An optimization model for course scheduling in Undergraduate Industrial Engineering Program of Universitas Sebelas Maret

M Pratiwi¹ ², C N Rosyidi¹ ³ and Yuniaristanto¹ ⁴

¹Industrial Engineering Department of Universitas Sebelas Maret, Jl. Ir. Sutami, 36 A, Surakarta, Indonesia

Email: ²mega.pratiwimp01@gmail.com, ³cucuknur@gmail.com, ⁴yuniaristanto@gmail.com

Abstract. Course timetabling is a common problem in many universities. With different number of students enrolled in every course, the number of lecturers, and various size of room's capacity, then it would be difficult for scheduler to assign courses manually. The assigning process must meet all of educational rules in order to satisfy students and lecturers for a better educational quality. There are sets of time slot, courses, and rooms. The room efficiency and the effectiveness needed due to limited available room. The problem is formulated in the form of binary integer linear programming. The objective function of the model is to maximise the room utility. The model also considers probability of a course taken by different student groups in order to avoid clash. The results show a significant difference between manual scheduling and optimization results can satisfy more constraints than manual scheduling.

1. Introduction

The problem of courses scheduling at universities is a combinatorial problem which consists of scheduling a set of courses with a number of rooms and time slots. Industrial Engineering Department of Universitas Sebelas Maret faces a complicated scheduling problem. There are four level of students: first year, second year, third year, and fourth year. They enrolled to different courses including the ones that must be retaken to remake the mark of certain courses. Hence the scheduler must separate them into several groups. The student groups separation is made based on the student-level, class, and the courses. Besides that, with different number of students, the scheduler has other difficulties regarding to the room availability as it is used together with other study programs. There are also elective courses which must be taken by the third and fourth-year students provided by six laboratories. The delivery time of each course depends on credit of each course whether two or three credits. The data used in this study which consist of the room available, the students, the courses, the time slots, and the lecturers are retrieved from a database provided by the industrial engineering department of Universitas Sebelas Maret.

Every course is taught by different lecturers based on the competency and teaching load they have. The lecturers must also be assigned to certain time slot where their mandatory and elective courses are not held simultaneously. Several research in course timetabling has been conducted. For example, [1] developed graph coloring, network flow techniques and artificial intelligence (simulated annealing, taboo search, genetic algorithms, constraint satisfaction). [1] also categorized scheduling problems in educational institutions into 3 groups as follows: scheduling courses at universities, scheduling
examinations at universities, and scheduling subjects at school. The problem of scheduling in educational institutions (educational timetabling) involves teachers or lecturers, students, and courses or subjects in a certain time and space. The problem can be formulated by finding the best allocation for both student and lecturer into the right time slot and limited rooms regarding to some educational rules or constraints. There are two constraints in timetabling, namely hard constraints and soft constraints. According to [2] hard constraint is a constraint in scheduling that must be met in any way so that the schedule is feasible. While soft constraints are constraint that must be met as much as possible, as long as they do not violate the hard constraints. Sometimes due to the complexity of scheduling problems at the university, not all hard constraints can be met.

This study develops course scheduling based on the model of [3] to maximize educational quality. Hence each course should be assigned to the most qualified lecturer. The educational quality can be maximized by assigning courses to the lecturer at the right time slot of a day for specific student group in different major. The study conducted by Komijan develop a model that assigning courses for the right time slot and room regarding to the student and lecturer. There are some things affecting the courses that should be considered before the assignment like student groups who take the courses, number of students, courses load, and the lecturer who taught the course. The student groups will later be an effective way to solve problem where student can’t attend more than one course at a time. Then the number of students is used to assign courses to appropriate room. It also shows that the room is used efficiently. Next the courses load will be used to put courses to the appropriate time slot which has different duration. Last, the lecturer that taught the course must be considered carefully as the lecturer have their unavailable time, and different courses to teach

2. Methods
Several authors have solved scheduling problems using integer linear programming techniques such as [4], [5], [6], [7] and [8]. Specifically, [7] used the Langrangian Relaxation technique and in [8] expanded his technique to complete subproblem grouping. Meanwhile, Ferland and Roy (1985) formulated the problem as an assignment problem, and solved the model with quadratic programming. This study use integer linear programming for the model. Linear programming allows us to formulate mathematical model based on real world problem. According to [9] One of the most popular methods for linear programming is simplex method. Simplex method tends to find the most feasible solution by modifying the value of basic variable, so that maximum value for objective function is obtained. And another method in linear programming specifically to solve transportation problem is northwest corner and least cost method. Both of these methods’ objective is to find the cheapest or smallest unit cost for demand and supply. The northwest corner method commonly used to find and calculate feasible solutions which include demand and supply problems involving many sources. The number of total demands should meet the number of total supplies is required for this method to work. And for the least cost method, based on [10] could find the better solution with the cheapest routes by assigning as much as possible cells with smallest unit cost. This method is conducted by crossing out the row or column and adjusting the amounts of demand of supply, until there’s only one row or column left uncrossed. Thus, the smallest unit cost can be obtained. The linear programming in this study use binary logic because according to [11], binary logic could indicate whether particular alternative should be performed or used and to force logical relations among decisions. Other than that, because of different constraints exist in this study also become one of the factors why binary logic is used. By implementing binary logic which consist of zero-one decisions for yes/no answer, then the suitable solution will show up when there are two options is given.

2.1 Notations
Parameter

- \( i \) = time slot
- \( j \) = courses
- \( k \) = rooms
\( K \) = sets of regular rooms
\( I \) = sets of time slots with load 2 credits
\( L \) = sets of time slots each day
\( J_m \) = sets of mandatory courses
\( J_e \) = sets of elective courses
\( J_c \) = sets of courses with load 3 credits
\( J_r \) = sets of courses thought by lecturer
\( J_s \) = sets of student groups that take the courses
\( T_r \) = sets of time slot where the lecturer is unavailable
\( e_j \) = number of students enrolled in a course
\( f_k \) = room capacity

Decision Variable
\[ x_{i,j,k} = \begin{cases} 1, & \text{if the courses } j \text{ is assigned to time slot } i \text{ and room } k \\ 0, & \text{otherwise} \end{cases} \]

2.2 Model Formulation

Objective function of the model is to maximize the number of course assignment as shown in Equation (1).

\[
Max = \sum_i \sum_j \sum_k x_{i,j,k}
\]  

(1)

The model consists of some constraints. The first constraint is to ensure that every course is assigned to only one room. It prevents one course getting held in different room. Equation (2) show the constraint.

\[
\sum_i \sum_k x_{i,j,k} = 1 \quad ; \forall j
\]  

(2)

The second constraint is used to ensure that each course held in one room and one time slot. So, there will be no other courses carried out in one room and one specific time slot.

\[
\sum_j x_{i,j,k} \leq 1 \quad ; \forall i, k
\]  

(3)

The third constraint is needed to ensure the match the credit course with the appropriate time slot. Thus, courses with a load of 3 credits cannot be held in a time slot for courses with a load of 2 credits. However, courses with a load of 2 credits can be held in a time slot for courses with a load of 3 credits.

\[
\sum_l \sum_k \sum_j x_{l,j,k} = 0
\]  

(4)

Equation (5) is used to ensure the lecturer assignment to exactly one time slot and one course. So, the lecturer can’t teach more than one course in one time slot.

\[
\sum_{j \in J_r} \sum_k x_{i,j,k} \leq 1 \quad \forall i
\]  

(5)
Equation (6) is used specifically if there’s any other agenda the lecturer must attend. So, then the teacher can’t be assigned to time slot where he’s unavailable, and there will be no course held at that time.

$$\sum_{j \in J_r} \sum_{k \in T_r} \sum_{i \in T_r} x_{i,j,k} = 0$$

(6)

The sixth constraint in Equation (7) ensures the student group as the main focus. This constraint prevent student who probably re-take the course from previous year to sit in two courses or more at the same slot time. This also prevent student from different student group to have a clashed schedule.

$$\sum_{j \in J_s} \sum_{k \in K_r} x_{i,j,k} \leq 1 \quad \forall i$$

(7)

The seventh constraint consists of two constraint: the first is to limit the use of regular classroom and second the use of laboratory room. Due to the room capacity, mandatory course is not possible to be held in laboratory room due to its capacity. Instead, laboratory room is used for elective course. The constraint to limit the use of regular room for elective course is shown in Equation (8).

$$\sum_{k \in K_r} \sum_{l \in J_e} \sum_{i \in I_e} x_{i,j,k} = 0$$

(8)

Equation (9) is used to match the number of students in a course with the room capacity.

$$e_j x_{i,j,k} \leq f_k \quad \forall i, j, k$$

(9)

The last constraint is used to restrict the same course for different student group held in the same day. This constraint prohibit lecturer to teach the same course simultaneously. The lecturer will teach the same course for different student group in the next day. Equation (10) shows the constraints.

$$\sum_{l \in I_d} \sum_{k \in K_r} \sum_{j \in J_m} x_{i,j,k} \leq 1$$

(10)

3. Result and discussion
The model is solved using Lingo 18 which provides report with all possibility combinations from every variable. The result from the Lingo report should be translated first into Microsoft Excel table because the notation is coded in number. The combinations of decisions variable contained in Lingo as binary code zero-one then listed to know which combination is possible for yes/no answer. Later, with the translated result in Microsoft Excel table, the schedule is formed. Table 1 shows the listed result of Lingo report with one/yes decision.
Table 1. Lingo report.

| No  | Variable  | No  | Variable  | No  | Variable  | No  | Variable  |
|-----|-----------|-----|-----------|-----|-----------|-----|-----------|
| 1   | X(I1, J59, K7) | 14  | X(I6, J25, K3) | 27  | X(I8, J38, K6) | 40  | X(I14, J38, K3) | 53  | X(I17, J38, K3) |
| 2   | X(I2, J37, K5) | 15  | X(I6, J28, K4) | 28  | X(I9, J16, K4) | 41  | X(I14, J40, K4) | 54  | X(I18, J35, K3) |
| 3   | X(I2, J30, K4) | 16  | X(I6, J56, K5) | 29  | X(I9, J20, K2) | 42  | X(I14, J53, K1) | 55  | X(I18, J38, K4) |
| 4   | X(I3, J1, K1) | 17  | X(I6, J60, K7) | 30  | X(I9, J43, K1) | 43  | X(I15, J6, K1)  | 56  | X(I18, J57, K5) |
| 5   | X(I3, J5, K2) | 18  | X(I6, J61, K8) | 31  | X(I9, J32, K3) | 44  | X(I15, J9, K2)  | 57  | X(I18, J65, K9) |
| 6   | X(I3, J24, K3) | 19  | X(I7, J33, K1) | 32  | X(I11, J28, K4) | 45  | X(I15, J41, K4) | 58  | X(I19, J12, K1) |
| 7   | X(I3, J36, K9) | 20  | X(I7, J15, K3) | 33  | X(I11, J19, K1) | 46  | X(I15, J44, K3) | 59  | X(I19, J14, K2) |
| 8   | X(I4, J32, K3) | 21  | X(I7, J42, K4) | 34  | X(I12, J9, K2) | 47  | X(I16, J31, K3) | 60  | X(I18, J39, K3) |
| 9   | X(I4, J37, K4) | 22  | X(I7, J48, K3) | 35  | X(I12, J13, K3) | 48  | X(I16, J36, K6) | 61  | X(I20, J14, K4) |
| 10  | X(I4, J34, K1) | 23  | X(I8, J15, K1) | 36  | X(I12, J13, K4) | 49  | X(I16, J36, K9) | 62  | X(I21, J21, K1) |
| 11  | X(I5, J12, K1) | 24  | X(I8, J19, K2) | 37  | X(I12, J49, K1) | 50  | X(I17, J10, K1) | 63  | X(I20, J32, K3) |
| 12  | X(I5, J17, K2) | 25  | X(I8, J23, K3) | 38  | X(I13, J46, K4) | 51  | X(I17, J18, K2) | 64  | X(I11, J35, K4) |
| 13  | X(I5, J48, K4) | 26  | X(I8, J59, K6) | 39  | X(I13, J51, K1) | 52  | X(I17, J47, K4) | 65  | X(I1, J34, K3) |

The report listed on above then one by one is translated based on the number code. For example X(I1, J59, K7) means the notation for i which means timeslot for timeslot number 1, and j which means courses for course number 59, and k which means room for room number 7, have value 1. It means that courses number 59 can be conducted in timeslot number 1, at the room number 7. Later, after all the report is translated into what timeslot, courses, and room, we can build an appropriate schedule form. And since every course is taught by different lecturer, we can also put the lecturer into suitable timeslot and room. Table 2 shows the results.

Based on Table 2, every course is well scheduled into appropriate timeslot and rooms. There are no clashes found between courses. Each course is taught by specific lecturer and taken by specific student group. As we can see above, different courses are assigned to different timeslot and rooms to prevent the lecturer teaching different student group by the same timeslot. For example, mandatory courses ‘Optimization’ taught by lecturer with initial SS is assigned to timeslot 2, room k=3. Later, lecturer SS has another assigned elective course of ‘Human Factor Based Product Development’ by timeslot 3, room k=9 which is suitable laboratory for that specific elective courses. By that, lecturer SS has 2 assigning courses for different student group 4A and group that take elective courses. We can also conclude that during assigning for elective courses ‘Human Factor Based Product Development’ or ‘Supply Chain Management’, no student group from third and fourth year is assigned to mandatory courses. The same condition is obtained in the following schedule.

In Table 3, some elective courses are held simultaneously. That make the student group taking elective course in specific field of interest has no option but to choose one elective course at one time. Even though, they can only choose one, it doesn’t limit the student group for having only 1 elective course in a day within the same laboratory. For example, student group taking elective course ‘Multi Variable Analysis’ can still take ‘Standardization’ in one day. This also work for student group taking different elective course from different laboratory.

From the Table 4, there’s a vacant timeslot from 09.20 WIB to 12.00 WIB where no courses are allowed to be held. This due to the unavailable time of lecturer to teach because of special agenda including department meeting routine and competitive improvement program held by each laboratory. This means that the constraint where the lecturer can’t teach on their unavailable time is achieved.
Table 2. The schedule optimization result.

| Timeslot | Day | Hour | k=1 | k=2 | k=3 | k=4 | k=5 | k=6 | k=7 | k=8 | k=9 | k=10 |
|----------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|          |     |      |     |     |     |     |     |     |     |     |     |      |
|          |     |      |     |     |     |     |     |     |     |     |     |      |
| 1        |     | 07:30-08:20 | Manufacturing Process II 4B (LH) | Work System Analysis and Design 6A (RDA,RDA) | Supply Chain Management (WS) |     |     |     |     |     |     |     |
|          |     | 08:25-09:15 | Manufacturing Process II 4B (LH) | Work System Analysis and Design 6A (RDA,RDA) | Supply Chain Management (WS) |     |     |     |     |     |     |     |
| 2        |     | 08:20-10:10 | Optimization 4A (SH) | Industrial Statistics 4B (EP,EP) |     |     |     |     |     |     |     |     |
| MONDAY   |     | 10:15-11:05 | Optimization 4A (SH) | Industrial Statistics 4B (EP,EP) |     |     |     |     |     |     |     |     |
|          |     | 11:10-12:00 | Optimization 4A (SH) | Industrial Statistics 4B (EP,EP) |     |     |     |     |     |     |     |     |
| 3        |     | 11:00-12:50 | Calculus II 2A (PHM) | Introduction to Engineering and Design 1B (WS,WS) | Human Factor Based Product Development (SH) |     |     |     |     |     |     |     |
|          |     | 12:55-14:45 | Calculus II 2A (PHM) | Introduction to Engineering and Design 1B (WS,WS) | Human Factor Based Product Development (SH) |     |     |     |     |     |     |     |
|          |     | 14:50-15:40 | Calculus II 2A (PHM) | Introduction to Engineering and Design 1B (WS,WS) |     |     |     |     |     |     |     |     |
| 4        |     | 15:45-16:35 | Entrepreneurship 8B (YAM,MH) | Database 4B (YP,EL,MNF) | Engineering Economics 6A (BS,FBS) |     |     |     |     |     |     |     |
|          |     | 16:40-17:30 | Entrepreneurship 8B (YAM,MH) | Database 4B (YP,EL,MNF) | Engineering Economics 6A (BS,FBS) |     |     |     |     |     |     |     |

Table 3. The schedule optimization result.

| Timeslot | Day | Hour | k=1 | k=2 | k=3 | k=4 | k=5 | k=6 | k=7 | k=8 | k=9 | k=10 |
|----------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|          |     |      |     |     |     |     |     |     |     |     |     |      |
|          |     |      |     |     |     |     |     |     |     |     |     |      |
| 5        |     | 07:30-08:20 | Computer Programming 2C (YP,EL) | Materials Engineering 2B (TR,RHS) | Occupational Health and Safety 6B (SH,SH)(SH) |     |     |     |     |     |     |     |
|          |     | 08:25-09:15 | Computer Programming 2C (YP,EL) | Materials Engineering 2B (TR,RHS) | Occupational Health and Safety 6B (SH,SH)(SH) |     |     |     |     |     |     |     |
|          |     | 09:20-10:10 | Multiple Variable Calculus 4A (SH,WK,WK) | Optimization 4B (SH) | Industrial Ecology 6B (RDA,RDA) | Performance Measurement (YDA) | Multi Variable Analysis (AP) |     |     |     |     |     |
| TUESDAY  |     | 10:15-11:05 | Multiple Variable Calculus 4A (SH,WK,WK) | Optimization 4B (SH) | Industrial Ecology 6B (RDA,RDA) | Performance Measurement (YDA) | Multi Variable Analysis (AP) |     |     |     |     |     |
|          |     | 11:10-12:00 | Multiple Variable Calculus 4A (SH,WK,WK) | Optimization 4B (SH) |     |     |     |     |     |     |     |     |
| 6        |     | 11:00-12:50 | Calculus II 2C (PHM) | Design of Production Sci 6A (LH) | System Modeling 4B (YP,CNR) |     |     |     |     |     |     |     |
|          |     | 12:55-14:45 | Calculus II 2C (PHM) | Design of Production Sci 6A (LH) | System Modeling 4B (YP,CNR) |     |     |     |     |     |     |     |
|          |     | 14:50-15:40 | Calculus II 2C (PHM) | System Modeling 4B (YP,CNR) |     |     |     |     |     |     |     |     |
| 7        |     | 15:45-16:35 | Engineering Mechanics 2C (RHS,TR) | Pancake 2A (B) | Relate 2B (SH) | Tolerance Design (SH) |     |     |     |     |     |     |
|          |     | 16:40-17:30 | Engineering Mechanics 2C (RHS,TR) | Pancake 2A (B) | Relate 2B (SH) | Tolerance Design (SH) |     |     |     |     |     |     |
### Table 4. The schedule optimization result.

| Timeslot | Day       | Start       | End         | 1=1.5 | 2=2 | 3=3 | 4=4 | 5=5 | 6=6 | 7=7 | 8=8 | 9=9 | 10=10 |
|----------|-----------|-------------|-------------|-------|----|-----|-----|-----|-----|-----|-----|-----|--------|
| 07-30    | WEDNESDAY | 07.30-08.20 | Marketing 6A (RZ,YA) |       |    |     |     |     |     |     |     |     |        |
| 08.25    |           | 08.25-09.15 | Facility Layout Design 6A (BS,RDA) |       |    |     |     |     |     |     |     |     |        |
| 09.20    |           | 09.20-10.10 | Pancasila 2B (IRF) |       |    |     |     |     |     |     |     |     |        |
| 10.15    |           | 10.15-11.05 | Marketing 6B (RZ,YA) |       |    |     |     |     |     |     |     |     |        |
| 11.10    |           | 11.10-12.00 | Materials Engineering 2A (TR,RHS) |       |    |     |     |     |     |     |     |     |        |
| 13.00    |           | 13.00-13.50 | Organizational Behavior and Design 6A (RZ) |       |    |     |     |     |     |     |     |     |        |
| 13.55    |           | 13.55-14.45 | Basic Physics II 2B (IRF) |       |    |     |     |     |     |     |     |     |        |
| 14.50    |           | 14.50-15.40 | Computer Programming 2B (VP,IL) |       |    |     |     |     |     |     |     |     |        |

### Table 5. The schedule optimization result.

| Timeslot | Day       | Start       | End         | 1=1.5 | 2=2 | 3=3 | 4=4 | 5=5 | 6=6 | 7=7 | 8=8 | 9=9 | 10=10 |
|----------|-----------|-------------|-------------|-------|----|-----|-----|-----|-----|-----|-----|-----|--------|
| 07.30    | THURSDAY  | 07.30-08.20 | Marketing 6A (RZ,YA) |       |    |     |     |     |     |     |     |     |        |
| 08.25    |           | 08.25-09.15 | Facility Layout Design 6A (BS,RDA) |       |    |     |     |     |     |     |     |     |        |
| 09.20    |           | 09.20-10.10 | System Modeling 6A (YP,CNR) |       |    |     |     |     |     |     |     |     |        |
| 10.15    |           | 10.15-11.05 | Database 4A (VP,IL,MO) |       |    |     |     |     |     |     |     |     |        |
| 11.10    |           | 11.10-12.00 | Project Management (SS) |       |    |     |     |     |     |     |     |     |        |
From Table 5, the course with 3 credits load (bold letters) is perfectly held in the time slot dedicated for that courses. The average number of mandatory courses assignment for student groups are no more than 3. For example, in table 5, the student group 6B has three different courses in a day as following courses: ‘Design of Production Aids’ from 07.30 WIB until 09.15 WIB, ‘Information System Management’ from 09.20 WIB until 12.00 WIB’, and last ‘Facility Layout Design’ from 13.00 WIB until 14.45 WIB. That means the student at least have a break between or after courses they take in a day.

Table 6. The schedule optimization result.

| Course                  | Day   | Time       | Room       |
|-------------------------|-------|------------|------------|
|                          | 17    | 07.30-08.20| Computer   |
|                          |       | 08.25-09.15| Programming 2A (VP,EL) |
|                          |       | 09.20-10.10| Materials Engineering 2C (TR,RHS) |
|                          |       | 09.30-11.10| Manufacturing Process II 6A (LH) |
|                          |       | 11.10-12.00| Computer Engineering 4A (WIF,FS) |
|                          | 18    | 13.00-13.50| Calculus II 2B (PMA) |
|                          |       | 13.55-14.45| Introduction to Engineering and Design 2A (NRE,TR) |
|                          |       | 14.50-15.40| Calculus II 2B (PMA) |
|                          | 19    | 15.45-16.35| Business Statistics II 4A (RHS,TR) |
|                          |       | 16.40-17.30| Business Statistics II 4A (RHS,TR) |

Another example can be found in Table 6 for student group 2A. They have three courses in a day, but there’s a long break between courses due to religious event held every Friday. Because of this event, the timeslot number 18, which supposed for 3 credits load is decreased for 2 credits load only. The duration is shortened from 09.20 WIB until 12.00 WIB to 09.20 WIB until 11.05 WIB to provide the time needed for religious event. And so, for other day, the number of assigned courses for every student group doesn’t exceed three. However, this doesn’t apply to lecturer. Some lecturer has a system team teaching which allows them to share teaching load/time based on material taught. The number of courses the lecturer has to teach in one day depends on their material sharing deals. It can be mid semester period teaching, or based on the number of the exam given.

4. Conclusion
This paper provides solution for course scheduling. The courses are well assigned to appropriate rooms and to specific time slot as expected. The previous work without optimization clearly has some difficulties in course-room assignment due to limited room available. But with optimization, it was obvious that with the limited number of rooms, the course can still be scheduled appropriately. The result shows that all constraint is fully satisfied even. There might be new constraint needed to limit the average number of course taken by student in a day. The limitation of courses will help student to have a break depending on credit load they have in a day, and also to prevent lecturer for having a nonstop teaching. Other than that, further research also needed to consider the agenda every lecturer could have.
has, because it can be vary from one lecturer to another lecturer. This mean to prevent lecturer absence due to sudden events or meetings.

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