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# AN APPLICATION OF INTEGER LINEAR PROGRAMMING TOWARDS UNIVERSITI MALAYSIA TERENGGANU COURSE SCHEDULING PROBLEM

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**Abstract:** University Course Timetabling (UCT) is a combinatorial optimization problem in which a set of events has to be scheduled in timeslots and assigned to suitable rooms by considering all the constraints. A feasible timetable plays an important role in ensuring the tasks or events are carried out appropriately. However, producing one is not an easy task due to large data size and a variety of requirements involved. In this research, a mathematical model using Integer Linear Programming (ILP) is applied for the university course timetabling problem. To validate the model, data from Universiti Malaysia Terengganu Academic Management Department is obtained. The data consists of 27 programmes, 1,261 classes of 265 core courses, 59 venues and 50 timeslots. Advanced Interactive Multidimensional Modelling System (AIMMS) mathematical software with CPLEX solver is used to solve the mathematical model. The research showed that the model developed is applicable to the university course timetabling problem. An optimized solution is achieved that fulfils the preferences of the users. The outcome of this research would indirectly assist the administrative staff who will be in charge in producing an effective course timetable for the university.

Keywords: University Course Timetabling (UCT), optimization, Integer Linear Programming (ILP), exact method, Advanced Interactive Multidimensional Modelling System (AIMMS).

## Introduction

A timetable is a plan of the times when particular events are to take place (Collins English Dictionary, 2011). It is the act of scheduling something to happen or do something at a particular time. University Course Timetabling (UCT) is the problem of assigning courses to a limited number of time periods and places, subject to a variety of hard constraints, with the quality of feasible solutions evaluated based on violations of soft constraints (Schaerf, 1999). UCT is a large resource allocation problem faced by thousands of academic institutions worldwide. Due to the significant investment required to employ staff and provide teaching facilities, these resources should be well-utilized. The timetable can be considered to be the production plan of a university, as it specifies the use of teaching facilities for thousands of students and staff.

Generating a timetable requires the consideration and understanding of many components within the complex and diverse university system. Broadly, this includes the interaction between students, teaching staff, courses, faculties, available time periods, and rooms. An advanced timetabling system should be able to find a high-quality solution within a relatively short timeframe and may even include sophisticated analytics capabilities. The constraints of the UCT problems are the core of these models and are defined by the true characteristics of each institution. Constraints are generally divided into two categories, hard and soft constraints (Burke & Qu, 2006). A solution to timetable production that violates even a single hard constraint is not a feasible one, whereas a solution that violates any number of soft constraints remains feasible, however produces a low quality of a timetable. Soft constraints are used to improve the solution's quality because satisfying one of them means the solution meets some particular preferences. These sum up to the definition of hard and soft constraints (Mohd Zaulir *et al*., 2022).

### *Problem Description*

Course timetabling problems are common to all educational institutions. It involves a few processes of allocating lecturers to courses, courses to timeslots and suitable venues whilst also considering each lecturer's preferences (Almond, 1966; Landa-Silva & Obit, 2009; Rezaeipanah *et al*., 2021). Manual development of a course timetable is found to be a common practice in several education institutions, either adjusted after the initial distribution of timetable or manually constructed from the beginning of the assignment. This process, without a doubt, requires a large amount of time and effort. Nevertheless, the outcome gained does not guarantee user's satisfaction. Some courses might be assigned to rooms with a capacity that is too big, some might have smaller venues. Considering the problems, there is a need of a mathematical model that could solve the timetabling problem and cater to all requirements at once.

In this research, we demonstrate the mathematical model developed, together with all related information. To construct the model, relevant constraints are needed. These constraints represent the requirements that an institution should consider in producing a timetable and are known as hard constraints. Hard constraints are the crucial elements in a timetabling model. The constraints have to be satisfied to obtain a feasible solution. However, to further satisfy the users, soft constraints are included. Soft constraints add value to the result. It is not necessary to satisfy soft constraints, but the more of the model addresses them, a better outcome (timetable) is obtained. Some of the common constraints employed in most of the mathematical models found in the literature (Aizam & Caccetta, 2014; Aziz & Aizam, 2017; Aziz & Aizam, 2018; Arratia-Martinez, 2021) are listed:

### *Hard Constraint*

(a) All courses must be assigned to respective place in the timetable

(b) No student takes more than one course in respective place at a timeslot

(c) A lecturer must not teach more than one course in respective place at a timeslot

(d) The absence of students and lecturers at certain timeslots in any place

(e) The maximum number of courses that can be assigned at each place and each timeslot

### *Soft Constraint*

(a) The lecturers' preferences of venue and timeslot

### *Mathematical Modelling*

Integer Linear Programming (ILP) is used as a standard formulation. It is a well-known method used by other researchers to solve scheduling problems (Lawrie, 1969; Daskalaki *et al*., 2004; Daskalaki & Birbas, 2005; MirHassani, 2006). In this research, ILP is used to construct the mathematical model for Universiti Malaysia Terengganu course scheduling problem. The standard form of ILP follows:

Maximize / Minimize $Z = C^T X$

subject to $Ax \leq b,$

$X \geq 0,$ and integers.

where:

$Z$ = Measure of performance based on decision variables

$C^T$ = A vector that represents total revenue of a firm based on the processes occur

$X$ = Decision variable represents as a vector of number of process or occurrence of process

$A$ = A matrix of number of supplies needed or used for a process

$b$ = A vector of feasible number of supplies

Before the model is discussed in detail, some notations used are introduced.

### A. *Notation*

**Sets:**

$C$ = Total number of courses to be scheduled

$T$ = Total number of timeslots

$I$ = Total number of venues

$P$ = Total number of programmes

$L$ = Total number of lecturers

**Index:**

$c$ = courses

$t$ = timeslots

$i$ = places

$g$ = lecturers

$p$ = programmes

$d$ = days

**Parameters:**

$E_{C,P}$ = Students enrollment for each course

$E_{C,g}$ = Lecturers enrollment for each course

$N_C$ = Number of students for each course

$N_i$ = Number of places available in each place type, $i \in l$

$N_t$ = Number of timeslots in a day, $d \in Day$ d

$t_{c,cc}$ = Consecutive timeslot

$t_{c,cc}$ = Not consecutive timeslot

$T_{brea}$ = Timeslots for lunch break

$n$ = Maximum number of timeslots per time period

$q$ = Number of consecutive timeslots preferred

$C_{t,i}$ = Maximum number of courses and venues at a timeslot

$P_{c,t,i}$ = Preference of courses to be assigned to venues at a timeslot

**Decision Variables**

$$X_{c,t,i} = \begin{cases} 1, \text{ if course } c \text{ is assigned to venue } i \text{ at timeslot } t \\ 0, \text{ otherwise} \end{cases}$$

### *B. Model Formulation*

The model that will be applied for UCT problem is shown below. The model consists of the requirements needed of the intended institution.

$$Max\ Z = \sum_{C}^{c} \sum_{t}^{T} \sum_{i}^{l} P_{c,t,i}\, x_{c,t,i} \quad (1)$$

$$\sum_{t}^{T} \sum_{i}^{l} x_{cti} = 1\ \forall c \quad (2)$$

$$\sum_{c \in E_{c,p}}^{C} x_{cti} \leq 1\ \forall t \text{ and } \forall p \quad (3)$$

$$\sum_{c \in E_{cg}}^{C} x_{cti} \leq 1\ \forall t \text{ and } \forall g \quad (4)$$

$$\sum_{t \in T_{break}}^{T} x_{cti} = 0\ \forall c \text{ and } \forall i \quad (5)$$

$$x_{cti} N_c \leq N_i\ \forall c,\ \forall i \text{ and } \forall t \quad (6)$$

$$x_{c,t,i} - x_{c,c,t+1,i} = 0\ \forall c,\ \forall c \text{ and } \forall t \quad (7)$$

$$x_{c,t,i} + x_{c,c,t+1,i} \leq 1\ \forall c,\ \forall c \text{ and } \forall t \quad (8)$$

$$\sum_{t \in_{Day\ d}} (x_{c,t,i} - x_{cc,t,i}) = 0\ \forall t \text{ and } \forall t \in Day\ d \quad (9)$$

$$\sum_{t \in_{Day\ d}} (x_{c,t,i} - x_{cc,t,i}) \leq 1\ \forall t \text{ and } \forall t \in Day\ d \quad (10)$$

$$\sum_{i}^{l} (x_{c,t,i} - x_{cc,t,i}) = 0\ \forall t \quad (11)$$

$$x_{c,t,i} \in \{0,1\} \quad (12)$$

As shown in the model, (1) represents the objective function that aims to maximize the preferences of assigning courses to venue and timeslot. The objective function normally is categorized as soft constraints. It aims to be fulfilled, where the more optimized the value of the objective function, the better the timetable is produced. Formulations (2)-(11) stated in the model are the representation of the core requirements needed for a university course timetable, and are categorized as hard constraints. Equation (2) is a completeness constraint that ensures all the courses listed to be assigned. To avoid conflicts among resources (students, lecturers, and rooms), Equations (3) and (4) ensure no conflicts are allowed. As for students, there will be no student to take more than one course at a time and a lecturer will only attend to one lecture at a time, respectively.

Equation (5) is a requirement of allocating lunch breaks in the day. Equation (6) is a venue capacity constraint. This is to ensure the number of students for each course assigned at a venue to be less or equal to the venue's capacity. Equation (7) accommodates the need of lectures to be conducted consecutively. This constraint is formulated to ensure that the lectures are two hours long and occur consecutively at the same venue. Equation (8) expresses otherwise. Equations (9) and (10) cater the need of having lectures of a course in the same day and in different days respectively. Some courses with large number of students are broken down into sub-classes. These sub-classes are anticipated to be conducted simultaneously. Equation (11) is a simultaneous constraint, which ensures the same courses to be scheduled parallel in respective venues at a timeslot. The last formulation denotes that the model is a binary, where the value of decision variables should be either be zero or one. All mentioned formulations are commonly found in most institutions and are employed as per UMT's requirements. The aforementioned requirements are to be satisfied to obtain a feasible timetable.

### *C. Data*

Data collection is defined as the procedure of collecting, measuring and analyzing accurate insights for research using standard validated techniques. The raw data is used in this research to preserve and guarantee the quality of the solution and the outcome produced. The data obtained in this research are listed as the following:

i. Raw data for all courses offered (university's core courses, open elective courses, curriculum courses, program core courses, and program elective courses).

ii. The raw data on the total number of students for each course.

iii. The total number of students enrolled for each year to each school in the university.

iv. The raw data on the total number of venues and their capacity.

v. The total number of lecturers and each subject they taught.

Advanced Interactive Multidimensional Modelling System (AIMMS) mathematical software with CPLEX as the solver will be used to assist in solving the mathematical model.

## Results and Discussion

The mathematical model is validated on a course timetabling problem in UMT. It runs on a machine with Intel® Core™ i5-4200CPU @ 1.60GHz – 2.30GHz with 4.00 GB of RAM. Several criteria that must be considered from the results gained are satisfaction of the users involved, which are determined from the objective function values and the computational time to obtain a complete timetable. Numerical results obtained are shown in Table 1. The total time taken to solve the mathematical model which produces an optimized timetable is 697.34 seconds. With the output gained, it has demonstrated that all constraints listed are fulfilled. This implies that a feasible timetable is produced. The slots and venues given are based on lecturers' preferences. Preference parameters were determined beforehand with the value of '5' given for the most preferred slots and venues and the value '1' for the least preferred. Catering to the preferences of courses assignments to the best possible slots and venues will add the value of the timetable produced and denote as an optimized timetable.

The satisfaction rate of the optimized timetable could be determined through the objective value given. As can be seen, we acquired 6,230 out of a maximum of 6,305 value of assignment. This denotes that the courses were mostly assigned to where they were most required (98.8%). The 1.2% of remaining courses were assigned to the second or third best preference, which is acceptable. No courses were being placed to their non-preferential slots, which are the preferences of lecturers having their classes assigned to the slots and venues with the value '1'. To visualize the result, an example of the produced timetable is given in Figure 1, together with its lecturers involved. Different colour refers to the different venues available. This is an example of a produced timetable for the undergraduate students of the Biology programme.

Table 1: Result of UCTP

| | |
|---|---|
| CPU time (seconds) | 697.34 sec |
| Best solution | 6,230 |
| Number of constraints | 7,429,866 |
| Number of variables | 3,719,951 (37919950 integer) |
| Number of non-zeros | 3,939,9965 |
| Number of iterations | 825 |

| | Year | 8.00 am | 9.00 am | 10.00 am | 11.00 am | 12.00 pm | 1.00 pm | 2.00 pm | 3.00 pm | 4.00 pm | 5.00 pm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sunday | 1 | | | | KIM3300 (G3) M.Sukeri | KIM3300 (G3) M.Sukeri | | | | | |
| | | | | | KIM3300 (G4) Md. Uwaisulqarni | KIM3300 (G4) Md. Uwaisulqarni | | | | | |
| | 2 | | BIO3603 (G1) Fatimah | BIO3603 (G1) Fatimah | | | | | | | |
| | 3 | | | | | | | | | | |
| Monday | 1 | | | | | | | | | BIO3001 (G1) Rohani | |
| | 2 | | | BDV4001 (G1) Wahizatul Afzan | BDV4001 (G1) Wahizatul Afzan | | | BIO3601 (G1) Malinna | | | |
| | 3 | | | | | BIO3802 (G1) Nakisah | | | | | |
| Tuesday | 1 | | | | BIO3000 (G1) Norasmah | | | | | | |
| | 2 | | | | | | | | | | |
| | 3 | | | | | | | | | | |
| Wednesday | 1 | | | | | | | KIM3200 (G3) Soraya Shafawati | | | |
| | 2 | | | | | | | | | | |
| | 3 | | | | | | | | | | |
| Thursday | 1 | KIM3200 (G3) Soraya Shafawati | | | | | | BIO3000 (G1) Norasmah | BIO3000 (G1) Norasmah | BIO3001 (G1) Rohani | BIO3001 (G1) Rohani |
| | 2 | | | | | | | | | BIO3601 (G1) Malinna | BIO3601 (G1) Malinna |
| | 3 | | | | BIO3802 (G1) Nakisah | BIO3802 (G1) Nakisah | | | BIO3602 (G1) Norhayati | BIO3602 (G1) Norhayati | |

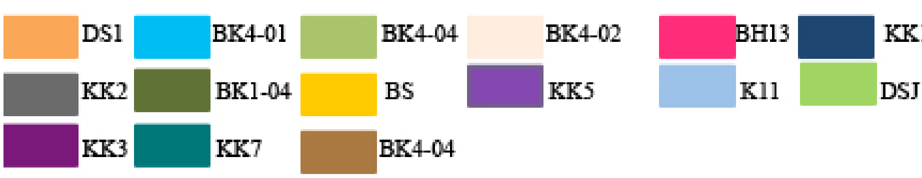


Figure 1: Example of the produced university course timetable for undergraduate student of Biology programme (Year 1, 2 and 3)

## Conclusion

In this research, we have employed ten hard constraints through Equations (2)-(11) that represent the university's requirement of course timetabling. In order to add value of the end result, we have included a preference constraint to the model, defined as the objective function. Assignment of the classes to the slots and venues are based on the preference parameter given by the lecturers before the model is solved. The model is expected to cater the lecturers' individual demands of courses allocation to avoid manual adjustments to the initial timetable produced. At the validation stage, the mathematical model solved a university problem and has produced an optimized university course timetable to be used. The timetable for the university strictly followed the essential requirements set by the management yet catering to other preferences. UCT is a tedious and difficult problem due to the complex process when dealing with a large number of courses offered at a university. However, it can be solved systematically using the mathematical model developed and thus can be used in other academic institutions.

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