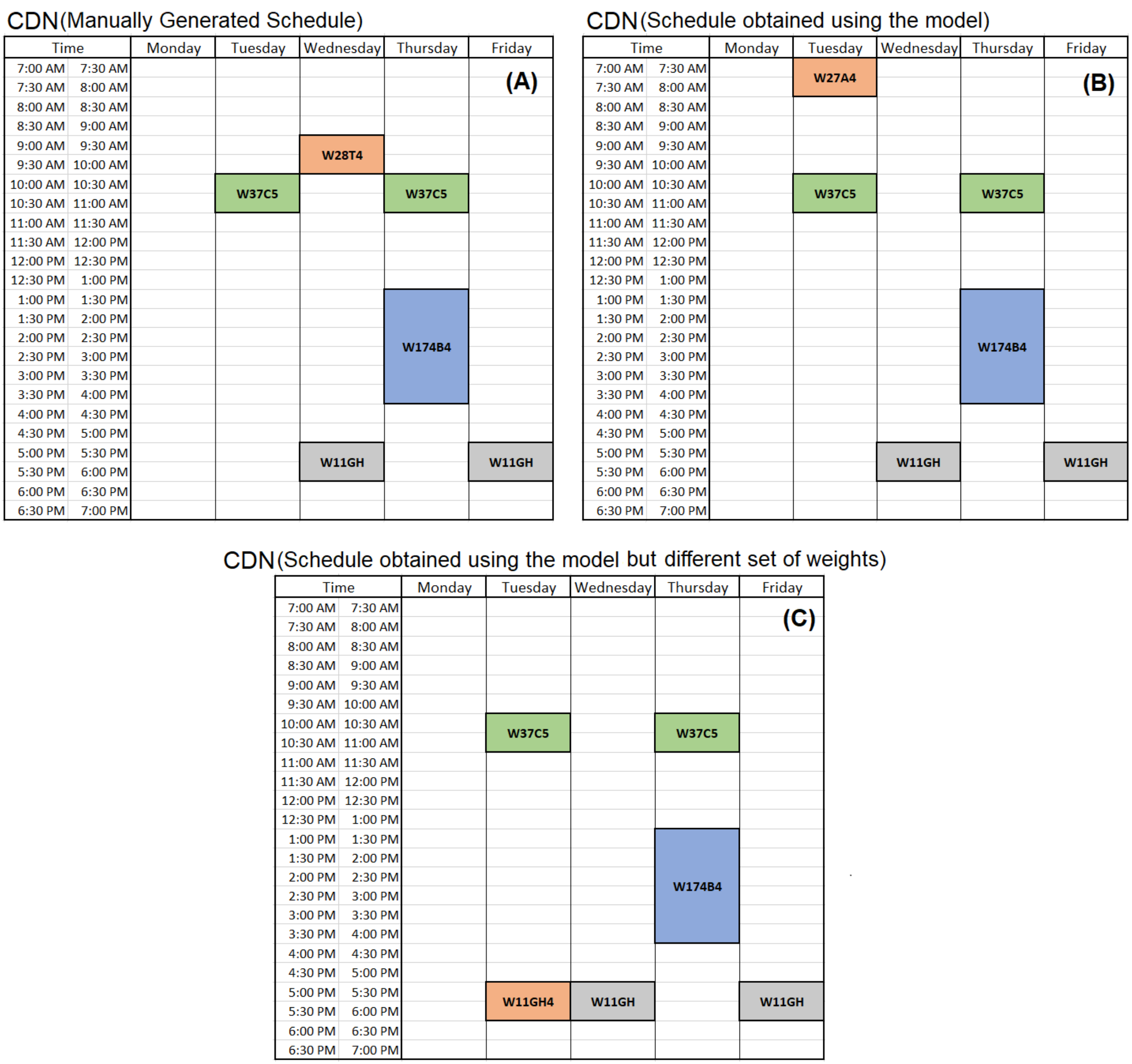

Figure 1. Schedule of the faculty member with code CDN: A) the original tabular schedule of CDN that was created manually; B) resulting tabular schedule from the solution obtained using the proposed binary integer programming model; C) resulting tabular schedule from the solution obtained using a different set of weights.

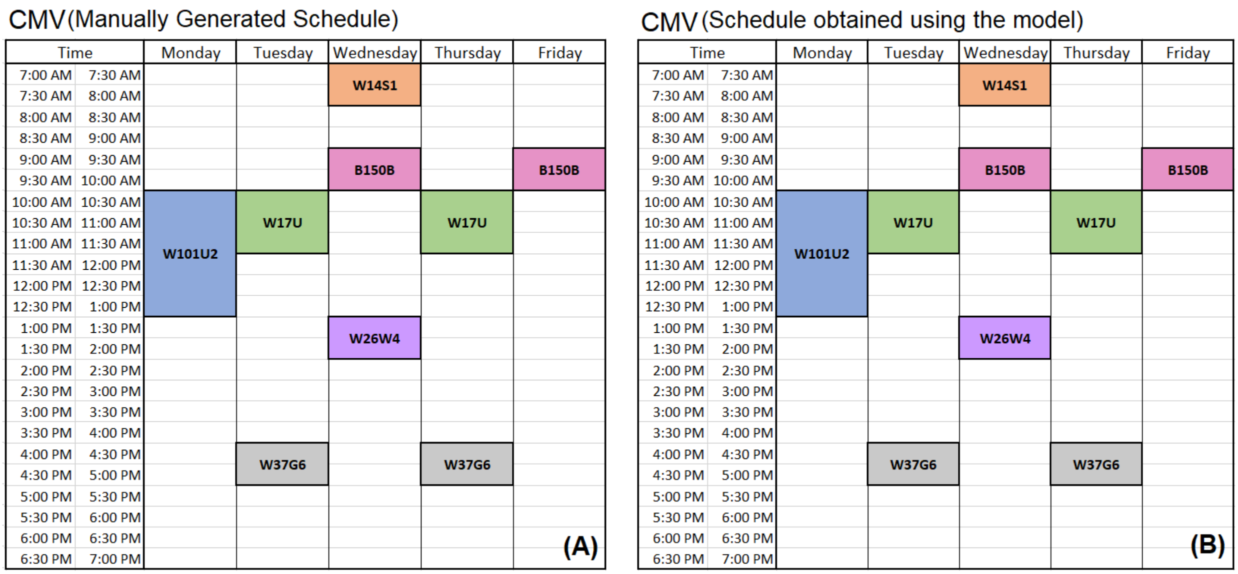

Figure 2. Schedule of the faculty member with code CMV: A) the original tabular schedule of CMV that was created manually; B) the resulting tabular schedule from the solution obtained using the proposed binary integer programming model.

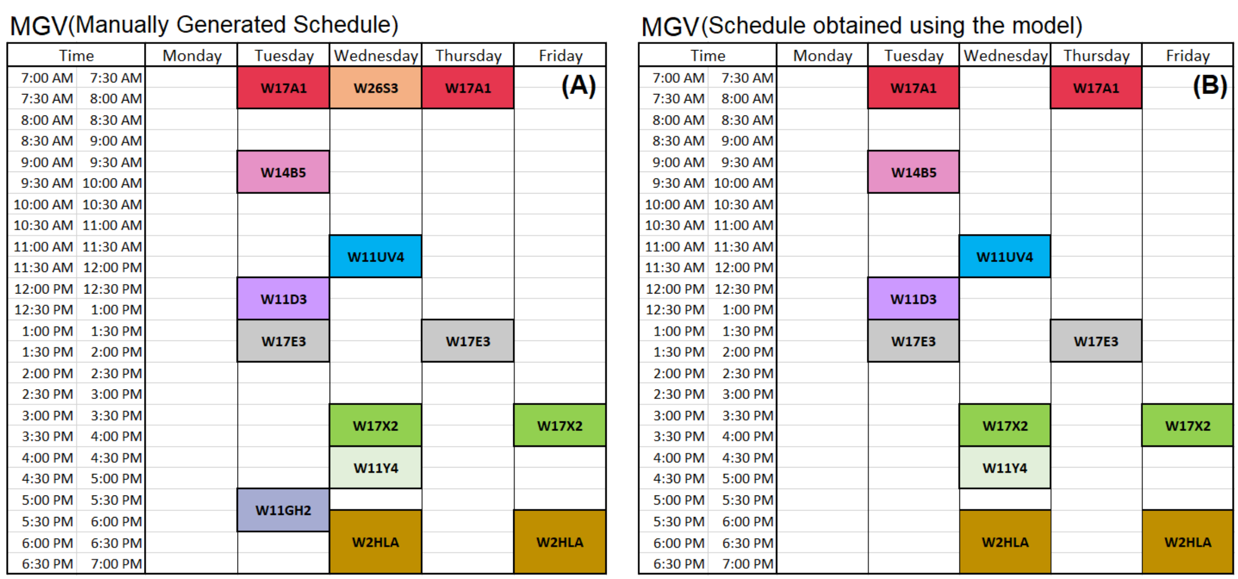

Figure 3. Schedule of the faculty member with code MGV: A) the original tabular schedule of MGV that was created manually; (B) the resulting tabular schedule from the solution obtained using the proposed binary integer programming model.

The generated schedules were almost similar to that of the manually determined schedule except for the subjects that were transferred because the schedules of the subjects do not satisfy constraints 10–21. These subjects were assigned to other faculty members who can still handle these subjects. See Figures 1–3 for the original assignments and the assignments generated using the proposed model. The class with code W27A4 was transferred to the teacher with code CDN (see Figure 1), which was originally assigned to another teacher. On the other hand, the resulting tabular schedule of CMV from the proposed model was the same as the original (see Figure 2). While it was shown in Figure 3 that the class with code W26S3, which is scheduled Wednesday 7:00–8:00 AM, was assigned to another faculty member since MGV has a 5:30–7:00 PM class during Wednesdays.

Weights are important factors that affect faculty assignments. Hence, the problem was solved using a different set of weights. A weight of 0.7 was set to the classes that were assigned to a faculty member while a weight of 0 was assigned to the faculty member-class pairing when then the faculty member may not teach the course. Lastly, a weight of 0.3 or 0 was assigned if the faculty member can teach the course but was not assigned to that course in the manually generated schedule. Some assignments have been changed upon changing the set of weights. See, for instance, Figure 1C where a new class was assigned to the faculty member with code CDN. It is important to note that although some changes in the teaching load occurred, all faculty members were assigned to courses that they are allowed to teach. Hence, the decision maker's inputs and decisions are important factors in this model. This model coupled with the inputs from the administration will give results desirable to both the administration and the faculty.

CONCLUSION

Faculty assignment is a challenging and time-consuming task that is performed every semester in educational institutions. Moreover, an individual assignment problem is different from another assignment problem. In this study, a binary integer programming model was developed and applied to assign 259 classes to 48 faculty members. The novelty of this study lies in the consideration of the preferences of faculty members. Furthermore, this model – through time blocks – allows faculty members to have time for non-teaching duties. The model was programmed and solved in GUSEK. Schedules that considered both the department's policies and the faculty members' preferences were obtained.

Current and future research involve variations such as faculty members will be handling courses for three days only, courses assigned to faculty members per day are limited, variety of courses to be taught are bounded above to consider the number of preparations done by each teacher in the department. A goal programming model may also be considered to include other important goals in a department. The faculty members may also be grouped according to their specializations. Furthermore, instead of maximizing the preferences of faculty members, the objective may also be changed. For example, the total skills of the faculty based on the courses that were assigned to the faculty members in the previous years or based on the students' evaluations to them is chosen to be maximized instead. The proposed model may be applied to other departments or other universities, assuming that the scheduling systems are similar.

SUPPLEMENTARY FILE

The program used in this study can be found online at
https://github.com/monicatorres00001/Scheduling/blob/main/Solving%20Faculty-Course%20Allocation%20Problem%20Using%20Integer%20Programming%20Model.mod

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STATEMENT ON CONFLICT OF INTEREST

The authors have declared no competing interest.

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