ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 10(31), DOI: 10.17485/ijst/2017/v10i31/116271, August 2017*

Examination Timetabling Problem: A Case Study

Nurul Farahin Jamaluddin and Nur Aidya Hanum Aizam*

School of Informatics and Applied Mathematics, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Malaysia; aidya@umt.edu.my

Abstract

Background/Objectives: This paper presents a real-world examination-timetabling problem associated with Universiti Malaysia Terengganu (UMT) in Malaysia. We aim to develop a mathematical model that considers the main requirements to produce the examination timetable at UMT and attempts to optimize the assignment of exam into room and timeslot as preferred by the communities whilst satisfying the requirements mentioned. **Methods/Analysis:** The main requirements is modelled using Binary Integer Programming method and is validated using a self-develop dataset with two different preferences assignment and the computational results are reported and analyzed directly using the AIMMS Software with CPLEX 12.6.3 solver. **Findings:** The results shows that the newly developed models have successfully produce an examination timetable that completely solve all basic requirements addresses by the university and through the application of the models, we manage to maximize the preferences of the communities with the assignment of exam into the best preferred slots. **Novelty/Improvement:** These results will be used as reference for developing a more sophisticated examination-timetable model that will incorporate more demanding and challenging constraints as well as the preferences from community, which will be significantly better than those constructed using the existing manual system especially in terms of solving all requirements which cannot be easily done using the former system in UMT.

Keywords: AIMMS Software, Exact Method, University Examination Timetabling Problem

1. Introduction

Over the years, the needs of planning and scheduling have becoming extremely important in worldwide organization. The organizational strategy is not only focusing on increasing the market sales but also to optimize resource and emerge as cost-efficient organization[1]. As examples, military drafting problem to control shortage of resources[2], travelling salesman problem to find the shortest salesmen travel route[3], cloud computing for energy management problem[4] and others. Hence, constructing a plan to execute a number of activities over a period of time with limited resources and various constraints or simply known as scheduling is the best way to achieve the goal. In associate with scheduling for examination problem, University Examination Timetabling Problem (UETP) is the assignment of exam subject to a limited number of available timeslots and rooms in such a way that there are no conflict or clashes[5,6]. In simpler word, an exam is assigned in any available timeslots with condition to satisfy all required constraints known as hard and soft constraints.

*Author for correspondence

Hard constraint is defined as a type of constraints that cannot be violated to avoid infeasible solution. An example of hard constraint is conflict of exam where two exams taken by the same student cannot be scheduled at the same time. The other constraint are soft constraint which is defined as a type of constraint that most required to be fulfilled as the more the better. Violation of soft constraint will not make the solution to be infeasible but the timetable may not be as expected. Most demanded soft constraint in literature is consecutiveness of exam where a student taken more than one exams cannot be scheduled for two or more exam adjacently. For examination timetabling problem in university, there are many constraint that usually added to solve the problem that vary depend on institutions[7,8,9].

Throughout the year, variations of approach have been developed by various researchers around the globe in order to find the best solution to solve the scheduling problem. Initiated using the manual solution to solve the problem to using computerized technique, researcher has used every possible way to find the best solution that is applicable to solve the similar problem in many field. The difference of constraints used in different institution only hardening the process of finding one feasible solution that can solve the problem generally as one. Therefore, many solution approaches have been widely applied to solve examination-timetabling problem considering different type of constraints. Some of the research on the same topic is as followed:

Examination Timetabling Problem in Kuwait University (KU) is discussed in Al-Yakoob et al[10]. The problem is divided into two sub-problem; Exam Timetabling Problem (ETP) and Proctor Assignment Problem (PAP). Two programming models are developed using Mixed Integer Problem (MIP) for the problem respectively. The model is noted as mixed integer exam timetabling programming model (ETM) for ETP and proctors assignment model (PAM) for PAP. ETM was developed to assign the exams of section of classes to exam-periods, considering the hard constraint. Meanwhile, they use the PAM for the assignment with condition to satisfy the proctors' preferences for their preferred days and periods. The analysis for solving ETM and PAM is done using the CPLEX Optimization Software (version 9.0). The result obtained significantly improves than existing method used at KU.

A research on the generalized model to solved various timetabling problem using one general model has been developed by Aizam and Sithamparam[11] to solve a general timetabling problem in three different fields. The Binary Integer Programming method is use to formulated the generalized 0-1 programming model for the problems. Basic common constraints for each problem are identified and they have successfully developed a general basic model that is applicable to solve the three different timetabling problems using one single model. Another study that improvised the timetabling problem in five different fields using one general model was formulated in Aizam and Uvaraja[12]. In the study, they analyzed the basic common constraints for university examination and course timetabling, flight-gate, nurse and bus crew scheduling. They used the Binary Integer Programming method to develop the models for the problems and managed to generate one binary model that can solve these types of timetabling problem using the same constraints.

Ayob et al[13] presented a new real-world examination timetabling dataset at University Kebangsaan Malaysia. A new objective function is introduced by considering both timeslot and days to solve the problem related to consecutiveness of exam. They successfully in producing a feasible timetable by applying the new objective function without violating the required constraints into the graph colouring technique. Other examples using the same method can be found in Burke and Newall[14] and Pillay and Banzhaf[15].

Etemadi and Charkari[16] proposed an algorithm using clustering and tabu search method to solve examination timetabling problem. They satisfy all the hard constraints by using the clustering algorithm and using the tabu search, they managed to allocate the examination clustered to the appropriate timeslots by maximizing the number of soft constraints that need to be satisfied. Paquete and Stützle[17] are another example of researcher who has done a research in tabu search method.

Kalayci and Gungor[18] researched on the student success in College of Engineering at Pamukkale University, Turkey, using Genetic Algorithm (GA) based examination timetabling model. An examination timetable is generated with focus on the student success rate based on good quality preparation and resting time between exams. They aim to minimize the time length between exams by applying the model. Two different types GA model is proposed to optimized the paper spreads among exam. First model, they managed to minimize the high penalty to discard infeasible solution and assuring all hard constraint is satisfied for each stage with the second model. The model is run using the dataset collected from the College of Engineering at Pamukkale University.

Apparently, numerous methods to solve examination-timetabling problem is proposed by researchers around the globe. These proposed methods are proved to give a feasible timetable and some of them can even work efficiently on determining the best solution as well as many improvements has been done in terms of methodology aspects. Thus, various application of method on the problem will help on finding the most satisfying solution to the problem faced by any institutions. We on the other hand, are adding on the literature by presenting a study on the same problem and discussed the possible way of solving the problem in UMT.

This paper, we present a UETP from a real world example from Universiti Malaysia Terengganu (UMT). The main requirement for examination scheduling task in UMT is studied and using these requirements as the basic constraint, a mathematical model is developed using BIP modelling method to produce an examination timetable. An overview of examination timetabling problem in UMT and the main requirement constraint are discussed in section 2. The new mathematical models which is designed based on the main requirement constraint as discussed in section 2 is presented in section 3 and the dataset used in this study is presented in section 4. The result will then be discussed especially on section 5 where AIMMS software is use to run the model. Finally, we will summarize the whole paper in our last section.

2. Examination Scheduling Problem in UMT

The Universiti Malaysia Terengganu (UMT) formerly known as Centre of Fisheries and Marine Science under directories of Universiti Putra Malaysia in 1979. However, it was officially renamed as UMT in 2007 as an effort to strengthen the position of the State universities in Malaysia. As of 2014, UMT has offered many programs that not only based on fisheries and marine science but also has offered program and courses in other areas such as mathematics, economics, social sciences and many more. More than twenty program and hundreds of courses to almost 10000 students from various schools in UMT have been offered. These numbers are expected to increase every semester with the introduction of new program and courses offered by the university. Although in the past years, timetabling system in UMT has successfully produce the timetable for their society, the process also involves manual process on certain assignment in order to solve the problem feasibly. In addition, this university is located near to the shore and needs to deal with the challenges of limited spaces, logistics and human resources to manage the scheduling process. Thus, with the limitation and increasing number of students and subject, the process of timetabling becomes more complicated especially with manual assignment whether for course or examination. Therefore, we aim to develop new mathematical models that will not only ease the process of examination timetabling in UMT but also satisfying the preferences of the communities in UMT.

The design of the examination problem involves an exam taken by a student to be assigned into an available timeslot without clashing with other exams taken by the same student. In UMT, students are allowed to take more than one exams in a semester depending on the credit requirement to complete a course. Thus, thousands of students may be taking extra elective exams beside their mandatory course subjects to complete the credit hour set by their school or faculty. The diversity of subject taken by one student has then complicates the process of examination scheduling. In addition to the problem, there are almost 9000 students taking various courses in every semester in UMT. This is the reality that needs to be faced by UMT scheduler. Hence, many constraints need to be considered during the process to make sure all student exams are scheduled perfectly without creating any conflict. Practicing manual solution as a norm to construct a timetable is almost an impossible task to do.

Our purpose is to develop mathematical models that can solve the problem efficiently in order to produce a better solution for examination timetabling problem in UMT in compared to the manual solution available. However, for this study, we will include only the main requirement constraints which are the basic constraints used by scheduler to produce the timetable for UMT in every semester. The main constraints for the UMT scheduling problem are as follows:

C1: All exams must be completely assigned and is assigned once in the timetable.
C2: There are no students assigned to take more than one different exam at the same time.
C3: Exams with the most students should be assigned early in the timetable.
C4: Exam A must be scheduled before Exam B (precedence).
C5: No students are scheduled into two consecutive exams whether in timeslots or days.

3. Problem Formulation

The binary models are developed based on the requirements of the university and are tested using a random generated data. The objective function is set in such a way that the exam assignments to timeslot are optimized. AIMMS Software with the aid from CPLEX 12.6.3 solver is used to solve the problem of examination assignment in UMT to optimal and test the validation of the newly developed model. The notation of the problem in UMT is as stated as follows:

Sets

E Set of exams, e.
T Set of available timeslots, t.
S Set of students, s.
E_s Exams taken by the same students.
E_{Large} Exams with large number of students.
T_{Early} Timeslots at the earliest time of exams.
E_{room} Room prepared for each exam
E_{Pre} Set of exams with different features (e_a, e_b) that need to be scheduled first before another.

Parameters

$P(e,t)$ The preferences of the communities

Decision Variable

$$X_{e,t} = \begin{cases} 1, & \text{if an exams, } e \text{ is assigned to timeslots, } t \\ 0, & \text{otherwise} \end{cases}$$

Objective Function

The objective function is to maximize the preference, $P_{e,t}$ assigned to examination such that $P_{e,t}$ is the preference of communities as to have exams as they desired where P is the preferences of communities, while e and t represent the exam and timeslot respectively. The preferences is ranged between 1 until 5 where 1 is the least preferred and 5 is the most preferred timeslot for exam to take place.

Maximize

$$\sum_{t\in T}\sum_{e\in E} P_{e,t} X_{e,t} \quad (1)$$

Subject to:

$$\sum_{t\in T} X_{e,t} = 1 \qquad \forall e \quad (2)$$

$$\sum_{e\in E_s} X_{e,t} \le 1 \quad \forall t \quad \forall s \in S \quad (3)$$

$$\sum_{e\in E_{Large}} \sum_{t\in T_{Early}} X_{e,t} \le 1 \quad (4)$$

$$X_{e_a,t} - \sum_{t=t-1} X_{e_b,t} = 0 \qquad \forall (e_a, e_b) \in E_{Pre}$$

$$\forall t \in \{1,2,\ldots,t-1\} \quad (5)$$

$$\sum_{e\in E_s} (X_{e,t} + X_{e.t+1} + X_{e.t+2} + \ldots + X_{e.t+n}) \le 1$$

$$\forall t \in (1,2,\ldots,n) \quad (6)$$

$$\sum_{e\in E_{room}} X_{e.t} = 1 \qquad \forall t \quad (7)$$

$$X_{e,t} \in \{0,1\} \quad (8)$$

Mainly, Constraint 2 until Constraint 6 is mostly used in the previous literatures as either hard or soft constraints of examination timetabling problem in other institutions. The objective function (1) is to maximize the communities' preference for their examination timetable where an exam will be assigned to the most preferred timeslot in the timetable as assigned for P(e,t). Constraint (2) is included for all exams to be completely assigned once in a slot. Constraint (3) will make sure that no students taking more than one exam at the same time. Constraint (4) is to assign the exams that have large number of enrolment at the earliest timeslot. There are some exams that need to be assigned beforehand, thus constraint 5 is included to allow exam to be scheduled before one another. The demand to ensure that no students are assigned in consecutive exam is interpreted in equation form as shown in constraint (6). As room for each exam is pre-assigned in the timetable, constraint (7) will assign all exams into the room as required. The last constraint shows the decision variable $X_{e,t}$ is assigned as binary which is either 0 or 1. All constraint is gathered after discussion with the scheduler in UMT.

4. Data

We will run the models in two cases of different preferences value where Case 1 involves a preferences value of 5 for all exam to timeslot assignment, while a random assignment of preferences ranged from 1-least preferred until 5-most preferred is use for Case 2. A small case dataset, which are taken from the UMT dataset as the base guidelines to run the basic model so that the models develop can most probably solve a bigger dataset of UMT. The data consists of 33 exams that are required to be assigned to 20 slots into five available rooms will be used for both cases analysis. Ten group of student taking averaged 4-5 exams is used to test this model as well as 30 lecturers' data to invigilate the exam. The timeslots are

Table 1. The self-generated examination data used to solve the problem in AIMMS

Sets	Notation	Data
Total number of examination, *E*	e	33
Total number of course sitting for exam, C_n	c	10
Total number of lecturer that invigilate exam, *L*	l n:{1,..,30}	30
Total number of exams taken by each student group	$c_1=\{e_1, e_2, e_3, e_{10}, e_{31}\}$ $c_2=\{e_4, e_5, e_6, e_{32}\}$ $c_3=\{e_7, e_8, e_9, e_{32}, e_{33}\}$ $c_4=\{e_{10}, e_{11}, e_{12}, e_{31}\}$ $c_5=\{e_{13}, e_{14}, e_{15}, e_{22}, e_{32}\}$ $c_6=\{e_{16}, e_{17}, e_{18}, e_{32}\}$ $c_7=\{e_{19}, e_{20}, e_{21}, e_{31}, e_{33}\}$ $c_8=\{e_{22}, e_{23}, e_{24}, e_{32}\}$ $c_9=\{e_{25}, e_{26}, e_{27}, e_{32}\}$ $c_{10}=\{e_{28}, e_{29}, e_{30}, e_{27}, e_{33}\}$	4-5 exam per group
Total number of exams invigilate by each lecturer	$\{l_1,\ldots,l_{26}\}$ $\{l_{27},\ldots,l_{30}\}$	1 2
Total number of timeslots, *T*	*T*	20
Parameters	Notation	Data

Table 1 Continued

<table>
<tr><td>Maximum number of timeslots per day</td><td>Monday = $\{t_1, t_2, t_3\}$
Tuesday = $\{t_4, t_5, t_6\}$
Wednesday = $\{t_7, t_8, t_9\}$
Thursday = $\{t_{10}, t_{11}, t_{12}\}$
Friday = $\{t_{13}, t_{14}, t_{15}\}$
Saturday = $\{t_{16}, t_{17}, t_{18}\}$
Sunday = $\{t_{19}, t_{20}\}$</td><td colspan="2">3</td></tr>
<tr><td rowspan="2">Preference of exams at timeslot *t* (matrix)</td><td rowspan="2">P(e,t)</td><td>Case 1</td><td>5–Preference value</td></tr>
<tr><td>Case 2</td><td>1–least preferred until
5–most preferred</td></tr>
<tr><td>Room assignment for each exam, *r*</td><td>$r_1=\{e_{31}, e_{32}, e_{33}\}$
$r_2=\{e_1, e_4, e_7, e_{10}, e_{13}, e_{16}\}$
$r_3=\{e_{19}, e_{22}, e_{25}, e_{28}, e_{29}, e_{30}\}$
$r_4=\{e_2, e_5, e_8, e_{11}, e_{14}, e_{17}, e_{20}, e_{23}, e_{26}\}$
$r_5=\{e_3, e_6, e_9, e_{12}, e_{15}, e_{18}, e_{21}, e_{24}, e_{27}\}$</td><td colspan="2">One exam per room</td></tr>
</table>

arranged from T1 until T20 where it is divided into seven exam days with three slots of exam per day. This data was designed to solve an exam-timeslot assignment where the exam subject is scheduled to a timeslot in the timetable. However, room assignment is assigned as a pre-scheduling problem where it is assigned in advanced based on the suitability of each room. The dataset is as shown in Table 1.

The implementation of the model into AIMMS software is as shown is Figure 1.

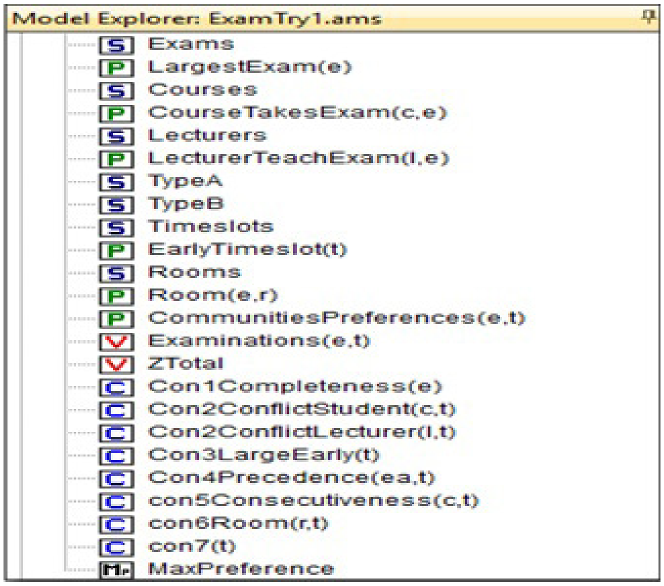

Figure 1. Notation of set, parameters and constraint in AIMMS software.

5. Results

The results for the implementation of the model into the data using AIMMS 3.13 mathematical software with CPLEX 12.6.3 using both case is as shown in Table 2. Both results are compared in terms of computational time and completion of exam-timeslot assignment to the preferred value of assignment.

Table 2. Results of constraint satisfaction using AIMMS Software for Case 1 and Case 2.

Progress	Output Reading	
	Case 1	Case 2
CPU Time (sec)	0.19	0.2
Objective Function Value	165	145
No. of Constraints	1177	1177
No. of Variable	661 (660 integer)	661 (660 integer)
No. of Non-Zeros	7639	7639
No. of Iterations	541	666

As stated in Table 2, we conclude that the model runs smoothly using AIMMS software. A number of 1177 constraints are solved to find the best solution to both problems. Case 1 is solved after 541 iterations within 0.19 second to obtain the optimal preference value of 165. Preference of '5' is set for each assignment of exam into timeslot for Case 1. Thus, it is expected that the result was to reach optimality at 165 values with each complete assignment of exams to timeslots due to all available timeslot is assign with '5' value of preferences. This optimality value may differ if we set different preferences for each exam, as can be seen in Case 2 where it takes slightly longer time of 0.20 second to solve the problem in 666 iterations with 145 optimal solutions. This may due to the different preference value used for each assignment of exam to timeslot where some exams may not be able to be assigned at the most preferred timeslot. However, as we aim to maximize the solution, exams will be assigned to the best value as preferred. In other word, exams that cannot be assigned at 5-most preferred timeslots may be assigned at 4-preferred timeslots or less depend on the constraints. The percentages of exams assignment to the preferred timeslot is shown in Figure 2.

Based on our analysis on the percentage of assigning exams towards the preferred timeslot, the models were able to avoid any exams from being assigned to the least preferred timeslots where the preferences value is 1 and 2 respectively. The assignment of exam into timeslot in the timetable is illustrated in Table 3 (see appendix 1 and appendix 2 for detailed result on examination assignment to slots and rooms given that rooms are pre-assigned at the early stage of the model).

Result in Table 3 shows the assignment of exam to timeslots is significantly different for both cases. This different is due to the preferences value setting in the objective function used in the study as well as the constraints demand in the model. However, as no difference in the assignment preferences value in Case 1 shows

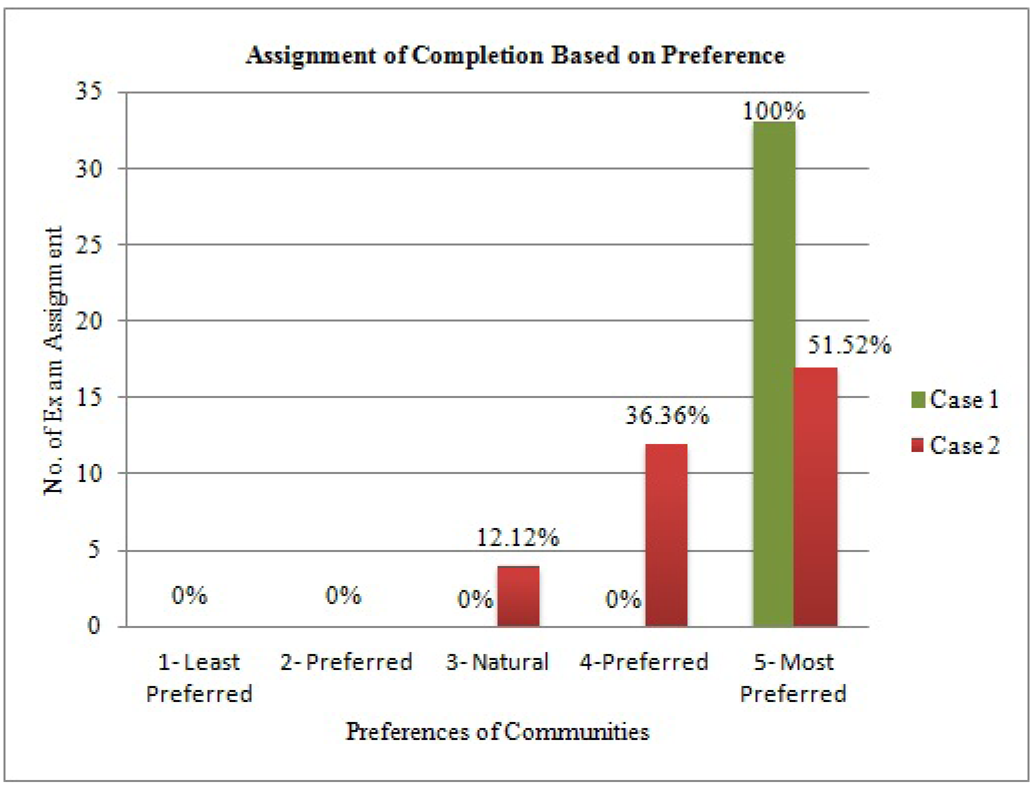

Figure 2. Percentage of exam assignment for both cases.

Table 3. The timetabling result for Case 1 and Case 2.

Day	T	Case 1		Case 2	
		Exam	Course	Exam	Course
Mon	t_1	$e_9, e_{13}, e_{23}, e_{28}, e_{31}$	$c_1, c_3, c_4, c_5, c_7, c_8, c_{10}$	$e_8, e_{18}, e_{30}, e_{31}$	$c_1, c_3, c_4, c_6, c_7, c_{10}$
	t_2	e_6	c_2	e_{22}	c_5, c_8
	t_3	e_{25}	c_9	e_{25}	c_9
Tues	t_4	e_{18}	c_6	e_5	c_2
	t_5	e_{22}, e_{33}	$c_5, c_8, c_3, c_7, c_{10}$	e_{33}	c_3, c_7, c_{10}
	t_6	e_4	c_2	e_{15}, e_{16}	c_5, c_6
Wed	t_7	e_2	c_1	e_1	c_1
	t_8	e_{11}	c_4	e_{11}	c_4
	t_9	e_{21}	c_7	e_{20}	c_7
Thu	t_{10}	e_{32}	$c_2, c_3, c_5, c_6, c_8, c_9$	e_{32}	$c_2, c_3, c_5, c_6, c_8, c_9$
	t_{11}	e_1	c_1	e_3, e_{28}	c_1, c_{10}
	t_{12}	e_{30}	c_{10}	e_{12}	c_4
Fri	t_{13}	e_{20}	c_7	e_{19}	c_7
	t_{14}	e_{12}, e_{14}, e_6	c_4, c_5, c_6	e_7, e_{24}, e_{26}	c_3, c_8, c_9
	t_{15}	e_3, e_5, e_7	c_1, c_2, c_3	e_2, e_4	c_1, c_2
Sat	t_{16}	e_{27}	c_9, c_{10}	e_{14}, e_{29}	c_5, c_{10}
	t_{17}	e_{24}	c_8	e_{21}	c_7
	t_{18}	e_{17}, e_{19}	c_6, c_7	e_9, e_{23}	c_3, c_8
Sun	t_{19}	e_8, e_{10}	c_3, c_4	e_6, e_{10}, e_{17}	c_1, c_2, c_4, c_6
	t_{20}	e_{15}, e_{26}, e_{29}	c_5, c_9, c_{10}	e_{13}, e_{27}	c_5, c_9, c_{10}

that all exams are perfectly assigned to the best timeslot demand. Different preferences values are given in Case 2 which shows that some exams may not be assigned to the best preferred timeslot. For example in Case 2 due to the constraints that demands exam with large number of enrolment must be assigned in earliest timeslot, exam 31, exam 32 and exam 33 is scheduled at the earliest timeslot T1, T5 and T10 despite the value of preferences at the three timeslot, the value of preferences is 5, 4 and 3 respectively. Thus, this setting has created a different output where the method used is prioritized on satisfying those that are considered as hard constraints first before going through the soft constraints which is the objective to maximize the preference of having an exam to a preferred timeslot on the result of optimal solution for Case 2. Nevertheless, all 33 exams have been assigned without violating any required constraints in both cases. We have successfully schedule a non-conflict examination timetable that solve the basic needs addresses by the university as well as maximizing the preferences of the communities based on the data generated using the newly generated binary model.

6. Conclusion

As conslusion, we studied UETP at UMT and using BIP method, we have developed a model using five main constraints in UMT system to produced an examination timetable using a random generated data with two different preferences setting. The application of the binary model into AIMMS software was a success and proven that our model are able to generate a conflict-free timetable with preferred number of gap which is a complicated task using UMT former system. From the result for both cases, the difference in the preference setting can affect the result whether in computational test or in the arrangement of the timetable itself. Thus, in this study, we have obtain useful information from this application to futher this research using the real dataset. As our future work, we are in the process of planning on producing the new examination timetable for UMT using the same method with few changes in exam-timeslot assignment where room assignment will also be included in the problem based on the preferences of their society.

7. Acknowledgement

All related information has been provided by Academic Management Department in UMT. We would like to thank Mrs. Adibah Amin and Mrs. Nurul Napisah Abd Rahman from the Academic Management Department in UMT for fruitful discussion and contribution in this research. This work has been supported by Ministry of Higher Education (MOHE) under Research Acculturation Grant Scheme (RAGS), Grant No. 57107.

8. References

1. Elmuti D. The perceived impact of outsourcing on organizational performance. American Journal of Business. 2003; 18(2):33–42. Crossref.
2. Hillier FS and Lieberman GJ. Introduction to Operations Research. McGraw Hill, New York; 2001.
3. Dantzig G, Fulkerson R and Johnson S. Solution of a large-scale traveling-salesman problem. Journal of the Operations Research Society of America. 1954; 2(4):393–410. Crossref.
4. Mohd Nor N, Hussin M and Selamat H. Energy management for cloud computing: a survey from scheduling perspective of heuristic, game theory and learning strategy. Journal of Computer Science and Computational Mathematics. 2014; 4(3):41–8. Crossref
5. Carter MW and Laporte G. Recent development in practical examination timetabling. Lecture Notes in Computer Science 1153. The Practice and Theory of Automated Timetabling I: Selected Papers from 1st International Conference on the Practice and Theory of Automated Timetabling (PATAT I). Springer-Verlag:Edinburgh, UK. 1996; p.3–21. Crossref.

6. McCollum B. University timetabling: bringing the gap between research and practice. Burke EK and Rudova H (eds.), Proceedings of the 6th International conference on the Practice and Theory of Automated Timetabling. Brno, Czech Republic; 2006. p.15–35.
7. Aizam NAH, Jamaluddin NF and Ahmad S. A survey on the timetabling communities' demands for an effective examination timetabling in Universiti Malaysia Terengganu. Special Issue: The 10th IMT-GT International Conference on Mathematics, Statistics and its Applications 2014 (ICMSA 2014), Malaysian. Journal of Mathematical Sciences. 2016; 10(S):105–16.
8. Malim RM, Khader AT and Mustafa A. University examination timetabling: a general model. UUM Prosiding Simposium Kebangsaan Sains Matematik ke-XIII. Alor Setar, Kedah. 2005; 2:714–24.
9. Mohmad Kahar MN and Kendall G. Universiti Malaysia Pahang examination timetabling problem: scheduling invigilators. Journal of the Operational Research Society. 2014; 65:214–26. Crossref.
10. Al-Yakoob SM, Sherali HD and AL-Jazzaf M. A mixed-integer mathematical modelling approach to exam timetabling, Computational Management Science. 2010; 7(1):19–46. Crossref.
11. Aizam NAH and Sithamparam T. General basic 0-1 integer programming model for timetabling problems. Special Issue: The 10th IMT-GT International Conference on Mathematics, Statistics and its Applications 2014 (ICMSA 2014), Malaysian. Journal of Mathematical Sciences. 2016; 10(S):143–54.
12. Aizam NAH and Uvaraja V. Generic model for timetabling problems by integer linear programming approach. World Academy of Science, Engineering and Technology (WASET). International Journal of Mathematical, Computational, Physical, Electrical and Computer Engineering. 2015; 9(12):668–75.
13. Ayob M, Abdullah S and Ab Malik AM. A practical examination timetabling problem at the Universiti Kebangsaan Malaysia. International Journal of Computer Science and Network Security. 2007; 7(9):198–204.
14. Burke EK and Newall JP. Solving examination timetabling problems through adaption of heuristic ordering. Annals of Operation Research. 2004; 129:107–34. Crossref.
15. Pillay N and Banzhaf W. A study of heuristic combinations for hyper heuristic systems for the uncapacitated examination timetabling problem. European Journal of Operational Research. 2009; 197:482–91. Crossref.
16. Etemadi R and Charkari NM. A novel combinational algorithm for solving the examination timetabling problem. International Conference on Industrial and Intelligent Information (ICIII 2012). 2012; 31:156–62.
17. Paquete L and Stutzle T. Empirical analysis of tabu search for the lexicographic optimisation of the examination timetabling problem. The Proceeding of the 4th International Conference on the Practice and Theory of Automated Timetabling (PATAT IV). Gent, Belgium, 2002; p.413–20. PMid:12423372
18. Kalayci CB and Gungor A. A genetic algorithm based examination timetabling model focusing on student success for the case of the college of engineering at Pamukkale University. Gazi University Journal of Science, Turkey. 2012; 35(1):137–53.

Appendix 1

T	Mon			Tues			Wed			Thu			Fri			Sat			Sun	
E	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}
e_1											c_1									
e_2							c_1													
e_3															c_1					
e_4						c_2														
e_5															c_2					
e_6		c_2																		
e_7															c_3					
e_8																			c_3	
e_9	c_3																			
e_{10}																			c_1, c_4	

e_{11}								c_4												
e_{12}														c_4						
e_{13}	c_5																			
e_{14}														c_5						
e_{15}																				c_5
e_{16}														c_6						
e_{17}																		c_6		
e_{18}				c_6																
e_{19}																		c_7		
e_{20}													c_7							
e_{21}									c_7											

e_{22}					c_5,c_8															
e_{23}	c_8																			
e_{24}																	c_8			
e_{25}			c_9																	
e_{26}																				c_9
e_{27}																c_9,c_{10}				
e_{28}	c_{10}																			
e_{29}																				c_{10}
e_{30}												c_{10}								
e_{31}	c_1,c_4,c_7																			
e_{32}										$c_2,c_3,c_5,$ c_6,c_8,c_9										
e_{33}					c_3,c_7,c_{10}															

Appendix 2

T	Mon			Tues			Wed			Thu			Fri			Sat			Day 7	
E	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14}	t_{15}	t_{16}	t_{17}	t_{18}	t_{19}	t_{20}
e_1							c_1													
e_2															c_1					
e_3											c_1									
e_4															c_2					
e_5				c_2																
e_6																			c_2	
e_7														c_3						
e_8	c_3																			
e_9																		c_3		
e_{10}																			c_1,c_4	

e_{11}								c_4												
e_{12}												c_4								
e_{13}																				c_5
e_{14}																c_5				
e_{15}						c_5														
e_{16}						c_6														
e_{17}																			c_6	
e_{18}	c_6																			
e_{19}													c_7							
e_{20}									c_7											
e_{21}																	c_7			
e_{22}		c_5,c_8																		

e_{23}																		c_8		
e_{24}														c_8						
e_{25}			c_9																	
e_{26}														c_9						
e_{27}																				c_9,c_{10}
e_{28}											c_{10}									
e_{29}																c_{10}				
e_{30}	c_{10}																			
e_{31}	c_1,c_4,c_7																			
e_{32}										$c_2,c_3,c_5,$ c_6,c_8,c_9										
e_{33}					c_3,c_7,c_{10}															