Mathematical Model and Simulation for Timetabling in Mathematics Department of Bandung Institute of Technology

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Abstract. A process to give teaching assignments for the teachers or lecturers to the available days and times by meeting certain goals is called timetabling. The lecturer's availability, number of courses, type of courses, number of course credits, classroom availability, course start time, and course end time are the factors that affect the learning schedule that makes timetabling complicated especially in university. Therefore, by using a mathematical optimization model, timetabling process becomes easier. Although many mathematical models have been made to do timetabling, there is no general model that can use in every university. In this paper, Binary Integer Programming is used to build the learning schedule in the Mathematics Study Program of Bandung Institute of Technology (ITB). The compulsory courses do not overlap, the courses with the same year are evenly distributed, the lecturer's schedule being unable to teach, the lecturer's schedule shouldn't be teaching, and the lecturer's schedule should be teaching become the consideration in this paper. Then, based on the given data, there are three outputs, that is the schedule of the lecturers, the schedule based on the course year, and the schedule based on the day. The schedule that has been made based on the model is quite good and can be implemented in the daily life.

INTRODUCTION

According to Oxford University Press, timetabling is the act of arranging for something to take place at a particular time. Almost all institutions and organizations use timetabling to manage their internal work system, one of the examples is timetabling or class scheduling in university. In general, many aspects need to be considered if we do timetables in university, like the number of students, courses, and classroom, up to the availability of lecturers, and these things depend on the university structure and policy [2]. However, there are various kinds of obstacles that will limit the completion process, such as conflicting class schedules, too busy class schedules, and many more. A conflicting and too busy class schedule will make the course will not be feasible to take.

Because of the complexity, especially in a large university, a manual approach for timetabling becomes inefficient and hard to do [3]. In addition, high accuracy is needed too so that there is no problem with the schedule that has been made. The term class scheduling means not only to fit or assign all courses to meet different time intervals, but it also includes the optimization of the available facilities in terms of operating cost [4]. The aspects and obstacles that we consider in optimizing the class schedule will be called constraint.

There are two types of constraints in this model, that is hard constraint and soft constraint. A hard constraint is a condition that **must** be filled by the optimization result, if the condition is violated, the optimization fails. Meanwhile, a soft constraint is a condition that **should** be filled by the optimization result, it is acceptable if there are some breaches for the soft constraint [5]. These constraints will be defined in such a way as to perform a good class scheduling optimization.

There is no general model that is applicable for all cases of university timetabling because every university has its problem and objective [6]. Therefore, we will restrict our scope of study in scheduling courses at Bandung Insitute of Technology Mathematics Department. The schedule of courses in the Mathematics ITB has never changed, each course has a schedule on the same day and time every year. This is because if we want to change the schedule for a course, it will affect most other course schedules so we need more cost and resources to do it.

There are four types of courses in Mathematics ITB based on student's duty, that is the compulsory course, directed elective course, inside elective course, and outside elective course (we don't observe the outside elective course in this case because Mathematics Department of ITB doesn't schedule that course). The students must take all compulsory courses, some designed directed elective courses, and some inside and outside elective courses to graduate. Based on student's years, there are second-year course, third-year course, and fourth-year course too. These types of courses must be highly considered for modeling. For example, we don't want to clash any compulsory course with the same or different year in the schedule. In terms of lecturers, we also don't want there to be any lecturer teach more than one course at the same time.

In Mathematics ITB, the assignment of courses taught by a lecturer has been made by the head office. We have given the data and we will focus on scheduling the day and time of courses by considering some constraints that we mention above. Martin (1999) said that Binary Integer Programming is a mathematical optimization model that has variable values 1 or 0 that generally represent yes (1) and no (0) [7]. Many cases in real life can be modeled by Binary Integer Programming, like the problem of funding a project or not, opening a warehouse or not, even the timetabling problem. Timetabling or scheduling in Mathematics ITB also can be approached by Binary Integer Programming (0-1 Integer Programming). Therefore, we will build the mathematics model based on Binary Integer Programming to process the data and find the optimal solution, so that an optimal class schedule is formed for lecturers and students.

The class in Mathematics ITB starts from Monday to Friday from 07.00 AM to 06.00 PM. To simplify the time, we divide the time by 1 hour and define every 1 hour as 1 session, so there are 11 sessions every day. The problem here is to determine the most suitable day and time for the schedule of lecturers who have been assigned to teach a course by considering the feasibility of the course schedule being taken by students.

This paper begins with the introduction which is we discuss above. After the introduction, we will discuss the materials and methods that are used in this paper that contains rules and assumptions, the lecturer assignment data, set, indices, parameters, variables, objective function, constraints, and simulation. Then we will discuss the results in the results and discussion section that contains the timetable of lecturers, the timetable of students based on day, and the timetable of students based on year. In the last section, we will present the conclusion of this paper.

MATERIALS AND METHODS

Rules and Assumptions

In order to build a mathematical model and solve the timetabling problem, there are some rules are based on the university's policy and some assumptions needed, that is:

1. The class starts from Monday to Friday from 07.00 AM to 06.00 PM
2. One session lasts for one hour
3. Only the courses held by the Mathematics Department are reviewed
4. Each course consists of two, three, or four credits
5. One credit is equivalent to one session
6. The schedule is made for one semester
7. There is always a classroom for course placement
8. The lecturers can make their own availability/unavailability schedule
9. The schedule of days and times for first-year courses has been determined by the head office
10. The same course with the different classes is treated as a different course

Besides that, there will be some additional rules too that will discuss in the constraint section.

The Assignment Data

TABLE 1 shows what courses will be taught by the lecturers with the number of credits, to protect the privacy of the lecturer's personal data, the lecturer's name is changed to a pseudonym.

TABLE 1. The Assignment Data of Lecturer (Source: The Administrative Officer of Mathematics Department ITB)

Lecturer's Name	Courses (CourseCode_Class)	Number of Credit
L01	AK4285_01	3
L01	MA3261_02	4
L02	MA1203_01	3
L03	MA3023_01	3
L04	MA2271_01	4
L04	MA5271_01	3
L05	MA1201_03	4
L05	MA3022_01	4
L06	MA2031_01	2
L06	MA5022_01	3
L07	MA3022_01	4
L08	MA5023_01	3
L09	MA3231_01	4
L10	MA2074_03	3
L11	MA4251_01	4
L12	AK4082_01	3
L12	MA2281_01	2
L13	MA5274_01	3
L14	MA6057_01	3
L15	MA1201_08	4
L15	MA2022_01	2
L15	MA4091_01	1
L16	MA5031_01	3
L17	MA2031_05	2
L18	MA3023_01	3
L19	SK5222_01	3
L20	MA1201_10	4
L20	MA6027_01	3
L21	MA5221_03	3
L22	MA1201_01	4
L22	MA5232_01	3
L23	MA2031_02	2
L23	MA2251_01	4
L24	MA3011_01	2
L24	MA5072_01	3
L25	MA5025_01	3
L25	MA5227_01	3

Continue from TABLE 1

Lecturer's Name	Courses (CourseCode_Class)	Number of Credit
L26	MA5217_01	3
L27	MA2231_01	4
L28	MA3231_02	4
L29	MA2031_04	2
L30	MA1201_04	4
L30	MA5032_01	3
L30	MA5041_01	3
L31	AK3283_01	3
L31	AK6083_01	3
L32	AK4261_01	3
L32	SK5001_01	3
L33	MA2074_01	3
L33	MA2271_02	4
L34	AK2263_01	3
L35	MA1201_07	4
L36	AK3251_01	3
L37	MA1201_02	4
L38	MA2041_03	2
L38	MA3022_01	4
L39	MA2074_02	3
L40	MA4072_01	4
L41	MA3261_01	4
L41	MA4072_01	4
L41	MA5263_01	3
L42	MA1201_11	4
L43	MA5217_01	3
L44	AK4285_01	3
L44	MA5074_01	3
L44	SK5001_01	3
L45	MA4095_01	2
L46	MA4272_01	4
L47	AK6061_01	3
L47	AK6282_01	3
L48	MA2231_02	4
L49	MA6052_01	3
L50	MA1201_02	4
L50	MA5021_01	3
L51	AK6091_01	3
L51	MA1201_05	4
L51	MA5251_01	3

Continue from TABLE 1

Lecturer's Name	Lecturer's Name	Lecturer's Name
L52	MA3041_01	4
L53	MA5272_01	3
L54	AK3081_01	3
L54	AK5281_01	3
L54	MA3281_02	4
L55	MA4071_01	4
L56	MA1201_06	4
L56	MA2252_01	4
L57	MA2081_01	3
L57	MA2281_02	2
L58	AK5282_01	3
L58	MA5281_01	3
L58	MA6082_01	3
L59	MA2271_03	4
L59	MA5273_01	3
L60	MA2251_02	4
L61	AK2264_01	3
L62	AK2281_01	2
L62	MA2081_02	3
L62	MA3281_01	4
L62	MA4281_01	4
L62	MA5287_01	3
L63	MA1202_01	3
L64	MA2031_06	2
L64	MA5231_01	3
L65	MA1201_09	4

To better understand the data, look at the first row of TABLE 1. From that row, we know that lecturer "L01" teaches the course "AK4285" at the class "01" three hours a week. Moreover, the first two letters of the course codes declare the major of the courses, AK for the Actuarial Major, MA for the Mathematics Major, and SK for the Computational Science Major. Besides that, the third letter of the course codes states the year of the courses. For example, AK4285 is a course of Actuarial Major for fourth-year students.

Set

We define some sets based on TABLE 1, the learning day, and the learning session that will be mapped by the model to build the learning schedule, that is:

1. Set of days (D)
   $D = \{Monday, Tuesday, Wednesday, Thursday, Friday\}$
2. Set of sessions (S)
   $S = \{1^{st}\ session, 2^{nd}\ session, 3^{rd}\ session, \dots, 11^{th}\ session\}$
   $= \{07.00\ AM - 08.00\ AM, 08.00\ AM - 09.00\ AM, \dots, 05.00\ PM - 06.00\ PM\}$
3. Set of courses (K)

The set of courses can be seen in the second column of TABLE 1.

4. Set of lecturers (L)
   $L = \{L01, L02, L03, \dots, L65\}$

Indices

Here are the indices that will be used in the mathematical model:

$l:$ *indices of lecturers*
$k:$ *indices of courses*
$d:$ *indices of days*
$s:$ *indices of sessions*

Parameters

A parameter is a quantity contained in mathematical programming whose value is known and can be adjusted [5]. Here are some parameters that will we use in our model:

1. The number of days (N_d)
2. The number of sessions (N_s)
3. The number of courses (N_k)
4. The number of lecturers (N_l)
5. The maximum number of courses for each session (M_{ks})

Variables

A variable is a quantity contained in mathematical programming whose value is unknown and wants to be determined based on the problem. We are free to define the form and definition of the variable. Here are the variables that will help us to solve the timetabling problem :

$$x_{l,k,d,s} = 1 \rightarrow \textit{The lecturer 'l' teaches the course 'k' on day 'd' in session 's'}$$
$$x_{l,k,d,s} = 0 \rightarrow \textit{The lecturer 'l' doesn't teach the course 'k' on day 'd' in session 's'}$$

In this case, we call the variables above as decision variable. [9][10]

Objective Function

After we have the sets, parameters, and variables, now we define the objective function to find the optimal value of each variable that will determine the best schedule based on our problem. We will use the minimize objective function, here it is :

$$Minimize \sum_{l=1}^{N_l} \sum_{k=1}^{N_k} \sum_{d=1}^{N_d} \sum_{s=1}^{N_s} c_{l,k,d,s} \cdot x_{l,k,d,s}\ , \forall l \in L, \forall k \in K, \forall d \in D, \forall s \in S$$

which is $c_{l,k,d,s}$ is the cost of the objective function that has a default value of 10. The selection of the cost value of 10 aims to simplify the calculation of the soft constraints. [11][12]

Constraints

If we perform the objective function above without constraints, we will get 0 value for each variable because of the minimize function. It means that there is no class schedule to be held. Therefore, we need to make some hard constraints and soft constraints to build the class schedule, then we also need to convert the constraints into the mathematical formulation. The main thing to know about the constraints is that the existing constraints will make the courses is feasible to take by the students and the lecturer is available to teach the course. [13]

- Hard Constraints
  1. Each lecturer teaches according to the assigned courses and the number of credits given

$$\forall l \in L, \forall k \in course\ assignment\ of\ lecturer\ l$$
$$\sum_{d=1}^{N_d} \sum_{s=1}^{N_s} x_{l,k,d,s} = the\ credit\ number\ of\ lecturer\ l's\ course$$

  2. Each course lasts a maximum of two consecutive sessions for each day
     - The constraint for a maximum of two sessions

$$\forall l \in L, \forall k \in K, \forall d \in D$$
$$\sum_{s=1}^{N_s} x_{l,k,d,s} \leq 2$$

     - The constraint for the consecutive course with even credit

$$\forall l \in L, \forall k \in K_{even}, \forall d \in D, \forall s \in [1,3,5,7,9]$$
$$x_{l,k,d,s+1} - x_{l,k,d,s} = 0$$

     - The constraint for the consecutive course with odd credit

$$\forall l \in L, \forall k \in K_{odd}, \forall d \in D, \forall s \in [1,4,7,10]$$
$$x_{l,k,d,s+1} - x_{l,k,d,s} = 0$$

$$\forall l \in L, \forall k \in K_{odd}, \forall d \in D, \forall s \in [3,6,9]$$
$$c_{l,k,d,s\_new} = c_{l,k,d,s\_old} \cdot 3$$

  3. Each lecturer can only teach one course in each session and each day

$$\forall l \in L, \forall d \in D, \forall s \in S$$
$$\sum_{k=1}^{N_k} x_{l,k,d,s} \leq 1$$

  4. There is only one compulsory course in each session and each day

$$\forall d \in D, \forall s \in S$$
$$\sum_{l=1}^{N_l} \sum_{k \in K_{compulsory}} x_{l,k,d,s} \leq 1$$

  5. Maximal course with the same year in the same session each day is 3

$$\forall d \in D, \forall s \in S$$
$$\sum_{l=1}^{N_l} \sum_{k \in K_{same\ year}} x_{l,k,d,s} \leq 3$$

6. The courses that have the same code, but different classes have the same schedule

$$\forall k \in K_{same\ code}, \forall d \in D, \forall s \in S$$
$$\sum_{l=1}^{N_l} x_{l,k,d,s} - \sum_{l=1}^{N_l} x_{l,k+1,d,s} = 0$$

7. The maximal course in each session is M_{ks} for everyday

$$\forall d \in D, \forall s \in S$$
$$\sum_{l=1}^{N_l} \sum_{k=1}^{N_k} x_{l,k,d,s} \leq M_{ks}$$

8. The course that teaches by 2 lecturers or more have the same schedule

$$\forall l \in L, \forall k \in K_{teaches\ by\ more\ than\ 1\ lecuter}, \forall d \in D, \forall s \in S_{odd}$$
$$x_{l,k,d,s+1} - x_{l,k,d,s} = 0$$

9. The lecturer can enter their unavailability schedule

$$\forall l \in L_{unavailable}, \forall k \in K, \forall d \in D_{unavailable}, \forall s \in S_{unavailable}$$
$$x_{l,k,d,s} = 0$$

10. There are several courses that have been scheduled at certain times and days

$$\forall l \in L_{scheduled\ teach\ k}, \forall k \in K_{scheduled}, \forall d \in D_{scheduled}, \forall s \in S_{scheduled}$$
$$x_{l,k,d,s} = 1$$

❖ Soft Constraints

1. The class is tried not to be held at some predetermined time like break time

$$\forall l \in L, \forall k \in K, \forall d \in D_{predetermined}, \forall s \in S_{predetermined}$$
$$c_{l,k,d,s\_new} = c_{l,k,d,s\_old} \cdot 100$$

2. The lecturer can suggest their schedule where they should teach

$$\forall l \in L_{suggest}, \forall k \in K, \forall d \in D_{should\ teach}, \forall s \in S_{should\ teach}$$
$$c_{l,k,d,s\_new} = c_{l,k,d,s\_old} \cdot 0.1$$

3. The lecturer can suggest their schedule where they should not teach

$$\forall l \in L_{suggest}, \forall k \in K, \forall d \in D_{shouldn't\ teach}, \forall s \in S_{shouldn't\ teach}$$
$$c_{l,k,d,s\_new} = c_{l,k,d,s\_old} \cdot 10$$

Simulation

In this paper, to perform the simulation, we need to determine the value of the parameters, determine which courses are compulsory, determine the break time, input the lecturer assignment data, the unavailability of the lecturer schedule, the suggestion of the lecturer's teaching schedule, and the suggestion of the lecturer's not teaching schedule [14][15]. Therefore, we determine the value of the parameters as follow:

- $N_l = 65$
- $N_k = 104$
- $N_d = 5$
- $N_s = 11$
- $M_{ks} = 7$

After that, we determine that the class is tried not to be held at 12.00 PM – 01.00 PM, 04.00 PM – 05.00 PM, and 05.00 PM – 06.00 PM every day for considering the break time. We also determine that the lecturer is suggested to teach from 07.00 AM until 11.00 PM and is not suggested to teach from 03.00 PM until 06.00 PM. After that, we determine that the first-year courses are held under 11.00 AM. Then based on reality, the compulsory courses are MA2231, MA2251, MA2271, MA3011, MA323. Last, we determine that $L01, L02, L03$ is unavailable to teach from 09.00 AM until 11.00 AM on Tuesday and Wednesday, $L10, L21, L22, L25$ is unavailable to teach from 07.00 AM until 8.00 AM on Monday, and $L60, L61, L63$ is unavailable to teach from 02.00 PM until 03.00 PM on Friday.

After we have all that we need, we perform the simulation in Python by transforming the mathematical model into the programming language and we used the MIP library to find the optimal solution of the model, here is the flowchart of the simulation:

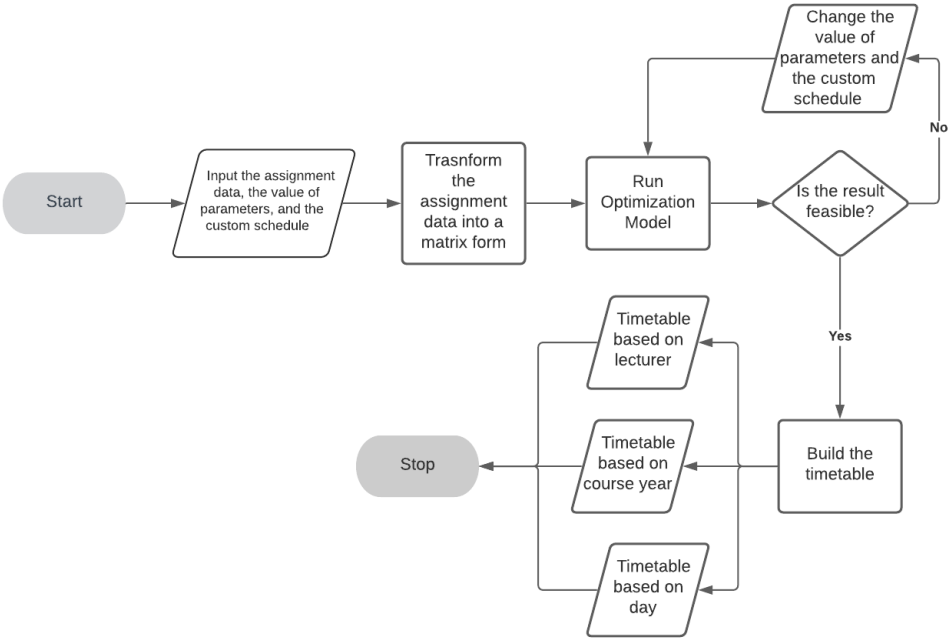

FIGURE. 1. The flowchart of the simulation

RESULTS AND DISCUSSION

The Timetable of Lecturers

L01 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	0	MA3261_02	0	0	0
8.00 - 9.00	0	MA3261_02	0	0	0
9.00 - 10.00	0	0	0	0	0
10.00 - 11.00	0	0	0	0	AK4285_01
11.00 - 12.00	0	0	0	MA3261_02	AK4285_01
12.00 - 13.00	0	AK4285_01	0	MA3261_02	0
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	0	0	0	0
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

L22 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	0	0	MA5232_01	0	0
8.00 - 9.00	0	0	MA5232_01	0	0
9.00 - 10.00	MA1201_01	0	MA1201_01	0	0
10.00 - 11.00	MA1201_01	0	MA1201_01	0	0
11.00 - 12.00	0	0	0	0	0
12.00 - 13.00	0	0	0	0	0
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	MA5232_01	0	0	0
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

L41 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	0	MA3261_01	0	0	0
8.00 - 9.00	0	MA3261_01	0	0	0
9.00 - 10.00	0	0	0	0	0
10.00 - 11.00	0	0	0	0	0
11.00 - 12.00	MA4072_01	0	0	MA3261_01	MA4072_01
12.00 - 13.00	MA4072_01	0	0	MA3261_01	MA4072_01
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	0	0	MA5263_01	0
16.00 - 17.00	0	0	MA5263_01	0	0
17.00 - 18.00	0	0	MA5263_01	0	0

L54 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	0	0	0	0	AK5281_01
8.00 - 9.00	0	0	0	0	AK5281_01
9.00 - 10.00	0	0	0	0	0
10.00 - 11.00	0	0	0	0	0
11.00 - 12.00	0	0	0	0	MA3281_02
12.00 - 13.00	0	0	0	0	MA3281_02
13.00 - 14.00	0	0	MA3281_02	0	0
14.00 - 15.00	0	0	MA3281_02	0	0
15.00 - 16.00	0	0	AK3081_01	AK5281_01	0
16.00 - 17.00	0	AK3081_01	0	0	0
17.00 - 18.00	0	AK3081_01	0	0	0

L62 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA4281_01	0	MA4281_01	0	AK2281_01
8.00 - 9.00	MA4281_01	0	MA4281_01	0	AK2281_01
9.00 - 10.00	0	MA5287_01	0	0	0
10.00 - 11.00	0	MA2081_02	0	0	0
11.00 - 12.00	0	MA2081_02	0	0	MA3281_01
12.00 - 13.00	0	0	0	0	MA3281_01
13.00 - 14.00	0	0	MA3281_01	0	0
14.00 - 15.00	0	0	MA3281_01	0	0
15.00 - 16.00	0	0	0	MA2081_02	0
16.00 - 17.00	0	0	MA5287_01	0	0
17.00 - 18.00	0	0	MA5287_01	0	0

L63 Lecturer Shcedule :

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA1202_01	0	0	0	0
8.00 - 9.00	MA1202_01	0	0	0	0
9.00 - 10.00	0	0	MA1202_01	0	0
10.00 - 11.00	0	0	0	0	0
11.00 - 12.00	0	0	0	0	0
12.00 - 13.00	0	0	0	0	0
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	0	0	0	0
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

FIGURE. 2. The Timetable of L01, L22, L41, L54, L62, and L63

FIGURE 2 shows some results of the simulation for build the timetable based on the lecturer's point of view. Look at the schedule of L01, the lecturer does not teach any course from 09.00 AM until 11.00 AM on Tuesday and Wednesday. So as L22 and L63, they do not teach any course at 07.00 AM until 08.00 AM on Monday and 02.00 PM until 03.00 PM (14.00–15.00) on Friday respectively. These things show the function of the ninth hard constraint. Then, every lecturer teaches only one course for each session each day, this is because of the third hard constraint. We also notice that the first and second hard constraints are satisfied by the results of the simulation. This kind of output is very suitable for the lecturers to arrange their schedules.

The Timetable of Students based on Day

	Courses
7.00 - 8.00	MA5023_01,MA2041_03,MA5272_01,MA6082_01,MA4281_01,MA1202_01,MA5231_01
8.00 - 9.00	MA5023_01,MA2041_03,MA5272_01,MA6082_01,MA4281_01,MA1202_01,MA5231_01
9.00 - 10.00	MA4251_01,MA1201_08,MA5221_03,MA1201_01,MA1201_07,MA1201_11,MA4071_01
10.00 - 11.00	MA5271_01,MA4251_01,MA1201_08,MA1201_01,MA1201_07,MA1201_11,MA4071_01
11.00 - 12.00	MA5271_01,MA2281_01,MA3011_01,MA4072_01,MA4072_01,MA4272_01,MA2281_02
12.00 - 13.00	MA2281_01,MA5031_01,MA3011_01,MA4072_01,MA4072_01,MA4272_01,MA2281_02
13.00 - 14.00	MA2271_01,MA3022_01,MA3022_01,MA2271_02,MA3022_01,MA5021_01,MA2271_03
14.00 - 15.00	MA2271_01,MA3022_01,MA3022_01,MA2271_02,MA3022_01,MA5021_01,MA2271_03
15.00 - 16.00	MA5217_01,MA5041_01,AK2263_01,MA5217_01,MA6052_01,AK6091_01,AK2264_01
16.00 - 17.00	MA5273_01
17.00 - 18.00	MA5273_01

FIGURE. 3. The Timetable for Monday

	Courses
7.00 - 8.00	MA3261_02,MA1203_01,MA5031_01,MA3261_01,MA4272_01,AK6282_01,AK2264_01
8.00 - 9.00	MA3261_02,MA1203_01,MA5031_01,MA3261_01,MA4272_01,AK6282_01,AK2264_01
9.00 - 10.00	MA1201_03,MA5022_01,MA5023_01,MA1201_10,MA1201_06,MA5287_01,MA1201_09
10.00 - 11.00	MA1201_03,SK5222_01,MA1201_10,MA1201_06,MA2081_01,MA2081_02,MA1201_09
11.00 - 12.00	MA3231_01,MA4251_01,SK5222_01,MA3231_02,MA2252_01,MA2081_01,MA2081_02
12.00 - 13.00	AK4285_01,MA3231_01,MA4251_01,AK4082_01,MA3231_02,AK4285_01,MA2252_01
13.00 - 14.00	MA2031_01,MA5274_01,MA2031_05,MA5221_03,MA2031_02,MA2031_04,MA2031_06
14.00 - 15.00	MA2031_01,MA5274_01,MA2031_05,MA5221_03,MA2031_02,MA2031_04,MA2031_06
15.00 - 16.00	MA3023_01,MA4091_01,MA3023_01,MA5232_01,AK3251_01,MA5074_01,MA5251_01
16.00 - 17.00	MA5227_01,AK3081_01
17.00 - 18.00	MA5227_01,AK3081_01

FIGURE. 4. The Timetable for Tuesday

	Courses
7.00 - 8.00	MA3022_01,MA3022_01,AK4082_01,MA5232_01,MA5025_01,MA3022_01,MA4281_01
8.00 - 9.00	MA3022_01,MA3022_01,AK4082_01,MA5232_01,MA5025_01,MA3022_01,MA4281_01
9.00 - 10.00	MA1201_01,MA1201_04,MA1201_02,MA1201_02,MA2252_01,MA1202_01,MA1201_09
10.00 - 11.00	MA1201_01,MA1201_04,MA1201_02,MA1201_02,MA2252_01,MA5281_01,MA1201_09
11.00 - 12.00	MA3231_01,MA2022_01,MA3041_01,MA3231_02,MA3041_01,MA4071_01,MA5281_01
12.00 - 13.00	MA3231_01,MA2022_01,MA3041_01,MA3231_02,AK4261_01,MA3041_01,MA4071_01
13.00 - 14.00	MA3023_01,MA3023_01,MA2251_01,MA6052_01,MA3281_02,MA2251_02,MA3281_01
14.00 - 15.00	MA3023_01,MA3023_01,MA2251_01,MA6052_01,MA3281_02,MA2251_02,MA3281_01
15.00 - 16.00	MA5072_01,MA5032_01,AK6083_01,AK6282_01,AK3081_01,AK5282_01,MA5273_01
16.00 - 17.00	MA5022_01,MA5263_01,MA5287_01
17.00 - 18.00	MA5022_01,MA5263_01,MA5287_01

FIGURE. 5. The Timetable for Wednesday

	Courses
7.00 - 8.00	MA6057_01,MA2231_01,MA5032_01,MA1201_02,AK6061_01,MA2231_02,MA1201_02
8.00 - 9.00	MA6057_01,MA2231_01,MA5032_01,MA1201_02,AK6061_01,MA2231_02,MA1201_02
9.00 - 10.00	MA1201_03,MA1201_10,MA1201_04,MA1201_11,MA1201_05,MA5272_01,MA6082_01
10.00 - 11.00	MA1201_03,MA1201_10,MA1201_04,SK5001_01,MA1201_11,SK5001_01,MA1201_05
11.00 - 12.00	MA3261_02,MA3041_01,SK5001_01,MA3261_01,SK5001_01,MA4095_01,MA3041_01
12.00 - 13.00	MA3261_02,MA5271_01,MA5025_01,MA3041_01,MA3261_01,MA4095_01,MA3041_01
13.00 - 14.00	MA2074_03,MA2251_01,MA2074_01,AK3251_01,MA2074_02,AK5282_01,MA2251_02
14.00 - 15.00	MA2074_03,MA2251_01,MA2074_01,AK3251_01,MA2074_02,AK5282_01,MA2251_02
15.00 - 16.00	SK5222_01,MA6027_01,AK3283_01,MA5263_01,AK5281_01,MA2081_01,MA2081_02
16.00 - 17.00	MA5217_01,AK6083_01,MA5217_01,MA5074_01
17.00 - 18.00	MA5217_01,AK6083_01,MA5217_01,MA5074_01

FIGURE. 6. The Timetable for Thursday

	Courses
7.00 - 8.00	MA6027_01,MA2231_01,AK4261_01,MA2231_02,AK6091_01,AK5281_01,AK2281_01
8.00 - 9.00	MA6027_01,MA2231_01,AK4261_01,MA2231_02,AK6091_01,AK5281_01,AK2281_01
9.00 - 10.00	MA1203_01,MA1201_08,MA5227_01,MA1201_07,MA1201_05,MA1201_06,MA5281_01
10.00 - 11.00	AK4285_01,MA1201_08,AK3283_01,MA1201_07,AK4285_01,MA1201_05,MA1201_06
11.00 - 12.00	AK4285_01,AK3283_01,MA4072_01,MA4072_01,AK4285_01,MA3281_02,MA3281_01
12.00 - 13.00	MA5274_01,MA6057_01,MA4072_01,MA4072_01,MA5021_01,MA3281_02,MA3281_01
13.00 - 14.00	MA2271_01,MA5072_01,MA5041_01,MA2271_02,AK2263_01,MA5251_01,MA2271_03
14.00 - 15.00	MA2271_01,MA5072_01,MA5041_01,MA2271_02,AK2263_01,MA5251_01,MA2271_03
15.00 - 16.00	MA2074_03,SK5001_01,MA2074_01,MA2074_02,SK5001_01,AK6061_01,MA5231_01
16.00 - 17.00	0
17.00 - 18.00	0

FIGURE. 7. The Timetable for Friday

FIGURE 3-7 show the course schedules each day from Monday to Friday. It can be seen that the courses from 04.00 PM to 06.00 PM (16.00 to 18.00) are relatively less than another session, this is because of the determination of the break time from the first soft constraint. Although the courses from 12.00 PM to 01.00 PM (12.00 – 13.00) are still quite a lot, this thing does not violate the constraints. We also can see that all the compulsory courses have different schedules, this is because of the fourth hard constraint. If we count the number of courses for each session every day,

we will find that the maximum number of courses at any session is seven. This thing happens because of the seventh hard constraint with $M_{ks} = 7$. This kind of output is very suitable for the administrative officer to manage and publish the course schedules.

The Timetable of Students based on Year

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA1202_01	MA1203_01	0	MA1201_02,MA1201_02	0
8.00 - 9.00	MA1202_01	MA1203_01	0	MA1201_02,MA1201_02	0
9.00 - 10.00	MA1201_08,MA1201_01, MA1201_07,MA1201_11	MA1201_03,MA1201_10, MA1201_06,MA1201_09	MA1201_01,MA1201_04, MA1201_02,MA1201_02, MA1202_01,MA1201_09	MA1201_03,MA1201_10, MA1201_04,MA1201_11, MA1201_05	MA1203_01,MA1201_08, MA1201_07,MA1201_05, MA1201_06
10.00 - 11.00	MA1201_08,MA1201_01, MA1201_07,MA1201_11	MA1201_03,MA1201_10, MA1201_06,MA1201_09	MA1201_01,MA1201_04, MA1201_02,MA1201_02, MA1201_09	MA1201_03,MA1201_10, MA1201_04,MA1201_11, MA1201_05	MA1201_08,MA1201_07, MA1201_05,MA1201_06
11.00 - 12.00	0	0	0	0	0
12.00 - 13.00	0	0	0	0	0
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	0	0	0	0
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

FIGURE. 8. The Timetable for first-year students

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA2041_03	AK2264_01	0	MA2231_01,MA2231_02	MA2231_01,MA2231_02,AK2281_01
8.00 - 9.00	MA2041_03	AK2264_01	0	MA2231_01,MA2231_02	MA2231_01,MA2231_02,AK2281_01
9.00 - 10.00	0	0	MA2252_01	0	0
10.00 - 11.00	0	MA2081_01,MA2081_02	MA2252_01	0	0
11.00 - 12.00	MA2281_01,MA2281_02	MA2252_01,MA2081_01,MA2081_02	MA2022_01	0	0
12.00 - 13.00	MA2281_01,MA2281_02	MA2252_01	MA2022_01	0	0
13.00 - 14.00	MA2271_01,MA2271_02, MA2271_03	MA2031_01,MA2031_05,MA2031_02, MA2031_04,MA2031_06	MA2251_01,MA2251_02	MA2074_03,MA2251_01,MA2074_01, MA2074_02,MA2251_02	MA2271_01,MA2271_02,AK2263_01, MA2271_03
14.00 - 15.00	MA2271_01,MA2271_02, MA2271_03	MA2031_01,MA2031_05,MA2031_02, MA2031_04,MA2031_06	MA2251_01,MA2251_02	MA2074_03,MA2251_01,MA2074_01, MA2074_02,MA2251_02	MA2271_01,MA2271_02,AK2263_01, MA2271_03
15.00 - 16.00	AK2263_01,AK2264_01	0	0	MA2081_01,MA2081_02	MA2074_03,MA2074_01,MA2074_02
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

FIGURE. 9. The Timetable for second-year students

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	0	MA3261_02,MA3261_01	MA3022_01,MA3022_01,MA3022_01	0	0
8.00 - 9.00	0	MA3261_02,MA3261_01	MA3022_01,MA3022_01,MA3022_01	0	0
9.00 - 10.00	0	0	0	0	0
10.00 - 11.00	0	0	0	0	AK3283_01
11.00 - 12.00	MA3011_01	MA3231_01,MA3231_02	MA3231_01,MA3041_01,MA3231_02, MA3041_01	MA3261_02,MA3041_01, MA3261_01,MA3041_01	AK3283_01,MA3281_02, MA3281_01
12.00 - 13.00	MA3011_01	MA3231_01,MA3231_02	MA3231_01,MA3041_01,MA3231_02, MA3041_01	MA3261_02,MA3041_01, MA3261_01,MA3041_01	MA3281_02,MA3281_01
13.00 - 14.00	MA3022_01,MA3022_01, MA3022_01	0	MA3023_01,MA3023_01,MA3281_02, MA3281_01	AK3251_01	0
14.00 - 15.00	MA3022_01,MA3022_01, MA3022_01	0	MA3023_01,MA3023_01,MA3281_02, MA3281_01	AK3251_01	0
15.00 - 16.00	0	MA3023_01,MA3023_01, AK3251_01	AK3081_01	AK3283_01	0
16.00 - 17.00	0	AK3081_01	0	0	0
17.00 - 18.00	0	AK3081_01	0	0	0

FIGURE. 10. The Timetable for third-year students

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA4281_01	MA4272_01	AK4082_01,MA4281_01	0	AK4261_01
8.00 - 9.00	MA4281_01	MA4272_01	AK4082_01,MA4281_01	0	AK4261_01
9.00 - 10.00	MA4251_01,MA4071_01	0	0	0	0
10.00 - 11.00	MA4251_01,MA4071_01	0	0	0	AK4285_01,AK4285_01
11.00 - 12.00	MA4072_01,MA4072_01, MA4272_01	MA4251_01	MA4071_01	MA4095_01	AK4285_01,MA4072_01, MA4072_01,AK4285_01
12.00 - 13.00	MA4072_01,MA4072_01, MA4272_01	AK4285_01,MA4251_01, AK4082_01,AK4285_01	AK4261_01,MA4071_01	MA4095_01	MA4072_01,MA4072_01
13.00 - 14.00	0	0	0	0	0
14.00 - 15.00	0	0	0	0	0
15.00 - 16.00	0	MA4091_01	0	0	0
16.00 - 17.00	0	0	0	0	0
17.00 - 18.00	0	0	0	0	0

FIGURE. 11. The Timetable for fourth-year students

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA5023_01,MA5272_01, MA5231_01	MA5031_01	MA5232_01,MA5025_01	MA5032_01	AK5281_01
8.00 - 9.00	MA5023_01,MA5272_01, MA5231_01	MA5031_01	MA5232_01,MA5025_01	MA5032_01	AK5281_01
9.00 - 10.00	MA5221_03	MA5022_01,MA5023_01, MA5287_01	0	MA5272_01	MA5227_01,MA5281_01
10.00 - 11.00	MA5271_01	SK5222_01	MA5281_01	SK5001_01,SK5001_01	0
11.00 - 12.00	MA5271_01	SK5222_01	MA5281_01	SK5001_01,SK5001_01	0
12.00 - 13.00	MA5031_01	0	0	MA5271_01,MA5025_01	MA5274_01,MA5021_01
13.00 - 14.00	MA5021_01	MA5274_01,MA5221_03	0	AK5282_01	MA5072_01,MA5041_01, MA5251_01
14.00 - 15.00	MA5021_01	MA5274_01,MA5221_03	0	AK5282_01	MA5072_01,MA5041_01, MA5251_01
15.00 - 16.00	MA5217_01,MA5041_01, MA5217_01	MA5232_01,MA5074_01, MA5251_01	MA5072_01,MA5032_01, AK5282_01,MA5273_01	SK5222_01,MA5263_01, AK5281_01	SK5001_01,SK5001_01, MA5231_01
16.00 - 17.00	MA5273_01	MA5227_01	MA5022_01,MA5263_01, MA5287_01	MA5217_01,MA5217_01, MA5074_01	0
17.00 - 18.00	MA5273_01	MA5227_01	MA5022_01,MA5263_01, MA5287_01	MA5217_01,MA5217_01, MA5074_01	0

FIGURE. 12. The Timetable for fifth-year students

	Monday	Tuesday	Wednesday	Thursday	Friday
7.00 - 8.00	MA6082_01	AK6282_01	0	MA6057_01,AK6061_01	MA6027_01,AK6091_01
8.00 - 9.00	MA6082_01	AK6282_01	0	MA6057_01,AK6061_01	MA6027_01,AK6091_01
9.00 - 10.00	0	0	0	MA6082_01	0
10.00 - 11.00	0	0	0	0	0
11.00 - 12.00	0	0	0	0	0
12.00 - 13.00	0	0	0	0	MA6057_01
13.00 - 14.00	0	0	MA6052_01	0	0
14.00 - 15.00	0	0	MA6052_01	0	0
15.00 - 16.00	MA6052_01,AK6091_01	0	AK6083_01,AK6282_01	MA6027_01	AK6061_01
16.00 - 17.00	0	0	0	AK6083_01	0
17.00 - 18.00	0	0	0	AK6083_01	0

FIGURE. 13. The Timetable for sixth-year students

FIGURE 8-13 are the timetables for the students with the point of view based on the course year. The course with the third letter is “1” represents the first-year courses, the course with the third letter is “2” represents the second-year courses, and so on. The fifth-year courses and the sixth-year courses are aimed at postgraduate students. We can see that the number of every course with the same major, same year, and different code is a maximum of three for each session, this is because of the fifth hard constraint. We also can see that the courses with the same code, but different classes have the same schedule, this is because of the sixth hard constraint. If we take a look at the first-year courses, they are held under 11.00 AM, these things happen because of the tenth hard constraint. This kind of output is very suitable for the students to arrange their schedules.

The output of this program shows that there is no violation of hard constraints and minimum violation of soft constraints which means the schedule that was built from the model on this paper is optimal. The optimal schedule represents that every lecturer will teach every assigned course without any problem and every student can take the obligatory courses without any problem too. Because the schedule in this paper has been optimized, we can say that this schedule can be applied to the real university timetable.

CONCLUSIONS

The timetabling process is a problem that appeared a long time ago. Even though, this problem has its own difficulties and complexities. The timetabling process of employee working schedules will have different solutions with student learning schedules, even so for another problem that required timetabling. So that the timetabling process is not an identical problem. It means there is no general solution for timetabling problems. Therefore, we focus on timetabling problems in making learning schedules in university, specifically in the Mathematics Department of Bandung Institute of Technology.

We use one of the optimization methods to solve this problem, which is Binary Integer Programming. We define an objective function, some hard constraints, and some soft constraints to build the learning schedule that can be seen in the Objective Function section and the Constraints section respectively. We also make some assumptions that can be seen in the Rules and Assumptions section.

After we have all the mathematical models of hard constraints and soft constraints, we try to test this model by using the actual data. Therefore we collect the lecturer assignment data to teach a course from the administrative officer. Then we run the simulation for solving this optimization problem by using Python Programming Language to find the optimal solution. After that, we build the learning schedule based on the optimal solution that we got. There are three types of output, that is the schedule of the lecturers, the schedule based on the course year, and the schedule based on the day.

If we look at the learning schedule that was built from the simulation, we notice that there is no violation of hard constraints, and the violation of soft constraints is minimum. We can say that this learning schedule is optimized. If we compare with the real schedule in the Mathematics Department, this schedule has some similarities. Therefore, this schedule can be applied in the real world.

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