Graph edges coloring to determine lecture classroom of mathematics education department at Muhammadiyah University of Surabaya

H Mursyidah
Muhammadiyah University of Surabaya, Jl. Sutorejo 59 Surabaya, Indonesia

E-mail: himmatul.pendmat@fkip.um-surabaya.ac.id

Abstract. A good college must provide good service for its students. One such service is the provision of supporting infrastructure facilities for the lecture process, such as the provision of lecture halls. Provision of lecture rooms related to scheduling lectures. We know that college is different from high school. Occasionally, students must repeat courses in the last semester, and sometimes students must take courses in the upper semester. Therefore, this article discusses the application of graph edges coloring to determine the lecture room of the mathematics education department at Muhammadiyah University of Surabaya which is effective and efficient, in accordance with the needs of students and the availability of space.

1. Introduction
A university is an education unit that organizes higher education [1]. Higher education is a level of education after secondary education which includes diploma programs, undergraduate programs, master programs, doctoral programs, and professional programs, as well as specialist programs. In carrying out the learning process, the universities in Indonesia are guided by the regulation of research, technology and higher education minister number 44 in 2015. The regulation states that national standards of higher education consist of national education standards, national research standards, and national standards for community service. The scope of higher education national standards i.e., a) graduate competition; b) learning content; c) learning process; d) learning assessment; e) lecturer and education staff; f) learning facilities and infrastructure; g) learning management; h) learning financing [2].

In the fourth section of regulation explain the standard of learning process. One of them explained that in order to obtain the achievement of graduate learning, the learning process must be carried out effectively, namely prioritizing the internalization of material properly and correctly in the optimum time frame [2]. To achieve an effective learning process, many aspects must be considered. They are establishment of the right schedule, the availability of lecture halls, the suitability of curriculum (arrangement of courses), and the synchronization of all these aspects.

Some previous studies explained that there were still universities that had not been balanced between the number of students and the availability of lecture halls, such as in the engineering department of Diponegoro University [3], and the engineering faculty of Yogyakarta State University [4]. Similarly at Muhammadiyah University of Surabaya. As a developing university, the number of students of Muhammadiyah University of Surabaya will increase from year to year. This must be balanced with the
availability of infrastructure. A good college must provide good service for its students. One such service is the provision of supporting infrastructure facilities for the lecture process, such as the provision of lecture halls.

Provision of lecture rooms related to scheduling lectures. We know that college is different from high school. Occasionally, students must repeat courses in the last semester, and sometimes students must take courses in the upper semester. So far, Mathematics Education Department, Muhammadiyah University of Surabaya has only three lecture rooms, i.e., AT1004, AT1005, and AT1006 rooms. Each batch of mathematics education students consists of one class, where class capacity is 20 to 50 students. Furthermore in preparing the class schedule, it still does not pay attention to the needs of students who will take courses in the last semester or the upper semester. Therefore, to obtain the achievement of graduate learning, it is necessary to evaluate the determination of the lecture hall based on the availability of facilities, scheduling in accordance with the curriculum i.e., pay attention to students who have to repeat courses or take courses in the upper semester, and the effectiveness of the use of lecture halls.

In mathematics lectures there are many subjects that can be used to solve scheduling problems and determine lecture halls, such as graph theory courses [5], max-plus algebra courses [6], operational research courses [7], and etc. For this study, we use simple theory namely, graph edges coloring to determine lecture classroom of mathematics education department at Muhammadiyah University of Surabaya in the odd semester, academic year 2018-2019. The difference between our research and previous research, our study looks at the prerequisite subjects in scheduling. So students who have to repeat last semester courses can choose courses that do not require the prerequisites for the course, and can repeat the last semester courses without having to along with the schedule of other courses.

2. Graph Edges Coloring

A graph is a set of a finite number of vertices and edges that connect the vertices. The notation of a graph is \( G = (V, E) \), where \( V \) is non-empty set of vertices, and \( E \) is a set of edges connecting vertices [8]. Graph coloring is giving colors to the vertices, edges, or regions in a graph, so that every two vertices, edges, or regions that related directly or adjacent have a different color. Based on the definition of graph coloring, there are three types of graph coloring. They are vertex coloring, edge coloring, and region coloring.

“The vertex coloring problem requires to assign a color to each vertex in such a way that colors on adjacent vertices are different and the number of colors used is minimized” [9].

**Definition 1.** [10] Let \( G \) is a graph and \( \Gamma \) is vertex set of a graph \( G \). A vertex \( k \)-coloring is an assignment \( f: \Gamma \rightarrow C \) from its vertex-set, onto the set \( C = \{1, \ldots, k\} \), or onto another set of cardinality \( k \), whose elements are called colors. For any \( k \), such an assignment is called a vertex coloring.

Based on Definition 1, it is better to assign colors with the minimum number of colors. So there is a term, namely proper vertex coloring on graph \( G \), i.e. an assignment of colors to the vertices of \( G \) such that no two adjacent vertices receive the same color [11]. The steps to do the vertex coloring are gathered in an algorithm. It is called the Welch-Powell Algorithm. “The vertex coloring problem consists of finding a vertex coloring with the minimum possible number of colors, number is called the chromatic number of graph \( G \)” [12]. The definition and symbol of the chromatic number are given in Definition 2.

**Definition 2.** [10] The (vertex) chromatic number of a graph \( G \), denoted \( \chi(G) \), is the minimum number of different colors required for a proper vertex coloring of \( G \). A graph \( G \) is (vertex) \( k \)-chromatic if \( \chi(G) = k \).

While the edges coloring definition on the graph is given in Definition 3.
Definition 3. [10] Let G be a graph and $E_G$ is edges set of graph G. An edge $k$-coloring is an assignment $f:E_G \rightarrow C$ from its edge-set, onto the set $C = \{1, ..., k\}$, or onto another set of cardinality $k$, whose elements are called colors. For any $k$, such an assignment is called an edge coloring.

Two edges in a graph are said to be adjacent if they are both incident with the same vertex, or they have at least one endpoint in common. In edge coloring, we also know a proper edge coloring, i.e. an edge coloring with the additional property that no two adjacent edges receive the same color [11].

Definition 4. [10] The edge-chromatic number of a graph $G$, denoted $\chi'(G)$, is the minimum number of different colors required for a proper edge coloring of $G$. A graph $G$ is edge $k$-chromatic if $\chi'(G) = k$.

A neighbour of an edge $e$ is another edge that shares one or both of its endpoints with $e$. An algorithm to do edge coloring, we call Sequential Edge Coloring Algorithm that steps are given as follows:

Algorithm 5. Sequential Edge Coloring [10]
Input: a graph with edge list $e_1, e_2, ..., e_p$.
Output: a proper edge coloring $f$, with positive integers as colors
For $i = 1, ..., p$
Let $f(e_i) \leftarrow$ the smallest color number not used on any of the smaller subscripted neighbours of $e_i$.
Return edge coloring $f$.

The last type of graph coloring is region coloring. Sometimes, region coloring of a graph is called as a map coloring. A map on a surface is an embedding of a graph on that surface. The definition of map coloring is given below.

Definition 6. [10] Let a graph $G$ and $S$ as a closed surface. A map $k$-coloring for an embedding $\iota : G \rightarrow S$ of a graph on a surface is an assignment $f:F \rightarrow C$ from the face set $F$ onto the set $C = \{1, ..., k\}$, or onto another set of cardinality $k$, whose elements are called colors. For any $k$, such an assignment is called a map-coloring.

A map coloring is proper if for every edge $e \in E_G$, the regions that meet on edge $e$ are colored differently.

Definition 7. [10] The chromatic number of a map $\iota : G \rightarrow S$, denoted by $\chi_r(\iota)$, is the minimum number of colors needed for a proper coloring.

3. Method
The stages that we use in this study are: 1) data collection, 2) classify the data based on needs, 3) graph formation, 4) graph coloring, and 5) making conclusions. The first stage, we collect data of the lecturer, names, and number of credits for all subjects offered to mathematics education department students in odd semester, academic year 2018-2019 as in Table 1. One credit is equivalent to 50 minutes. Besides collecting subject data, we also collect learning hours data that apply in the lecture process at the Muhammadiyah University of Surabaya, see Table 2.

The second stage, we classify the data based on needs, i.e., data classified based on interrelated courses, and sort them according to the levels in the Curriculum Development for Higher Education in Mathematics Education Department guide book [13]. It can be seen in Table 3. The third stage, we create graphs that correspond to the results of grouping and sorting data. Where the vertices represent the applicable lesson hours at Muhammadiyah University of Surabaya, and edges represent all subjects of mathematics education department in the odd semester.
Table 1. Mathematics education department subjects in odd semester, academic year 2018-2019

| Batch         | Lecturer Name | Subjects                                      | Symbols | Credit Number |
|---------------|---------------|-----------------------------------------------|---------|---------------|
| 1st Semester  | A             | Computer Application                          | 1A₁     | 3             |
|               |               | Introduction to Education                     | 1A₂     | 2             |
|               | C             | Basic Mathematics                              | 1C      | 3             |
|               | F             | Statistics and Data Processing                 | 1F      | 3             |
|               | H             | Islamic Education                              | 1H      | 2             |
|               | I             | Indonesian Language Education                  | 1I      | 3             |
|               | J             | Education Management                          | 1J      | 2             |
|               | L             | Pancasila Education                           | 1L      | 2             |
| 3rd Semester  | A             | Mathematics for Elementary School             | 3A      | 2             |
|               | B             | Integral Calculus                             | 3B₁     | 3             |
|               | D             | Analytical Geometry                           | 3D      | 3             |
|               | E             | Arabic                                        | 3E      | 2             |
|               | F             | Mathematical English                          | 3F      | 2             |
|               | G             | Statistics of Mathematical Probability        | 3G      | 3             |
|               | H             | AIK (Worship, Morals, and Muamalah)           | 3H      | 2             |
|               | J             | Curriculum Development Theory                 | 3J      | 2             |
| 5th Semester  | B             | Mathematics for Senior High School            | 5B      | 3             |
|               | D             | Transformation Geometry                       | 5D₁     | 3             |
|               | G             | Learning Assessment and Evaluation            | 5G₁     | 3             |
|               |               | Research Methodology                          | 5G₂     | 2             |
|               | H             | AIK (Islam and Science)                       | 5H      | 2             |
|               | J             | Development of Teaching Materials             | 5J      | 3             |
|               | K             | Multiple Variable Calculus                    | 5K      | 3             |
|               | M             | Entrepreneurship                              | 5M      | 2             |
| 7th Semester  | C             | Numerical Method                              | 7C      | 3             |
|               | F             | Graph Theory                                  | 7F      | 3             |
|               | K             | Non-Eucl Geometry                             | 7K      | 3             |

The fourth stage, the edges of the graph are colored using Algorithm 5. The last stage, we make conclusions based on the results of edges coloring on the graph that has been made.

Table 2. Learning hours in the lecture process at the Muhammadiyah University of Surabaya

| Learning Hours | Time Intervals  |
|----------------|-----------------|
| 0              | 07.10 – 08.00   |
| 1st            | 08.00 – 08.50   |
| 2nd            | 08.50 – 09.40   |
| 3rd            | 09.40 – 10.30   |
| 4th            | 10.30 – 11.20   |
| 5th            | 12.30 – 13.20   |
| 6th            | 13.20 – 14.10   |
| 7th            | 14.10 – 15.00   |
| 8th            | 15.0 – 15.50    |
4. Result and Discussion
After we collect the data, we classify them into one class of interrelated courses, i.e., a subject becomes a prerequisite for another course. If subjects that have prerequisite course in even semester, then we give an additional minus symbol such that we obtain a result as follows:

| Subjects | Symbols | Credits |
|----------|---------|---------|
| 1st Group | 1H, 3H, 5H | 2, 2, 2 |
| 2nd Group | 3A, 5B | 2, 3 |
| 3rd Group | 1F, 3G | 3, 3 |
| 4th Group | 1C, 3B₁, 5K | 3, 3, 3 |
| 5th Group | 3D, 5D₁, 7K | 3, 3, 3 |
| 6th Group | 1A₂, 3B₂, 5G₁ | 2, 2, 3 |
| 7th Group | 1J, 3J, 5J | 2, 2, 3 |
| 8th Group | 1A₁, 7C | 3, 3 |
| 9th Group | 1I | 3 |
| 10th Group | 1L | 2 |
| 11th Group | 3E | 2 |
| 12th Group | 3F | 2 |
| 13th Group | 5D₂⁻, | 3 |
| 14th Group | 5G₂⁻ | 2 |
| 15th Group | 5M | 2 |
| 16th Group | 7F⁻ | 3 |

We create graphs that represent data in Tables 2 and 3 with the following conditions: 1) each batch of mathematics education students consists of one class, 2) vertices represent learning hours, 3) edges represent courses or subjects, 4) edges are drawn sequentially based on the classification on Table 3, 5) subjects in a classification group have to be adjacent, except those that have the same letter symbols, 6) edges with the same letter or numerical symbols cannot be adjacent, 7) subjects located in different groups can be adjacent if they have a numerical symbol difference more than one, for example 1 can be adjacent with 5, 3 with 7, and etc., 8) in a graph, there are maximum 3 subjects with the same numerical symbol and 2 subjects with the same letter symbol.
The seventh condition means that students are considered to have completed the courses two years ago. Although not, they still have opportunity to repeat the course in the next years. The seventh condition also shows that students may not take courses in the semester that are more than one year above. This is to minimize excess quota in a class. Based on these conditions, the graphs obtained are given in Figures 1, 2, 3, 4, and 5. The graph that we have got is certainly not unique. However, we look for graphs that can best represent the entire data, and satisfy all of the conditions.

“Graph coloring has considerable application to a large variety of complex problem involving optimization” [14]. So, after we obtain the graphs, we give colors to the edges of them by using Algorithm 5 to determine lecture classes. By using Algorithm 5, we can also obtain the edge-chromatic number for each graph to determine the number of room needed, they are $\chi'(G_1) = 2$, $\chi'(G_2) = 3$, $\chi'(G_3) = 3$, $\chi'(G_4) = 2$, and $\chi'(G_5) = 2$.

The colored graphs are shown in Figures 6, 7, 8, 9, and 10. The colors on the graph represent the room, where red is AT1004 room, green is AT1005 room, and black is AT1006 room. The courses schedule and room distribution is given in Table 4, 5, 6, 7, and 8.

We can see in Tables 4 until 8 that courses are interrelated and have prerequisites located at one learning hour. This automatically limits students who want to take courses where they have not passed the prerequisites course.
As for the determination of room, for the first day only 2 rooms are needed, i.e., AT1004 and AT1005. The second and the third days, we need 3 rooms for learning process, i.e., AT1004, AT1005, and AT1006. It means in those days, all rooms owned by the mathematics education department at Muhammadiyah University of Surabaya are used for the learning process.

Table 4. Schedule and class distribution based on colored graph for first day

| Subjects | Room | Subjects | Room | Subjects | Room | Subjects | Room |
|----------|------|----------|------|----------|------|----------|------|
| 07.10 – 08.00 | 3A | AT1004 | 5B | AT1005 |   |   |   |
| 08.00 – 08.50 | 3A | AT1004 | 5B | AT1005 |   |   |   |
| 08.50 – 09.40 | 1H | AT1004 |   |   | 5B | AT1005 |   |
| 09.40 – 10.30 | 1H | AT1004 |   |   | 5M | AT1005 |   |
| 10.30 – 11.20 |   |   | 5M | AT1005 |   |   |   |
| Break | 12.30 – 13.20 | 1A | AT1004 | 7C | AT1005 |   |   |
| 13.20 – 14.10 | 1A | AT1004 |   |   | 7C | AT1005 |   |
| 14.10 – 15.00 | 1A | AT1004 |   |   | 7C | AT1005 |   |
| 15.00 – 15.50 |   |   |   |   |   |   |   |

While on the fourth and fifth days, only 2 rooms are needed, they are AT1004 and AT1005. Actually, when only two rooms are needed, we are free to determine which rooms are chosen from three rooms owned by mathematics education department.

Similar research has been conducted, namely course scheduling optimization using graph coloring [5]. But there are some differences with the research we did. 1) In the previous research, courses were represented as vertices. In our research, vertices represent learning hours. 2) Courses with the same lecturers were linked by an edge in the previous research. In this research, edges represent courses where the beginning and end of the lesson hours represented by vertices, and they connected by an edge. 3) The process of drawing graphs in this research must fulfil the 8 conditions mentioned earlier, because the purpose of graph modelling here is to get a schedule arrangement that pay attention to the needs of students, such as courses they may not take and which they must repeat. 4) Previous research used the
Welch-Powell Algorithm because they colored the vertices. In this study, we used Sequential Edge Coloring Algorithm because we are coloring the edges. 5) Courses schedule with lecturers and rooms that do not take place simultaneously are the results of previous studies. For our results, besides getting a schedule that pay attention to the needs of students, we also get a schedule with courses, lecturers, and rooms that do not take place or are used simultaneously. In addition, we can also evaluate the number of room availability for the learning process in Mathematics Education Department, Muhammadiyah University of Surabaya.

Table 5. Schedule and class distribution based on colored graph for second day

| 1<sup>st</sup> Semester | 3<sup>rd</sup> Semester | 5<sup>th</sup> Semester | 7<sup>th</sup> Semester |
|------------------------|------------------------|------------------------|------------------------|
| 07.10 – 08.00          | 1A<sub>2</sub>          | 3B<sub>2</sub>          | 5G<sub>1</sub>          | AT1004 |
| 08.00 – 08.50          | 1A<sub>2</sub>          | 3B<sub>2</sub>          | 5G<sub>1</sub>          | AT1005 |
| 08.50 – 09.40          |                        |                        | 5G<sub>1</sub>          | AT1006 |
| 09.40 – 10.30          | 3E                      | AT1005                 |                        |        |
| 10.30 – 11.20          | 3E                      | AT1005                 |                        |        |

**Break**

| 12.30 – 13.20          | 1C                      | AT1004                 | 3B<sub>1</sub>          | AT1005 |
| 13.20 – 14.10          | 1C                      | AT1004                 | 3B<sub>1</sub>          | AT1005 |
| 14.10 – 15.00          | 1C                      | AT1004                 | 3B<sub>1</sub>          | AT1005 |
| 15.00 – 15.50          |                         |                        |                        |        |

Table 6. Schedule and class distribution based on colored graph for third day

| 1<sup>st</sup> Semester | 3<sup>rd</sup> Semester | 5<sup>th</sup> Semester | 7<sup>th</sup> Semester |
|------------------------|------------------------|------------------------|------------------------|
| 07.10 – 08.00          |                        |                        | 5D<sub>2</sub>          | AT1004 |
| 08.00 – 08.50          |                        |                        | 5D<sub>2</sub>          | AT1004 |
| 08.50 – 09.40          | 1I                      | AT1005                 | 5H<sub>2</sub>          | AT1004 |
| 09.40 – 10.30          | 1I                      | AT1005                 | 5H<sub>2</sub>          | AT1004 |
| 10.30 – 11.20          | 1I                      | AT1005                 | 5H<sub>2</sub>          | AT1004 |

**Break**

| 12.30 – 13.20          | 1J                      | AT1005                 | 5D<sub>1</sub>          | AT1004 |
| 13.20 – 14.10          | 1J                      | AT1005                 | 5D<sub>1</sub>          | AT1004 |
| 14.10 – 15.00          |                         |                        | 7K<sub>1</sub>          | AT1006 |
| 15.00 – 15.50          |                         |                        | 7K<sub>1</sub>          | AT1006 |

This scheduling model has limitations, i.e., students are prioritized to repeat courses one semester below, and take courses one semester above. Furthermore, this scheduling applies to each batch consists only one class.

However, this study is in accordance with real data in the field. So that it can be applied in the Mathematics Education Department, Muhammadiyah University of Surabaya for odd semester, academic year 2018-2019.
Table 7. Schedule and class distribution based on colored graph for fourth day

| Time     | 1st Semester | 3rd Semester | 5th Semester | 7th Semester |
|----------|--------------|--------------|--------------|--------------|
|          | Subjects     | Room         | Subjects     | Room         | Subjects     | Room         |
| 07.10–08.00 | 1F AT1005   | 1F AT1005   | 5G AT1004   | 5G AT1004   |
| 08.00–08.50 | 1F AT1005   | 1F AT1005   | 5G AT1004   | 5G AT1004   |
| 08.50–09.40 | 1F AT1005   | 3G AT1004   | 7F AT1005   | 7F AT1005   |
| 09.40–10.30 | 3G AT1004   | 3G AT1004   | 7F AT1005   | 7F AT1005   |
| 10.30–11.20 | 3G AT1004   | 3G AT1004   | 7F AT1005   | 7F AT1005   |
| Break     |
| 12.30–13.20 | 3J AT1004   | 3J AT1004   | 3J AT1004   | 3J AT1004   |
| 13.20–14.10 | 3J AT1004   | 3J AT1004   | 3J AT1004   | 3J AT1004   |
| 14.10–15.00 | 3F AT1004   | 3F AT1004   | 3F AT1004   | 3F AT1004   |
| 15.00–15.50 | 3F AT1004   | 3F AT1004   | 3F AT1004   | 3F AT1004   |

Table 8. Schedule and class distribution based on colored graph for fifth day

| Time     | 1st Semester | 3rd Semester | 5th Semester | 7th Semester |
|----------|--------------|--------------|--------------|--------------|
|          | Subjects     | Room         | Subjects     | Room         | Subjects     | Room         |
| 07.10–08.00 | 1L AT1005   | 1L AT1005   | 5J AT1004   | 5J AT1004   |
| 08.00–08.50 | 1L AT1005   | 1L AT1005   | 5J AT1004   | 5J AT1004   |
| 08.50–09.40 | 1L AT1005   | 1L AT1005   | 5J AT1004   | 5J AT1004   |
| 09.40–10.30 | 3H AT1004   | 3H AT1004   | 3H AT1004   | 3H AT1004   |
| 10.30–11.20 | 3H AT1004   | 3H AT1004   | 3H AT1004   | 3H AT1004   |
| Break     |
| 12.30–13.20 | 3D AT1004   | 3D AT1004   | 3D AT1004   | 3D AT1004   |
| 13.20–14.10 | 3D AT1004   | 3D AT1004   | 3D AT1004   | 3D AT1004   |
| 14.10–15.00 | 3D AT1004   | 3D AT1004   | 3D AT1004   | 3D AT1004   |
| 15.00–15.50 | 3D AT1004   | 3D AT1004   | 3D AT1004   | 3D AT1004   |

5. Conclusion

We can conclude that the number of room needed for the lecture process in mathematics education department, Muhammadiyah University of Surabaya is compatible with the number of availability room. In a day, it only takes 2 until 3 rooms from 3 rooms that are owned. So mathematics education department, Muhammadiyah University of Surabaya has fulfilled a standard in the regulation of research, technology and higher education minister, number 44 in 2015, i.e., learning facilities and infrastructure standard. Furthermore, by applying the scheduling model, it is expected that mathematics education department, Muhammadiyah University of Surabaya will also fulfilled the learning process standard. It is because in this scheduling research process, we pay attention to the needs of students. Especially, students who have to repeat courses or students who have opportunity to take course in the semester above.
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