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A MATHEMATICAL MODEL FOR UNIVERSITY COURSE SCHEDULING: A CASE STUDY

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Abstract- University timetabling problem is to determine which course is assigned to which lecturer and is held on which day and time slot in order to satisfy a specific objective. It is a time consuming and complex task as it includes a large number of educational rules. On the other hand, the existence of numerous courses and lecturers makes the problem much more complicated. Because of the complexity of the problem, an efficient timetable is achieved when a mathematical model is used. In this paper, a new binary model is used to develop a timetable for an Iranian university. One of the main novelties of the paper is considering multi-offered courses, courses that are offered more than once in a term due to large number of students who wish to take them. The objective function of the model is maximizing education quality. In fact, the model assigns each course to the most eligible lecturer. The model is developed based on the real constraints of the case and is solved using GAMS software.

Keywords: University timetabling; Binary programming; multi-offered course

I. INTRODUCTION

University timetabling problem has been considered in different researches as it directly affects the education quality and should satisfy existing rules and constraints. The problem is to determine which course is assigned to which lecturer, on which day and time slot. This is a hard task as the problem includes a lot of rules, constraints, courses and lecturers. It is a NP-hard problem as the complexity of solving process grows exponentially with a bit increase in the model dimension. In this paper, the management department of an Iranian university (Islamic Azad University) is considered as a real case. We specifically focus on post graduate level. There are three different majors at post graduate level in management department: Industrial, Business and Administrative management. There are a number of rules that should not be violated. Also, there are some constraints that should be satisfied. Some of them are common in timetabling problems whereas others are specifically imposed in the case.

It is clear that empirical timetables satisfy neither students nor lecturers. For example, students wish to attend classes in one or two days in order to have more free days to study at home. Moreover, they wish to take each course with the most qualified lecturer. On the other hand, some of the lecturers are not resident and come from the nearby cities. Naturally, they wish to have maximum courses on each day of their attendance at the university. Due to the failure of empirical timetables, a mathematical model is applied to assign each course to the most qualified lecturer while satisfying rules and constraints. The proposed model aims to maximize education quality. Maximizing the objective function ensures that each course is assigned to the most qualified lecturer and education quality is maximized as well. Then, logical constraints and rules are formulated. In the proposed model, *multi-offered courses* are considered. Naturally, a course is offered once in a term, on a specific day and time slot. However, if the number of students requesting a course is more than the capacity of a single class (room), the course is multi-offered. Finally, the model is solved using GAMS. The structure of the paper is as follows:

In Section 2, the literature is reviewed. In Section 3, the problem is briefly discussed. Mathematical model and computational results are presented in Sections 4 and 5 respectively. Finally, concluding remarks are presented in Section 6.

II. LITERATURE REVIEW

In reviewing the literature of timetabling problem, the researches are categorized in three levels: university, examination and school timetabling. In university timetabling, it is determined which course should be assigned to which lecturer on which day and time slot. Daskalaki *et al.* (2004) developed an integer programming model for department of Electrical and Computer Engineering at the University of Patras. They consider some constraints ensuring no conflict is in the timetable, the schedule includes all courses with the desired teaching periods, etc. The objective function of their model minimizes a linear cost function regarding the assignment of courses to lecturers. Aladag and Hocaoglu (2007) formulated university timetabling problem for Statistics Department of Hacettepe University in Turkey and solved it using Tabu Search technique. Gunawan *et al.* (2007) considered timetabling problem for an Indonesian university and divided it in to two sub-problems. The first one was about assigning courses to lecturers and the other one was to develop the final timetable. They solved the first problem using exact methods and the second one using Simulated Annealing. Gunawan *et al.* (2008) formulated timetabling problem as a mathematical model and solved it using Genetic Algorithm in two phases. At the first phase, courses were assigned to the lecturers and then they were scheduled in the second phase. They applied it in an Indonesian Institute. In a similar study, Qin and Ma (2014) established an Intelligent Course Scheduling Model and solved it using Genetic Algorithm. They improved the genetic algorithm encoding mode, initialization method and crossover and mutation probability. This process was performed by selection operation, crossover operation and mutation operation. Burke *et al.* (2007) applied graph coloring heuristics to solve both exam and course timetabling problems. They used Tabu Search in finding permutations and search space of graph coloring heuristics. De Causmaecker *et al.* (2009) used a decomposed metaheuristic to solve timetabling problem. According to the method, constraints were not considered at once but were solved one by one. Bai *et al.* (2006), Mushi (2006), Basir (2013) and Caballero (2014) applied Simulated Annealing and Tabu Search to solve timetabling problem, respectively. In addition to metaheuristic approaches, constraint logic programming (Cheng *et al.*, 1995; Rudova and Murray, 2003), graph coloring (Asratian and De Werra, 2002; Burke *et al.*, 1994; De Werra, 1985) and local search (Soria-Alcaraz et al., 2014; Duan et al. 2013; Conant-Pablos et al, 2009) were considered in university timetabling problem too. Wood and Whitaker (1998) developed a nonlinear programming model for university timetabling problem. Bardi and Davis (1998) considered university timetabling problem as a multi objective model. Lach and Lubbecke (2008) used decomposition approach to schedule courses and assigned rooms to them. Akintayo and Oluleye (2009) discussed timetabling in a resource constrained environment and improved the quality of solution from 76 to 83 percent. Some comprehensive surveys on university timetabling were done by Schaerf (1999), Lewis (2007) and Burke and Petrovic (2002). The objective functions of the previous works are various. Some focus on minimizing the cost function (Daskalaki *et al.*, 2004; Nakasuwan *et al.*, 1999). Gunawan *et al.* (2010) considered maximization of utility resulted from assigning courses to lecturers. Benil and Botsali (2004) tried to minimize the total movements of students between rooms. Bakır and Aksop (2008) aimed to minimize the dissatisfaction degree of lecturers and students from the schedule.

For some researches on examination timetabling, we can refer to Valdes *et al.* (1997), Reis and Oliveria (1999), McCollum *et al.* (2008), Burke *et al.* (1996 and 2004) and Xu et al. (2014). Also, some researches on school timetabling are done by Filho and Lorena (2001), Souza *et al.* (2001), Carrasco and Pato (2004), Kochetov *et al.* (2008), Sorensen and Dahms (2014) and Dorneles et al. (2014).

III. PROBLEM DEFINITION

In this paper, a zero-one model is developed for timetabling of post graduate courses in management department of Islamic Azad University. There are three different majors at post graduate level in that department: industrial, business and administrative management. Although the education quality of post graduate level is very important for top management of the university, current timetables satisfy neither lecturers nor students. As a result, a mathematical model is proposed to maximize education quality. The problem is to define which course is assigned to which lecturer, on which day and time slot. Lecturers are divided in to four groups: instructors, full time, part time and invited lecturers. Instructors are those who are currently at the final stage of getting Ph.D. degree. Invited lecturers are not official faculties of the university. Because of the large number of courses and limited number of official faculty members, some lecturers are invited each semester in order that all courses can be covered.

There are about 1000 post graduate students in the department and are divided in to two groups: first year and second year ones. Also, there are 67 different courses to be scheduled; some of them are mandatory (for first year students) and others are elective (for second year ones). In order to maximize education quality; each course should be assigned to the most qualified lecturer. In this paper, the efficiency of a lecturer on teaching a course is given based on five criteria: teaching experience, number of related papers or books, number of related research plans, relationship of the course with the Ph.D. dissertation and willingness to teach. In this paper, the utility of assigning each course to each lecturer is assumed known. Maximizing the objective function ensures optimum assignment and consequently, it leads to the highest education quality.

IV. MATHEMATICAL MODEL

In order to develop mathematical model, some rules and assumptions should be described first. Some of them are common in universities whereas others are imposed in the case. The rules and assumptions are as follows:

1. Post graduate courses are only scheduled on three days of the week (Wednesday, Thursday and Friday).

2. Courses can be scheduled from 8:30 to 17:30. This interval includes five time slots. Each time slot takes 90 minutes.

3. Each course has two units and takes one time slot.

4. Some demanding courses may be offered more than once in a term. The dean of department makes decision about it regarding the number of students want to take the course. These are called *multi-offered courses*.

5. Some courses are common between different majors. Naturally, students with different majors can take *common courses*.

6. Students are divided in to two groups: First and second year students.

7. Courses are divided in to two groups: Mandatory and elective. Mandatory courses are offered to the first year students while electives are offered to the second year ones.

8. It is ideal for a student to have his courses in one day. In this case, he just attends one day at the university and saves transportation time and cost. As a result, he has more free time to study.

9. Lecturers are divided in to four groups: Instructors, full time, part time and invited lecturers. The first three ones are official faculties while invited lecturers are not officials.

10. Maximum number of courses assigned to a lecturer in a week is limited. Also, minimum number of courses assigned to an official lecturer in a week is limited.

11. Maximum number of courses that may be assigned to a lecturer in a day is limited.

12. As invited lecturers come from the nearby cities, it is better for them to assign a minimum number of courses on each day of their attendance at the university. For example, it is not desirable for an invited lecturer to attend for just one class in a day.

13. Each lecturer can only teach the courses that are in his expertise field.

14. Each class is assigned to only one lecturer. In other words, lecturers cannot share the teaching load.

15. Each lecturer is accessible on specific days and time slots and he can only be assigned classes at those times.

16. Some lecturers are research society members and should come together for session at a specific time (Thursdays, time slot 3). They cannot be assigned any class at that time.

A. *Sets and indices*

i Index of course.

I Set of all courses, I = {1,…,60}.

j Index of lecturer.

J Set of all lecturers.

k Index of day.

K Set of all days to schedule post graduate courses, K = {Wednesday, Thursday, Friday}.

l Index of time slot.

L Set of all time slots, L = {1, 2, 3, 4, 5}.

m Index of major.

M Set of all majors, M = {Ind, Bus, Adm}.

n Index of student group.

N Set of all student groups, N = {1, 2}. (1 and 2 indicate first and second year students respectively).

I_j Set of courses that can be taught by lecturer *j*.

$I_{m,n}$ Set of courses related to student group *n* of major *m*.

I_{P1} Set of courses that are single-offered.

I_{com} Set of courses that are common between at least two majors,

J_i Set of lecturers that can teach the course *i*.

$J_{i,k}$ Set of lecturers that can teach course *i* and can attend on day *k*, $(J_{i,k} = J_i \cap J_k)$.

$J_{i,k,l}$ Set of lecturers that can teach course *i* and can attend at time slot *l* of day *k*.

J_{Ins} Set of instructors.

J_F Set of full time lecturers.

J_P Set of part time lecturers.

J_{Inv} Set of invited lecturers.

J_R Set of lecturers that are research society members.

K_j Set of days that lecturer *j* is accessible.

$L_{j,k}$ Set of time slots of day *k* that lecturer *j* is accessible.

M_i Set of majors include course *i*.

$N_{i,m}$ Set of students of major *m* for which course *i* is offered.

B. *Parameters*

$c_{i,j}$ Utility of assigning course *i* to lecturer *j*.

Low_j Minimum number of courses that should be assigned to faculty member *j* in a week. $(j \in J_P \cup J_F \cup J_{Ins})$

Up_j Maximum number of courses that can be assigned to lecturer *j* in a week.

Min_j Minimum number of courses that should be assigned to invited lecturer *j* on a day, $(j \in J_{Inv})$.

Max_j Maximum number of courses that can be assigned to lecturer *j* on a day.

$R_{k,l}$ Maximum number of rooms assignable to management department at time slot *l* of day *k*.

$P_{i,m}$ Number of times that course *i* is offered for major *m*.

C. *Variables*

$x_{i,j,k,l,m,n}$ A binary variable that equals one if lecture *j* presents course *i* at the *l*th time slot of day *k* for the student group *n* of major *m*, otherwise it equals zero.

$y_{j,k}$ A binary variable that equals one if invited lecture *j* is assigned a course on day *k*, otherwise it equals zero $(j \in J_{Inv})$.

$z_{k,m,n}$ A binary variable that equals one if a course of major *m* is offered for the student group *n* on day *k*, otherwise it equals zero.

D. *Objective function*

Each course is assigned to the most qualified lecturer. In that case, the education quality is maximized.

$$Max\ \sum_{i\in I}\sum_{j\in J_i}\sum_{k\in K_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} c_{i,j}\, x_{i,j,k,l,m,n} \quad (3)$$

E. *Constraints*

The model includes some hard and soft constraints. Hard constraints should not be violated and should be necessarily satisfied. Although violation of soft constraints will not lead to infeasible solution, they are better to be satisfied as this improves the satisfaction resulted from the solution.

1. *Hard Constraints*

In this section, hard constraints are discussed:

a) Collision is not permitted:

A lecturer cannot be assigned more than one course at the same time slot. Constraint (4) ensures it.

$$\sum_{i\in I_j}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le 1 \quad \forall j \in J, k \in K_j, l \in L_{j,k} \quad (4)$$

b) Constraint on the number of courses assigned to a lecturer in a week (Rule 10):

Official lecturers are required to teach at least a specific number of courses in a week (Constraint (5)). Also, the maximum number of courses that are assigned to a lecturer in a week is limited (Constraint (6)).

$$\sum_{i\in I_j}\sum_{k\in K_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \ge Low_j \quad \forall j \in (J_{Ins} \cup J_F \cup J_P) \quad (5)$$

$$\sum_{i\in I_j}\sum_{k\in K_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le Up_j \quad \forall j \quad (6)$$

c) Constraint on the number of courses assigned to a lecturer in a day (Rule 11):

Maximum number of courses that may be assigned to a lecturer in a day is limited. The related constraints for an official lecturer and invited lecturer are shown as Constraints (7) and (8).

$$\sum_{i\in I_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le Max_j \quad \forall j \in (J_{Ins} \cup J_F \cup J_P), k \in K_j \quad (7)$$

$$\sum_{i\in I_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le Max_j y_{j,k} \quad \forall j \in J_{Inv}, k \in K_j \quad (8)$$

It worth noting that minimum number of courses that can be assigned to an invited lecturer in a day is also limited but it is considered as a soft constraint and will be discussed later.

d) Multi-offered courses constraint (Rule 4):

Some demanding courses may be offered more than once in a semester. These are called *multi-offered courses*. Constraint (9) ensures that these courses are offered properly.

$$\sum_{j\in J_i}\sum_{k\in K_j}\sum_{l\in L_{j,k}}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} = P_{i,m} \quad \forall i, m \in M_i \quad (9)$$

e) Room constraint:

As the number of classrooms in management department is limited, the following constraint ensures that the number of courses scheduled for a time slot does not exceed the available rooms.

$$\sum_{i\in I}\sum_{j\in J_{i,k,l}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le R_{k,l} \quad \forall k \in K, l \in L$$

(10)

f) Research society members constraint (Rule 16):

The research society members come to gather on a regular basis for session. It is held at the third time slot of Thursdays. As a result, constraint (11) shows that they cannot be assigned any course at that time. The related variables are pre-defined variables and are set to zero.

$$\sum_{i\in I_j}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,thu,3,m,n} = 0 \quad j \in J_R \quad (11)$$

2. *Soft constraints*

Some constraints will not cause infeasibility in the case of violation. However, the less they are violated, the more satisfaction is resulted from the solution. These are called soft constraints and are discussed as follows:

g) Less overlap in the courses of the same group of students:

Mandatory courses are offered to the first year students and electives are offered to the second year ones. In order to offer more options to students, it is ideal that mandatory courses are not offered at the same time slot. In this case, first year students have more options to choose. Similarly, it is better that elective courses are not offered at the same time. It is clear that this is a soft constraint and in the case of violation, solution will not be infeasible. However, it is better to be satisfied as much as possible.

$$\sum_{i\in I_{m,n}\cap I_{P1}}\sum_{j\in J_{i,k,l}} x_{i,j,k,l,m,n} \le 1 \ \forall k \in K, l \in L, m \in M, n \in N$$

(12)

h) Number of days to schedule courses for the same group of students (Rule 8):

For students' convenience, it is better that mandatory / elective courses are offered on one or two days. For example, a first year student is not satisfied if he has to be at the university three day in a week for attending 4 classes. He preferably wishes to take his courses in one day. The related constraint is as follows:

$$3z_{k,m,n} \le \sum_{i\in I_{m,n}}\sum_{j\in J_{i,k}}\sum_{l\in L_{j,k}} x_{i,j,k,l,m,n} \le Mz_{k,m,n} \quad \forall k \in K, m \in M, n \in N$$

(13)

i) Common courses constraint (Rule 5):

Some courses are common between different majors. It is better that *common courses* are not offered at the same time slot. For example, Advanced Operations Research is common between three majors. Naturally, each major offers this course. If these three similar classes are scheduled at different time slots, a student who cannot take it at one time slot has the chance to take the other one. Constraint (14) ensures it.

$$\sum_{i\in I_{Com}}\sum_{j\in J_i}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \le 1 \quad \forall k \in K, l \in L$$

(14)

j) Number of courses assigned to an invited lecturer in a day (Rule 12):

As invited lecturers come from the nearby cities, they will not be satisfied if they are assigned only one course in a day. They prefer to teach several courses in each day of their attendance at the university.

$$Min_j\, y_{j,k} \le \sum_{i\in I_j}\sum_{l\in L_{j,k}}\sum_{m\in M_i}\sum_{n\in N_{i,m}} x_{i,j,k,l,m,n} \quad \forall j \in J_{Inv}, k \in K_j$$

(15)

V. COMPUTATIONAL RESULTS

The proposed model was applied for scheduling post graduate courses at management department of Islamic Azad University. There are three different majors at the department: Industrial, Business and Administrative management. These majors include 26, 29 and 23 courses of which 11 courses are common. As a result, 67 different courses should be scheduled. These majors include 9, 7 and 9 mandatory and 17, 22 and 14 elective courses respectively. Totally, there are about 1000 students at the department. Also, there are 4 instructors, 18 full time, 3 part time and 3 invited lecturers at the department. The developed zero-one model includes 149960 constraints and 151221 binary variables. As all lecturers cannot attend in all days and cannot teach all courses, some of the variables are predefined and are set to zero. The model was solved using GAMS 22.5 in 9.089 seconds and the objective function value was 61.498. The results are shown in Figures 1 to 3. In these figures, *i*, *b* and *d* stand for industrial, business and administrative management courses respectively. Also, *c* stands for common course, *S*, *F*, *P* and *I* stand for instructors, full time, part time and invited lecturers respectively.

Time Slot 1		Time Slot 2		Time Slot 3		Time Slot 4		Time Slot 5	
d_4	F_{10}	c_7	F_1	b_9	I_1	i_8	F_{17}	c_8	P_2
d_3	F_6	d_8	I_2	i_2	S_1	c_2	F_4	b_{13}	F_2
b_{12}	P_3	d_7	F_6	b_{16}	F_7	i_5	S_1	b_{12}	F_{10}
b_5	P_2	i_{10}	F_5	c_5	F_{16}	c_7	F_3	b_2	I_2
b_2	I_2	d_1	S_4	c_4	F_{10}	d_9	F_6	b_1	F_{15}
i_{15}	F_{16}	b_{18}	I_1	c_1	P_3	c_{10}	F_{14}	i_{13}	F_{17}
i_8	F_{17}	c_1	P_3			b_7	F_{10}	i_9	F_{16}
i_7	F_5	i_3	F_{12}			b_6	F_7	c_6	F_7
c_{11}	S_1					b_4	F_{13}	c_4	F_9
c_2	F_4					b_3	F_2	c_2	F_4
c_1	S_2					i_{14}	S_3	c_1	P_3
i_4	F_{18}					c_8	P_2	i_4	F_{18}
						i_{11}	F_{18}		

Fig. 1: Timetable for Thursday.

Time Slot 1		Time Slot 2		Time Slot 3		Time Slot 4		Time Slot 5	
b_{14}	F_{15}	i_{12}	S_3	i_{12}	S_3	b_{17}	P_1	d_{13}	I_3
d_{14}	I_3	d_{15}	I_3	c_9	F_{11}	i_{13}	F_{17}	b_{18}	F_3
c_7	F_3	c_9	F_{11}	c_7	F_3	c_7	F_3	i_6	F_{17}
		c_{11}	P_1	i_6	F_{17}	c_3	F_5	c_{11}	P_1
				c_{11}	P_1			c_3	F_5
								c_1	F_{11}

Fig. 2: Timetable for Friday.

VI. CONCLUSION

Education quality of post graduate level is very important for top management of Islamic Azad University – Firoozkooh Branch. Empirical timetables satisfy neither lecturers nor students. In this paper, a zero-one model is developed to generate a timetable that meets rules and constraints and maximizes education quality. The model assigns each course to the most qualified lecturer. Constraints are divided to hard and soft ones. Hard constraints should not be violated and soft ones should be satisfied as much as possible. Model constraints ensure that lecturers and students preferences are considered.

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