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# An Integer Programming Model for University Timetabling: A Study Case in Petroleum University of Technology

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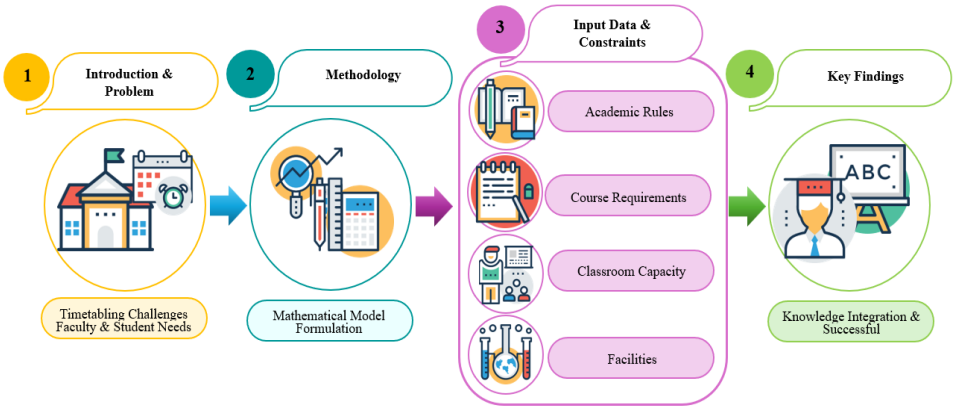
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*A B S T R A C T*

This study presents an Integer Programming (IP) approach for developing an effective and feasible university course timetable. The proposed model is adapted to consider academic constraints, course requirements, instructor availability, classroom capacity, and available facilities. The timetabling problem is formulated as an Integer Programming model in which courses are assigned to appropriate time periods and facilities while satisfying the required constraints. The objective function incorporates the experience and knowledge of the user to improve the quality and practicality of the generated timetable. The proposed model was successfully implemented and solved, demonstrating its capability to generate an organized and feasible academic schedule. In addition to the computational and optimization aspects, this study highlights the psychological importance of effective timetabling for students. A well-designed timetable can reduce scheduling conflicts, unnecessary waiting periods, fatigue, and academic stress while improving learning conditions. Finally, limitations and future research directions are discussed, including different course durations, gender-specific courses, and more comprehensive investigations of the psychological effects of academic timetabling.




## 1. Introduction

Nowadays, with the penetration of the computer in educational environments, people have tried to solve University Course Timetabling Problem (UCTP) using mathematical models. The UCTP is the process of assigning lectures that presented by appropriate lecturers and presence of group of students, into 'room–time' slots while take into account the specific constraints that there are in Petroleum university. The resulting weekly schedule is used to organize the teaching process at a university in time and space during the course of a semester. A teaching group is defined by a subject or topic, the teacher(s) and in some cases a specific set of students. The number of teaching groups and the assignment of teachers to the different groups are often given to the UCTP. Both the objectives and the constraints of this problem are usually highly institution-specific. It is therefore not surprising, that there is not a single commonly used tool to solve this planning problem, even though a rich body of literature on academic, school and university timetabling exists. So it remains a compelling research area even after

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many years of research .In this theme of research I face tow issues: university course and exam timetabling which are different in nature. In exam timetabling the goal is to spread, as far as possible, the different number seat for each individual student with various exams, while in our problem, the UCTP, the students want to fill slot time and their timetabling in a compact way. Decisions that made about assigning courses to lecturers in setting time during the week in appropriate classroom depend on the structure of the school, the departments' curriculum, the availability of resources .The problem is then formulated with the help of an Integer Programming (IP) model using a large number of suitably defined binary variables .The first researches on this problem return to 1960 and since that time several researchers worked on this theme. As the UCTP vary widely, the solution approaches also vary and this variation rooted in size of the problem .Every approach to solve this problem such as Local search techniques, tabu search, constraint programming, genetic algorithms, and goal programming and heuristics or techniques from graph theory and network flows that you may find in the timetabling literature, are applicable for a set of the UCTP [1] Criticism for the IP-based approaches is heavy computational requirements sometime for a simple case you should define and recognize rather 500-700 binary variable. My reason to do so is that although knowing heuristic and meta-heuristic methods would take less time with regard to global optimum answer and first best to be solved and would cost less CPU processing time, but as assigning the classes and timetabling would repeat once or twice a semester, it values to hold global optimum answer and first best despite of its cost .After finding the optimal solution of timetabling for each semester, it is important to notice to the results of implementing this solution from psychological point of view and see and try to find that by measuring some indices like educational satisfaction of students and comments of heads and experts of the university through a focus group.

### *1.1. Literature review*

The UCTP is one of the hardest problems faced by academic institutions throughout the world [2]. This problem is a large resource allocation challenge, in which both times and rooms are determined for each class meeting. Due to the difficulty and size of the modern UCTPs, much of the academic literature proposes purely heuristic solution methods [3]. It is always necessary to approach the problem in a systematic way that facilitates the inclusion of real-world variants of the problem along with automation and solution of big problems. Among the first approaches in mathematical programming, Lawrie and Akkoyunlu present linear and integer programming models for some versions of the problem and thus succeed in computing optimal solutions for a school and a UCTP, respectively. Introductions to the basic elements of (automated) timetabling, approaches to solve the problem and surveys of course and examination timetabling can be found, e.g. in Carter and Laporte, Schaerf. For a review of recent developments in timetabling I refer to the surveys in Asratian and De Werra, Baker et al., Burke and Petrovic, Lange and Petrovic and Burke. Methods to solve the problem are primarily based on three different approaches: local search (see Di Gaspero and Schaerf), constraint logic programming (see Rudová and Murray) and integer or mixed-integer programming, as presented in this paper . Also many solution approach is extended for this problem but IP approach is a good solution and would lead to optimum solution, so many researchers work on it, good work in this approach that I know are Werra [4], Tripathy [5], Dinkel [6] and Successful solutions with help of IP have been reported in paper of Daskalaki and Birbas and Housos ,Dimopoulou and colleague, Tripathy [7], [8], [9]. The successful work that was inspiration despite of different approach are Welsh and Powell [10] that use the graph coloring technique to solve a UCTP, while Schmidt and Strohlein [11] report on simulation techniques.While there are numerous publications on the UCTP models and methods, the number of papers describing actual implementations of automated timetabling systems appears to be rather limited. In many cases, numerical results are reported for data sets that are "inspired" by a real-world setting, but it remains unclear to which extent an automated timetabling system has actually been implemented. The performance of an automated timetabling system, however, can only be assessed when it is used. This includes teacher, student and/or administration satisfaction which is rarely studied and reported in detail [12]. This paper reports our experience from implementation of a formalized planning process, based on a complex integer programming model at Tehran faculty of Petroleum University of technology in Iran. After explaining the way of finding the optimal solution which is customized for Petroleum University, I explored that how much productivity affected by this method of timetabling and its side effects on students and lecturers. As it comes in the literature personalizing education for students produces multiple benefits regarding the academic performance, as well as behavioral gains such as student retention in the education, responsibility, and development of transferable skills like collaboration, communication, and problem solving [13,14].

## 2. Materials and Methods

### *2.1. The Modeling and Stage Preparing*

In this study, the model developed by Daskalaki and Birbas is utilized and further customized for the Petroleum University, taking into account its specific constraints and facilities. First, it is necessary to consider the types of courses offered within the faculty. The majority of courses in the Tehran faculty of the Petroleum University fall into the category of theoretical lectures and recitations, including subjects such as Project Cost Management, Engineering Economics, and Financial Institutions. A second category comprises practical courses, such as Physical Education, which are conducted in facilities outside the faculty premises. The final category consists of research-based courses, such as master's theses or bachelor's internships, which do not require a specific physical classroom. Therefore, the allocation of classrooms is only required for the first category of courses. Furthermore, it is important to distinguish between mandatory and elective courses. In the initial years of the program, most courses are mandatory; however, some elective courses may be introduced as students approach the completion of their studies. Given the low number of students in each major within this faculty, elective courses are not a significant factor; consequently, courses for students in a given major are primarily offered by the education department. Based on their major and year of study, each student is assigned to a specific group, which is then incorporated into the model.

### *2.2. Intuition of the Model*

Before stipulating the mathematical form of the model, it is useful to make a comprehensive intuition of what the model is saying. As usual the model is consisted of 2 parts, objective which is subjected to some constraints.

#### *2.2.1. The Objective*

The objective of the model is to minimize the empty times between the classes which assigned to a certain group of students. This approach may lead to a coherence scheduling. I made a focus group study about the consequences of this objective on educational satisfaction of students which is presented at the latter part of the article.

#### *2.2.2. The Constraints*

The first category of constraints demonstrates that overlapping is not possible. Overlapping may occur in the following subjects: Overlapping in lecturers timetable which means that it is not possible that a lecturer has more than one class in one time interval. Overlapping in students timetable which means that it is not possible that a certain student group has more than one class in one time interval. Overlapping in classrooms timetable which means that it is not possible to hold more than one course or lecture in a certain classroom in one time interval. The second category of constraint is about presence of lecturers in the faculty in certain time intervals. Before starting the semester, education department asks the lecturers about time intervals which they could be at the faculty to take decision about timetabling of the coming semester. This category of constraints prevents the lecturer's absence time intervals to be planned for. The third category of constraints says that timetabling and courses for all certain student groups should be complete and cover all the materials, courses and hours essential for graduating each student group with specified lecturers in a defined timetable. The fourth category of constraints points to the required number of sessions for each course in a week. Some courses may need one time interval per week and the other courses may need two or even more time intervals. Besides, it is possible to put the time required for the extension of a class e.g. TA classes or guest speaker classes which are held regularly per week. Although I considered that the sessions of each class should not hold continuously and sessions have to be separate regarding the faculty policies. The fifth category of constraints considers the facilities required for each course to be held. In Tehran faculty of Petroleum university facilities like video projection machine, computers, etc. are required for some courses which stated by this constraint. The sixth category of constraints catches the capacity of each classrooms. And finally the last category of constraints take attention to pre-assigned courses.as some courses may assigned by dean of the faculty and education department couldn't change it. By considering the assumption mentioned above, the model works like a function. Takes some data from planner as input, processes on it and finally give us an output. The model asks us about list of courses presented in considered semester, the lecturers who teach each course, the facilities required for each course, presence time intervals of lecturers in the faculty, the offered plan of education department for each student group, the number of classes and their capacities and facilities. So these are the inputs of the model. After processing on inputs, it give us the optimum timetable of the semester i.e. the output [15].

### *2.3. The mathematical model*

Regarding objectives, constraints and elements, the mathematical model is as follow.

#### *2.3.1. Objective function of the model*

It is defined based on minimizing two cost terms of assigning as follow:

$$Minimize\{\sum_{l\in L}\sum_{m\in M_l}\sum_{n\in N_m}\sum_{i\in I}\sum_{j\in J} s_{i,j,l,m,n}x_{i,j,l,m,n} + \sum_{l\in L}\sum_{m\in M_l} p_{l,m} * y_{l,m}\}$$

The cost coefficients si,j,l,m,n is a way to enter the education department and students preferences to the model which correspond to those time intervals that are preferred for a given course are assigned lower values than those assigned to the coefficients that correspond to non-preferred time periods. These coefficients determine by education department planner.

### *2.3.2. Constraints of the model*

$$\sum_{m\in M_1}\sum_{n\in N_m} x_{i,j,l,m,n} \le 1, \qquad \forall_i\in I,\forall_j\in J,\forall_l\in L \tag{I}$$

$$\sum_{l\in L_m}\sum_{n\in N} x_{i,j,l,m,n} + \sum_{l\in L_p}\sum_{n\in N} x_{i,j,l,m,n} \le b_{mp} + 2(1-b_{mp}), \tag{II}$$
$$\forall_i\in I,\forall_j,\forall_l\in \forall_m\in M,\forall_p\in M$$

$$\sum_{l\in L}\sum_{m\in M_l} x_{i,j,l,m,n} \le 1, \qquad \forall_i\in I,\forall_j\in J,\forall_n\in N \tag{III}$$

$$\sum_{m\in M_1}\sum_{n\in N} x_{i,j,l,m,n} \le a_{ijl}, \qquad \forall_i\in I,\forall_j\in J,\forall_l\in L \tag{IV}$$

$$\sum_{n\in N_i}\sum_{l\in L_m}\sum_{j\in J}\sum_{i\in I} x_{i,j,l,m,n} \le c_m * d_m, \qquad \forall_m\in M \tag{V}$$

$$\sum_{n\in N_i}\sum_{i\in I}\sum_{j\in J} x_{i,j,l,m,n} \le d_m * f_{l,m} * y_{l,m}, \qquad \forall_m\in M,\forall_l\in L \tag{VI}$$

$$\sum_{l\in L_m} y_{l,m} = 1, \qquad \forall_m\in M \tag{VII}$$

$$\sum_{n\in N} x_{i,j,l,m,n} + \sum_{n\in N} x_{i,j+1,l,m,n} \le 1, \qquad \forall_i\in I,\forall_j\in J,\forall_m\in M,\forall_l\in L \tag{VIII}$$

$$\sum_{l\in L_m} x_{i,j,l,m,n} \le e_{m,n}, \qquad \forall_i\in I,\forall_j\in J,\forall_m\in M,\forall_n\in N \tag{IX}$$

$$x_{i,j,l,m,n} = 1, \qquad \forall(i,j,l,m,n)\in PRA \tag{X}$$

Which each equation demonstrates:

I. Overlapping in lecturers timetable is not allowed.
II. Overlapping in students timetable is not allowed.
III. Overlapping in classrooms timetable is not allowed.
IV. Lecturer's presence time in the faculty.
V. Timetabling for each course has to be complete.
VI. Required sessions for each course during the week.
VII. Presenting each course with one lecturer.
VIII. 3 hours sessions will dividing to two 1.5 hours sessions.
IX. Considering the required facilities for each course.
X. Considering pre-assigned courses.

### *2.4. Elements of the model*

The helicopter view of this article is that it is supposed to assign a scares resource to some objects. i.e. a classroom in a timeslot about a certain course with a lecturer to a certain group of students. I used the model of Daskalaki & Birbas[1] and customized the elements of the model for the faculty. **Time:** First I consider the timeslots of the model (Table1). The courses are presented from 8 a.m. till 7 p.m. in time intervals of 1:30 or 3 hours by considering that usually there is 15 minutes break between each 1:30 hour timeslots and also at noon in 12:30-13 whole the faculty stop working for praying and serving a meal and lunch. By this rule there is 7 timeslots of 1:30 hour in a working day in the faculty as follow and denoted by J. so J={1,2,…,7}

**Table1.** The timeslots of the model

| Time Interval | J |
|---|---|
| 8:00-9:30 | 1 |
| 9:30-11:00 | 2 |
| 11:00-12:30 | 3 |
| 12:30-13:00 | Lunch time |
| 13:00-14:30 | 4 |
| 14:30-16:00 | 5 |
| 16:00-17:30 | 6 |
| 17:30-19 | 7 |

Source: Research Findings

The courses always are planed from Saturday to Wednesday and there is no class at Thursdays and Fridays. The days of the week are denoted by I and hence $I = \{1,2,\dots,5\}$ as follow in Table2:

**Table 2.** The days of the week are denoted

| Day of week | Saturday | Sunday | Monday | Tuesday | Wednesday |
|---|---|---|---|---|---|
| I | 1 | 2 | 3 | 4 | 5 |

Source: Research Findings

**Lecturers:** People who teach the courses and are denoted by L in the model and is defined in this way: L={lecturer#1,lecturer#2,…}

**Courses:** The materials which have to be taught to students by lecturers, denoted by M and defined as M={course#1,course#2,…}

**Classrooms:** The physical places that sessions of a course hold there, denoted by N and is defined as N={classroom#1,classroom#2,…}

**Group of students:** each group of students has common courses and are planned equal, denoted by K and is defined as

K={group#1,group#2,…}

In the faculty usually the students with same major and entrance year are categorized in one group. e.g. the students of master in Finance with entrance year of 2014 are in one group.Two different sets of binary variables are adopted. The first comprises the basic variables, denoted by xi,j,k,l,m,n , which takes the value of 1, when course m, taught by lecturer l to the group of students k, is scheduled for the jth period of day I in classroom n. The second set comprises the auxiliary variables, denoted by yi,Pv,k,hv,m,n where i∈I, k∈K, m∈M, and n∈N, are defined as previously, while pv and hv are natural numbers. The variable yi,Pv,k,hv,m,n takes the value of 1, when course m, which requires a session of hm consecutive periods, is scheduled for day i for the group of students k in classroom n. Index pv takes the values 1;2;3;...;p maxm, when the session is repeated p maxm times (repetitive sessions). When variable yi,Pv,k,hv,m,n refers to those sessions of course m, which are intended for lectures and are given just once, then pv takes the value of 1 [1,16].

### *2.4.The Model's Building Blocks*

I have to define some sets as the bricks of the model building which is as follow:

ML={m∈M; m=courses which could be taught by l-th lecturer}

Lm={l∈L; l=lecturers who could teach the m-th course}

Nm={n∈N; n=classrooms which are suitable for m-th course}

PRA={(i,j,m,l,n)∈I×J×L×M×N | ; (i,j,l,m,n=pre-assigned courses)}

aijl: takes the value of 1, if lth lecturer, in jth day of the week, in ith time interval of the day, could teach. i∈I ,j∈J, l∈L.

bmp: takes the value of 1, if course#m and course#p simultaneously are presented in one semester. m,p∈M.

cm: takes the value of 1, if course#m is presented in the intended semester. m∈M.

dm: demonstrates the required time intervals for a course. m∈M.

emn: takes the value of 1, if classroom#n has the required facilities for presenting course#m in it. n∈N , m∈M.

flm : takes the value of 1, if lecturer#l desires to teach course#m. m∈M , l∈L.

## 3. Results and Discussion

### *3.1. Running the model*

The model was tested by some instances from Tehran faculty of Petroleum University. The model was initially tested with General Algebraic Modeling System (GAMS) and solved with the CPLX solver on a Intel® Core™ i5-2410M CPU @ 2.30 GHz with 6.00 GB RAM. There were some pre-assigned courses during each semester and some special constraints shall be considered. I used the 5 last semesters data to compare the actual schedules which have been used with the model calculations and results. When I tested the previous semesters schedules of the faculty with the model, the results were showed that there are some variances between the implemented schedules and the Model's results. By investigating the variances and an interview with education department of the faculty, it was found that what model offered is better able to satisfy the faculty's constraints. Determination of cost coefficients in the objective function was done by an interview with the education department of the faculty. This coefficient describes the assignment cost of each class in each time slots. For example some courses is better to hold in mornings. For this aim the cost coefficient in morning time slots is16 less than afternoon ones. The following diagram is an example of a penalty function for assigning values to each cost coefficients.it is obvious that less cost is preferred. The x-axis is the time-periods and y-axis is the value of cost coefficients corresponding to each time periods (Figure1).

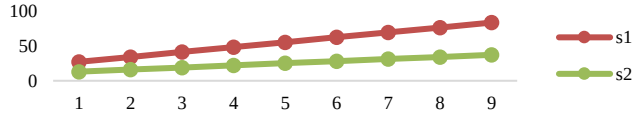



**Figure 1.** Penalty functions assigned to each cost coefficients

Source: Research Findings

After running the model, some results were found which one of them for second semester of 2014 is brought in appendix.

### *3.2. Psychological window of the problem*

For investigating about the UCTP, I believe that the psychological side of timetabling has equal importance as mathematical side and each one roles as a wing for the bird of timetabling. I made a focus group of experts of educational psychologists as a start point to understand the effects of a correct timetabling on students and educational performance. When the timetabling for a semester is spread, it may have some negative effects on students. For example in a day if I plan a class at 8-9:30 and the other class on 14:30-16, there are 5 hours empty between two classes. Regarding the focus group, following results was obtained: In the empty time, students may being confused and not to know what they have to do. This empty time may lower the students' concentration and makes them physically and mentally tired. This kind of programming would have this outcome for students to lose the day when the morning and evening have occupied so they miss time for other kinds of work. by repeating the same spread program in the day, the student may decide to be absent in some sessions. and finally whole the above reasons and also lots of unconsidered reasons here, may have a negative effect on educational performance of students and lower their educational satisfaction. We found here about negative side effects of spread timetabling and conclude by positive outcomes of correct and coherence timetabling in a university, it is strictly justifiable to try to improve timetabling and each educational unit has to try it with a customization which fit to their constraints and facilities [17-23].

## 4. Conclusion

This paper proposes a model for university course timetabling. To this end, the model originally developed by [1] was adopted and customized to incorporate the specific constraints of the Tehran Faculty of the Petroleum University of Technology (PUT). The refined model was subsequently applied as a case study and solved successfully. Beyond solving the mathematical model, this paper highlights the importance of considering psychological aspects and recommends that future research explore this subject with greater rigor. Such an approach would assist academic institutions in implementing automated timetabling more effectively, allowing for the integration of features and constraints that align with both physical and psychological considerations. It should be noted that this study was limited to course durations of 1.5 or 3 hours, and certain requirements, such as gender-based course segregation (e.g., Physical Education), were not included in the model. Therefore, further investigation is recommended to robustly explore the psychological impacts of optimized timetabling. Finally, the study discusses the significance of well-defined timetabling for students and presents an illustrative system dynamics model (Figure 2).

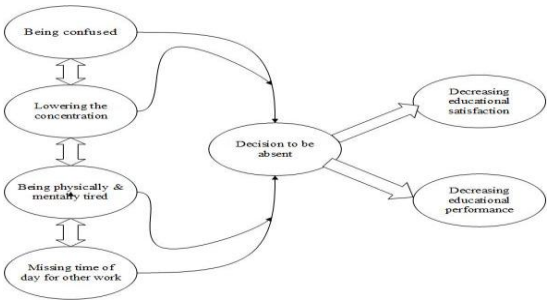



**Figure 2.** A system dynamics model of some effects of spread timetabling

Source: Research Findings

## Author Contributions

All authors contributed equally to the conception, preparation and writing of this manuscript.

## Conflict of Interest

M. Fotros, in the capacity of Editorial board, had no involvement in the selection of reviewers or the management of the peer-review process, and the other authors, while observing publication ethics in referencing, declare the absence of any conflict of interest.

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## AI Used Statment

The author retain full responsibility for the accuracy, originality, integrity, legality, and ethical compliance of all text, data, tables, figures, analyses, references, and conclusions, and have verified all AI-assisted outputs. Any fabrication, falsification, manipulation, plagiarism, copyright infringement, or other misuse of AI remains solely the responsibility of the authors and does not transfer or diminish their accountability for the published work.

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