An Integer Goal Programming Model for Faculty-Course-Time Scheduling in University

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Abstract

The allocation of resources problem faced by academic institutions involves the assignment of faculty-course-time that must be performed periodically. This problem is becoming more complex when there is conflicting goals between department and faculty members. The scheduling of faculty members has to satisfy departmental policies as well as recognizing the personal preferences of faculty members for teaching particular courses during certain time period.

This paper formulates a faculty-course-time scheduling as a zero-one integer programming model. The model could take into account faculty members' preferences to courses and times while meeting department requirements. The objectives are satisfied using 'preemptive' philosophy, based on their relative importance. This model solution is obtained by using LINDO optimization software version 61.

The result of application of this model to Department of Management, Maranatha Christian University, Bandung shows the model's capability to provide scheduling that overcome conflicting goals between faculty members and departmental policies by minimizing undesirable deviation from objectives.

Keywords: integer goal programming, faculty-course-time scheduling

Introduction

In managing organization, one process to be done by decision maker is planning. Plans give the organization its specific goals and set up the procedures of using all available organizational resources to achieve the goals. Planning occurs in every organization, regardless of the nature of its activities.

In the planning or decision making hierarchy, scheduling decisions are the final step that must be made within the constraints established by many other decisions. Scheduling pertains to establishing the timing of the use of specific resources of organization. It relates to the use of equipment, facilities, and human activities. Manufacturers must schedule production, which means developing schedules for workers, equipment, maintenance, and so on. Hospitals must schedule admission, surgery, nursing assignments and all supporting services. University must schedule courses, classrooms, and faculty staffs. Lawyers, doctors, dentists, hairdressers, and auto repair shops must schedule appointments (Stevenson, 1999).

The objectives of scheduling are to achieve trade-offs among conflicting goals, which include minimization of process time and inventories, maximization of the utilization of available resource, and so on. In service system, there may be considerably more criteria of interest, especially when one of the resources being schedules is staff. Staff desires in terms of shifts, holidays, and work schedules become critically important when work schedules are variable and not all employees are on the same schedules. In this situation, there usually exist schedules that will displease everyone and schedules that will satisfy most of staffs' more important priorities.

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The primary scheduling problem in university involves the scheduling of classes and allocation of facility and faculty staffs. One of difficult elements that must be coordinated in this process is the multiple needs and desires of the faculty staffs such as teaching during certain times, teaching certain courses, etc.

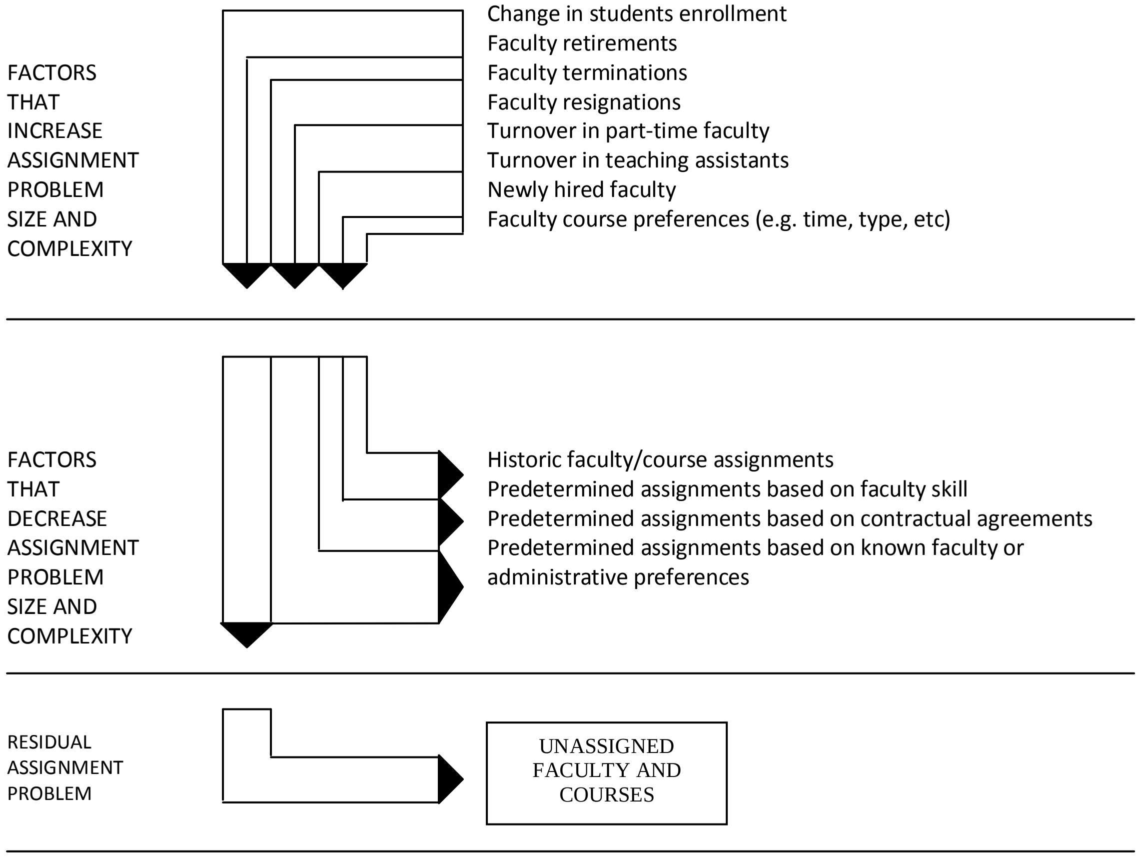

Figure 1. Factors that increase and decrease the size and complexity of faculty assignment problem (Source: Schniederjans and Gyu, 1987)

There have been several mathematical models that proposed scheduling in university. Andrew and Collins (1971) in Badri (1996) proposed the use of linear programming methods in conducting educational staff scheduling. This model aims to optimize the assignment of faculty staffs to courses subject to the number of courses needed and faculty teaching load.

Harwood and Lawless [1975] considered conflicting goals in the assignment of faculty staffs. Therefore, Harwood and Lawless suggested goal programming for staffs scheduling, because the conflicting goals can not be solved by using linear programming. This model also considers the preference factor for the faculty staffs who are assigned to teach at a specific time period. However, this model still has a drawback, it may be difficult to implement.

McClure and Wells (1984) suggested educational staffing models by using an integer programming linear development. This model tried to overcome the weaknesses of the model proposed by Andrew and Collins (1971) that gave infeasible solutions to some educational staffing issues and the model proposed by Dyer and Mulvey (1976) that gave non integer values for the decision variables. The characteristic that distinguishes this model

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from other models is its use of decision variables that represent schedules instead of courses.

Schniederjans and Gyu (1987) carry out further research to overcome the limitation of the model proposed by Harwood and Lawless (1975). This model demonstrated how to satisfy departmental goals on the number and types of course offerings required, as well as the faculty teaching load requirements, but also deal with faculty staffs preferences. The limitation of this model is that it did not consider the dimension dealing with course-time assignment, while the dimension is the main thing to be considered in scheduling.

Badri (1996) proposed a model taking into account the educational staffing preference educational staff to subjects or specific time period. This model formulates a multi objective zero-one scheduling model through a two-stage optimization procedure. In the first stage, the model uses a modification of the model Schniederjans and Gyu (1987) to assign staff to the educational courses. In the second stage, the model assigns time blocks to the courses or faculty staffs. Then, Badri (1998) improved the model and introduced a zero-one integer programming model that provides a one stage solution to the assignment model. In addition to considering departmental goals, the model attempts to simultaneously accommodate for faculty preferences to teach certain courses and during certain time slots. This paper describes the application goal programming model proposed by Badri (1998) in faculty-course-time scheduling at Management Department, Maranatha Christian University, Bandung.

Literature Study

Scheduling occurs in a very wide range of economic activities. It always involves accomplishing a number of things that tie up various resources for periods of time. The resources are in limited supply. The things to be accomplished may be called 'jobs' or 'projects' or 'assignment' (Morton and Pentico, 1993). In practice, scheduling results in a time-phased plan, or schedule, or activities. The schedule indicates what is to be done, when, by whom, and with what equipment (Schroeder, 2000).

Scheduling service systems differs from scheduling manufacturing systems in several ways. First, in manufacturing, the scheduling emphasis is on materials, in services, it is on staffing levels. Second, service systems seldom store inventories. Third, services are labor intensive, and the demand for this labor can be highly variable (Heizer & Render, 2004). In a university, academic departments have to assign courses to faculty staffs and time slots. These are important administrative tasks that must be performed in academic departments each semester (Badri, 1998).

Several mathematical modeling models have been proposed for generating faculty-course-time scheduling in university. One of quantitative procedure currently used to facilitate the process of making resource allocation decisions (scheduling) is linear programming (Lapin & Whisler, 2002). Linear programming uses a mathematical model to describe the problem of concern. The adjective 'linear' means that model are required to be linear functions. The word 'programming' is essentially a synonym for planning. Thus, linear programming involves planning of activities to obtain an optimal result that reaches the specified goal best (according to the mathematical model among all feasible alternatives (Hillier & Lieberman, 2005).

In particular, from a mathematical viewpoint, the assumptions of linear programming simply are that the model must have a linear objective function subject to linear constraints. However, from a modeling viewpoint, these mathematical properties of a linear

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programming model imply that certain assumptions must hold about the activities and data of the problem being modeled, including assumptions about the effect of varying the levels of the activities. The assumptions are (Hillier & Lieberman, 2005):

- Proportionality, the contribution of each activity to the value of the objective function Z in proportional to the level of the activities X_j, as represented by C_jX_j term in the objective function.
- Additivity, every function in a linear programming model is the sum of the individual contributions of the respective activities.
- Divisibility, decision variables in a linear programming model are allowed to have any values that satisfy the functional and non negativity constraints. Thus, these variables are not restricted to just integer values.
- Certainty, the value assigned to each parameter of a linear programming model is assumed to be a known constant.

One key limitation that prevents many more application of linear programming is the assumption of divisibility, which required that non integer values be permissible for decisions variables. In many practical problems, the decision variables actually make sense only if they have integer values. If requiring integer values is the only way in which problem deviates from linear programming formulation, then it is an integer programming problem. There have been numerous such applications of integer programming that involve a direct extension of linear programming where the divisibility assumption must be dropped. However, another area of application may be of even greater importance, namely, problem involving a number of interrelated 'yes or no decisions'. With just two choices, we can represent such decisions by variables that are restricted to just two values, say zero and one. Thus the *j*th yes or no decision would be represented by X_j such that (Hillier & Lieberman, 2005):

$$X_j = \begin{cases} \text{If decision j is yes} \\ \text{If decision j is no} \end{cases}$$

The other shortcoming of linear programming is that their objective function is measured in one dimension only. It is not possible for linear programming to have multiple goals unless they are all measured in the same units, a highly unusual situation. An important technique that has been developed to linear programming is goal programming. Goal programming is capable of handling decision problems involving multiple goals. In typical decision making situations, the goals set by management can be achieved only at the expense of other goals. It is necessary to establish a hierarchy of importance among these goals so that lower priority goals are tackled only after higher priority goals are satisfied. Since it is not always possible to achieve every goal to the extent the decision maker desires, goal programming attempts to reach a satisfactory level of multiple objectives. Thus, specifically, the difference of goal programming from linear programming is the objective function. Instead of trying to maximize or minimize the objective function directly, with goal programming we try to minimize deviations between set goals and what we can actually achieve within the given constraint (Render, et al., 2009).

Faculty-Course-Time Scheduling Model in University

The model proposed by Badri (1998) formulates an integer goal programming for faculty-course time scheduling in university. Variables used in this model are:

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i = number of faculty staff
j = number of courses
k = time slot
n = total number of faculty to be assigned
m = total number of courses to be assigned
o = total number of time slot to be assigned
q = total number of ranks used by faculty to define their course preference
g = total number of ranks used by faculty to define their time preference
c_k = total number of courses permitted within the k^{th} time
r_t = number of courses permitted with the same t^{th} ranking
h_u = number of courses permitted within the same u^{th} ranking
s_j = number of sections of each j^{th} course to be offered in the semester
t_i = teaching load for each i^{th} faculty member
d_j^{s+}, d_j^{s-} = positive and negative deviation from the j^{th} course offering
d_i^{t+}, d_i^{t-} = positive and negative deviation from the teaching load for i^{th} faculty member
d_k^{c+}, d_k^{c-} = positive and negative deviation from the total number of classes for the k^{th} time slot
d_t^{r+}, d_t^{r-} = positive and negative deviation from the number of course section offerings at the same faculty assigned t^{th} preference level for courses
d_u^{h+}, d_u^{h-} = positive and negative deviation from the number of course section offerings at the same faculty assigned u^{th} preference level for the time slot

Constraints of the model could be groped in these categories:

- The first constraint represent a set of goals that need to be satisfied to ensured that all required courses are assigned:

$$\sum_{i=1}^{n}\sum_{k=1}^{o} X_{ijk} + d_j^{s-} - d_j^{s+} = s_j \text{ (for } j = 1,2,3\ldots,m) \qquad (1)$$

- The second set of constraints represent available teaching loads for each faculty member:

$$\sum_{j=1}^{m}\sum_{k=1}^{o} X_{ijk} + d_i^{t-} - d_i^{t+} = t_i \quad \text{(for } i = 1,2,3,\ldots,n) \qquad (2)$$

- The third set of constraints represent the limited number of resources in terms of the available number of classrooms per time block:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X_{ijk} + d_k^{c-} - d_k^{c+} = c_k \text{ (for } k = 1,2,3,\ldots,o) \qquad (3)$$

- The fourth set of constraints represent the faculty preferences for courses:

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{o} X_{ijk} + d_t^{r-} - d_t^{r+} = r_t \text{ (for } t = 1,2,3,\ldots,q) \qquad (4)$$

- The fifth set of constraint represent the faculty preferences for time:

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$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{o} X_{ijk} + d_u^{h-} - d_u^{h+} = h_u \quad \text{(for } u = 1,2,3,\ldots,g) \qquad (5)$$

- The sixth set of constraint that will assure that X_{ijk} is not split since each faculty member was given the same opportunity to provide different preferences for courses and time slots:

$$\sum_{k=1}^{o} X_{ijk} \leq 1 \text{(for } i = 1,2,3,\ldots,n;\ \text{ for } j = 1,2,3,\ldots,m) \qquad (6)$$

- The seventh set of constraint that will assure that for a certain faculty member during a certain time slot, only one course is assigned:

$$\sum_{j=1}^{m} X_{ijk} \leq 1 \text{(for } i = 1,2,3,\ldots,n; \text{ for } k = 1,2,3,\ldots,o) \qquad (7)$$

The objective function is:

- Minimize

$$Z = P_1\sum_{j=1}^{m}(d_j^{s+} + d_j^{s-}) + P_2\sum_{i=1}^{n}(d_i^{t+} + d_i^{t-}) + P_3\sum_{k=1}^{o}(d_k^{c+} + d_k^{c-})$$
$$+ P_4\sum_{t=1}^{q}(d_t^{r+} + d_t^{r-}) + P_5\sum_{u=1}^{g}(d_u^{h+} + d_u^{h-}) \qquad (8)$$

Application

The model will be applied to faculty-course-time scheduling at Department of Management, discipline group of Marketing Management, Maranatha Christian University, Bandung, Indonesia. The assignment is applied for only full time faculty of discipline group of Marketing Management in odd semester, academic year 2013-2014. The model data is presented in a matrix as shown in Table 2. In the odd semester, there are 13 courses (with index 1 to 13) in discipline group of Marketing Management:

Table 1. Number of Class Required

Course Index	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of Class Required	3	2	2	3	4	4	3	1	3	5	3	1	2

The courses are offered to 9 faculty members (with index A to I). For each faculty member, course preferences are given in rows. If a course appears in first row, that course has first priority. Meanwhile, if a course appears in the second row, that course is assigned second priority. Time slot priorities are indicated by using letters. The first priority is denoted by using the letter 'a' and the second priority is denoted by using the letter 'b'.

Then, the data in Table 2 could be translated into another form as shown in Table 3, so the model can be solved easily by using linear programming software LINDO 61.

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Table 2. Matrix of Faculty-Course-Time Priorities Requested

Faculty	Monday				Tuesday				Wednesday			
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00
A	XA7a XA8a	XA7b XA8b			XA7a	XA7b			XA11a	XA11b		
B	XB7a	XB13b XB7b	XB13a			XB10a	XB10b			XB13b	XB13a	
C			XC2a XC6a	XC2b XC6b		XC10a XC9a	XC10b XC9b			XC10a	XC10b XC11a	XC11b
D										XD9a	XD9b	
E					XE4a	XE4b	XE12a XE5a	XE12b XE5b				
F		XF1a	XF1b			XF1a	XF8a XF1b	XF8b			XF10a	XF10b
G									XG7a XG8a	XG7b XG8b		
H			XH6b	XH6a			XH6b XH7b	XH6a XH7a			XH1a XH3a	XH1b XH3b
I	XI2b	XI2a	XI5a	XI5b			XI5a XI4a	XI5b XI4b			XI3a	XI3b
Number of courses	3	2	3	3	2	2	4	3	2	2	2	3

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Table 2. Matrix of Faculty-Course-Time Priorities Requested (concluded)

Faculty	Thursday				Friday			Saturday				Teaching Load
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	01.00-03.30	03.30-06.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	
A			XA5a	XA5b		XA5a	XA5b					4
B		XB12a	XB12b						XB10a XB7b	XB10b XB7a		4
C	XC5a	XC6a	XC5b XC6b			XC2b	XC2a					4
D		XD9a XD2a	XD9b XD2b		XD10a XD3a	XD10b XD3b				XD9b	XD9a	4
E	XE4a XE10a	XE4b XE10b			XE10a	XE10b		XE4a XE5a	XE4b XE5b			4
F			XF6a XF9a	XF6b XF9b						XF6b	XF6a	4
G		XG11a	XG11b			XG11a XG13a	XG11b XG13b		XG11a	XG11b XG5a	XG5b	4
H										XH1a	XH1b	4
I	XI4a	XI4b	XI3a	XI3b					XI10a	XI10b		4
Number of courses	4	4	4	3	2	3	4	3	2	4	2	

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Table 3. Translation Matrix of Faculty-Course-Time Priorities Requested

Faculty	Monday				Tuesday				Wednesday			
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00
A	YI Y9	Y2 Y10			Y3	Y4			YII	Y12		
B	Y21	Y13 Y22	Y14			Y15	Y16			Y17	Y18	
C			Y27 Y37	Y28 Y38		Y29 Y39	Y30 Y40			Y31	Y32 Y41	Y42
D										Y45	Y46	
E					Y57	Y58	Y59 Y65	Y60 Y66				
F		Y81	Y82			Y83	Y73 Y84	Y74			Y75	Y76
G									Y87 Y95	Y88 Y96		
H			Y101	Y102			Y103 Y109	Y104 Y110			Y105 Y111	Y106 Y112
I	Y113	Y114	Y115	Y116			Y117 Y123	Y118 Y124			Y119	Y120
Number of courses	3	2	3	3	2	2	4	3	2	2	2	3

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Table 3. Translation Matrix of Faculty-Course-Time Priorities Requested (concluded)

Faculty	Thursday				Friday			Saturday				Teaching
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	01.00-03.30	03.30-06.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	Load
A			Y5	Y6		Y7	Y8					4
B		Y23	Y24						Y19 Y25	Y20 Y26		4
C	Y33	Y43	Y34 Y44			Y35	Y36					4
D		Y47 Y53	Y48 Y54		Y49 Y55	Y50 Y56				Y51	Y52	4
E	Y61 Y67	Y562 Y68			Y69	Y70		Y63 Y71	Y64 Y72			4
F			Y77 Y85	Y78 Y86						Y79	Y80	4
G		Y89	Y90			Y91 Y97	Y92 Y98		Y93	Y94 Y99	Y100	4
H										Y107	Y108	4
I	Y125	Y126	Y121	Y122					Y127	Y128		4
Number of courses	4	4	4	3	2	3	4	3	2	4	2	

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From Table 3, we have 128 zero-one variables to be solved. Constraints of the model can presented below:

- Offer all courses:
  $Y_{81}+Y_{82}+Y_{83}+Y_{84}+Y_{105}+Y_{106}+Y_{107}+Y_{108}+d_1^- - d_1^+=3$
  and so forth.

- Satisfy faculty teaching load:
  $Y_1+Y_2+Y_3+Y_4+Y_5+Y_6+Y_7+Y_8+Y_9+Y_{10}+Y_{11}+Y_{12}+d_{14}^- - d_{15}^+=4$
  and so forth.

- Required limited resources:
  $Y_1+Y_9+Y_{21}+Y_{113}+d_1^- - d_1^+=3$

- Faculty preference for courses:
  $Y_1+Y_2+Y_3+Y_4+Y_5+Y_6+Y_7+Y_8+Y_9+Y_{10}+Y_{13}+Y_{14}+Y_{15}+Y_{16}+Y_{17}+Y_{18}+Y_{19}+Y_{20}+Y_{27}+Y_{28}+Y_{29}+Y_{30}+$
  $Y_{31}+Y_{32}+Y_{33}+Y_{34}+Y_{35}+Y_{36}+Y_{45}+Y_{46}+Y_{47}+Y_{48}+Y_{49}+Y_{50}+Y_{51}+Y_{52}+Y_{57}+Y_{58}+Y_{59}+Y_{60}+Y_{61}+Y_{62}+$
  $Y_{63}+Y_{64}+Y_{73}+Y_{74}+Y_{75}+Y_{76}+Y_{77}+Y_{78}+Y_{79}+Y_{80}+Y_{87}+Y_{88}+Y_{89}+Y_{90}+Y_{91}+Y_{92}+Y_{93}+Y_{94}+Y_{101}+Y_{102}+$
  $Y_{103}+Y_{104}+Y_{105}+Y_{106}+Y_{107}+Y_{108}+Y_{113}+Y_{114}+Y_{115}+Y_{116}+Y_{117}+Y_{118}+Y_{119}+Y_{120}+Y_{121}+Y_{122}+$
  $d_{23}^- - d_{23}^+=76$
  and so forth.

- Faculty preference for time slots:
  $Y_1+Y_3+Y_5+Y_7+Y_9+Y_{11}+Y_{14}+Y_{15}+Y_{18}+Y_{19}+Y_{21}+Y_{23}+Y_{26}+Y_{27}+Y_{29}+Y_{31}+Y_{33}+Y_{36}+Y_{37}+Y_{39}+$
  $Y_{41}+Y_{43}+Y_{45}+Y_{47}+Y_{49}+Y_{52}+Y_{53}+Y_{55}+Y_{57}+Y_{59}+Y_{61}+Y_{63}+Y_{65}+Y_{67}+Y_{69}+Y_{71}+Y_{73}+Y_{75}+Y_{77}+Y_{80}+$
  $Y_{81}+Y_{83}+Y_{85}+Y_{87}+Y_{89}+Y_{91}+Y_{93}+Y_{95}+Y_{97}+Y_{99}+Y_{102}+Y_{104}+Y_{105}+Y_{107}+Y_{110}+Y_{111}+Y_{114}+Y_{115}+$
  $Y_{117}+Y_{119}+Y_{121}+Y_{123}+Y_{125}+Y_{127}+d_{25}^- - d_{25}^+=64$
  and so forth.

- System constraints to ensure that only one ranking for each course is selected:
  $Y_1+Y_2\leq 1$
  and so forth.

- System constraints to ensure that only for a certain faculty member, only one course is assigned during a certain time slot:
  $Y_1+Y_9\leq 1$
  and so forth.

- The objective function:

$$Z = P_1\sum_{j=1}^{13}(d_j^{s+}+d_j^{s-}) + P_2\sum_{i=14}^{22}(d_i^{t+}+d_i^{t-}) + P_3\sum_{k=23}^{24}(d_k^{c+}+d_k^{c-})$$

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$$+ P_4 \sum_{t=25}^{26} (d_t^{r+} + d_t^{r-}) + P_5 \sum_{u=27}^{49} (d_u^{h+} + d_u^{h-})$$

Result

The formulated problem consisted of 128 variables, 49 goal constraints, and 99 system constraints. The problem was solved by using LINDO optimization software version 61. The solutions are shown in Table 4.

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Table 4. Faculty-Course-Time Scheduling Results

Faculty	Monday				Tuesday				Wednesday			
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00
A	XA7a											
B			XB13a			XB10a					XB13a	
C			XC2a			XC10a				XC10a		
D										XD9a		
E					XE4a		XE12a					
F		XF1a					XF8a					
G									XG7a			
H				XH6a				XH6a			XH1a	
I			XI5a				XI5a				XI3a	
Number of courses	1	1	3	1	2	2	3	1	1	2	3	0

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Table 4. Faculty-Course-Time Scheduling Results (concluded)

Faculty	Thursday				Friday			Saturday				Teaching Load
	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	07.00-09.30	01.00-03.30	03.30-06.00	07.00-09.30	09.30-12.00	12.00-2.30	2.30-5.00	
A			XA5a			XA5a						4
B									XB10a			4
C							XC2a					4
D		XD9a			XD10a						XD9a	4
E	XE4a							XE4a				4
F			XF6a								XF6a	4
G		XG11a				XG11a			XG11a			4
H										XH1a		4
I			XI3a									4
Number of courses	1	2	3	0	1	2	1	1	2	1	2	

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Summary

The faculty-course-time scheduling uses decision variables that represent schedules. The multi objective structure has enabled the model to capture the dynamic aspects of the problem. The core of the procedure is formed by a matrix where two rows are provided for each faculty member demoting two preferences respectively for teaching certain courses. The matrix also contains elements indicating faculty preferences for teaching during certain time slots.

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