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Volume 7 Issue 11, November 2018: Page 4

[Impact of Stake Holders in Technology Design Life Cycle in Tanzania](#)

Authors: Dr. Fredrick Michael Sanga

[Natural Language Processing and Digital Library Management System](#)

Authors: Krishna Karoo

[Evaluation of Functional Outcome Following Total Knee Arthroplasty Using Radiographic and Patient-Reported Measures](#)

Authors: Dr Aravinda Hegde K, Dr Tilak Rommel Pinto

[Evaluation of Intra - Articular Hyaluronic Acid Injection in Primary Osteoarthritis of Knee](#)

Authors: Dr Janak Rathod, Dr Vikram Jasoliya, Dr Mitesh Patel, Dr Divyaprakash Sharma

[Effect of Heat Treatment on Mechanical and Microstructure Properties of PbO Glass Reinforced Metal Matrix Composite](#)

Authors: Akhil R

[Teaching Competency of Prospective Teachers](#)

Authors: Soumya Mary Mathews

[A Study on the Convergence of Financial Development on Province Level in China](#)

Authors: Cao Dong, OU Rui

[Mortality in Emergency Department Sepsis Score \(MEDS\): Predictive Accuracy and Feasibility for 28-Day Mortality of Patients with Sepsis in an Indian Emergency Department](#)

Authors: Dr. Shameem K U

[Artificial Neural Network](#)

Authors: Manoj Kumar Tiwari

[Parents' Values on Child Socialization and Changes toward Modernization in Vietnam](#)

Authors: Vu Tuan Huy

[Clinical Differences between Shoulder Impingement Syndrome and Frozen Shoulder](#)

Authors: Muliani

[Impact of International Trade on Economic Growth in Bangladesh](#)

Authors: Md. Hasnain Ahamad

[Analysis of Food Label Reading Behavior](#)

Authors: Ridanti Indraswari Prasiwi, Lilik Noor Yuliati, Megawati Simanjuntak

[Subcondral Geoda - Case Report: Occupational Medicine Approach](#)

Authors: Loio-Marques Noemia, Ribeirinho Soares Joao, Jose Costa Almeida Maria, Matos Sara, Oliveira Silvia, Pereira Filipe

[Role of Community in Grove Management - An Appraisal of Sacred Groves of Aravalli Hills in Haryana Sub-Region, NCR](#)

Authors: Ajay Sudharsan L, Srinidhi Hariharan, Shivendu Kumar, Ritik Roushan, Kumud Dhanwantri

[Shear Strength Behaviour of Jointed Mass at 15° Orientation](#)

Authors: Dr. Subir Kumar Sharma, Dr. S. S. Gupta

[How Electrons Behave in an Atom](#)

Authors: Gandeep Bhattarai

[Odds Exponential Log-Logistic Distribution - An Economic Reliability Test Plan](#)

Authors: K. Rosaiah, G.Srinivasa Rao, K. Kalyani, D. C. U. Sivakumar

[Lean and Agile Supply Chain: Strategy for Increased Agility in Supply Chain Management](#)

Authors: Tonga Yopa Christel Gabin, Sodonchimeg Erdenesuren

[The Salfist Movement, Historical Backgrounds and Its Streams](#)

Authors: Dr. Taghreed Ali

[Effects of EMG Biofeedback Training on Facial Muscle Strength and Motor Nerve Latency in Bell's Palsy](#)

Authors: Dr. Nilesh Andhare, Dr. Ujwal Yeole, Urvashi Ghodasara

[Componeers Vs Porcelains](#)

Authors: Stela Panteqi, Agron Meto, Orges Simeon

[Effectiveness of Sambote Extract on Decreasing Blood Glucose Levels of Male White Rats \(*Rattus norvegicus*\) Induced with Sucrose](#)

Authors: Dingse Pandiangan, Nelson Nainggolan, Febby Kandou, Edwin de Queljoe

[Evaluation of the Physico - Chemical Properties of Acha \(*Digitaria Exilis*\) for the Beverage Industries in Nigeria](#)

Authors: Bulus, Daniel Sadiq Mnifst

[Using Graph Coloring for University Timetable Problem](#)

Authors: R. Kristoforus J. Bendi, Theresia Sunarni, Achmad Alfian

[Correlation between Spatial Involvement and Systemic Disease with the Length of Hospital Stay in Odontogenic Maxillofacial Infection Patients](#)

Authors: Endang Sjamsudin, Lira Masri, Asri Arumsari

[Maize-Haricot Bean Intercropping on Soil Fertility Improvement under Different Planting Methods, at Kiremu District, Eastern Wollega Zone, Oromia Region, Ethiopia](#)

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[Triple Impact, Central Incisor, Lateral Incisor and Canine, Caused by Pediatric Dental Trauma \(Case Report\)](#)

Authors: Nineta Fino, Ramazan Isufi

[Interstate Trade and Commerce under Indian Constitution](#)

Authors: K. Anusha

[Performance Analysis of Human Action Recognition System between Static k-Means and Non-Static k-Means](#)

Authors: Tin Zar Wint Cho, May Thu Win

----- [\[1\]](#) - [\[2\]](#) - [\[3\]](#) - [\[4\]](#) - [\[5\]](#) - [\[6\]](#) -----

Using Graph Coloring for University Timetable Problem

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Abstract: *Univeristy Timetabling is a way of allocating students who take courses, lecturers who teach courses, and space used for lectures at available time slots. The problem that often arises in the lecture scheduling process is the occurrence of clash of subjects because lecturers or students with the same semester are scheduled in the same time slot, and violations occur in scheduling the lecturers' requests not to be scheduled at certain time slots. For this reason, the scheduling of courses needs to be improved to optimize the available resources. The technique of graph node coloring with the Welsh Powell algorithm was chosen as the starting method in this study. With the graph coloring technique each event will be calculated the degree of connection with other events and then given a certain color based on the order of degrees. After that each event will be placed sequentially into a time period based on the priority of the restrictions made. The results of the study show that coloring is the basis for allocating time and space slots in the scheduling process. In this study the process was made in 2 scenarios with different sessions available, available space, and available days. The two scenarios show that with scenario 2 time slots, 4 spaces, and 5 days get optimal results where constraint violations occur at least and the level of space utilization is greater.*

Keywords: university timetabling, graph coloring, welsh-powell algorithm.

1. Introduction

University Timetable Problems (UTP) have become one of the research topics that have been widely conducted [1, 2, 3]. Jat & Yang [4] states that UTP is a multidimensional allocation issue, where students and lecturers are allocated in courses, subject classes and time preferences (both lecturers and students) are allocated in classrooms and time slots (timeslots). UTP is a type of time allocation problem that is solved by evaluating the limits given.

Lecture scheduling is a routine activity conducted every semester at a college. Lecture scheduling is a way of allocating students who take courses, lecturers who teach courses, and space used for lectures at available time slots. Lecture activities are carried out by considering the number of lecturers and classrooms and available time slots.

Often in the process of arranging the lecture schedule there are conflicts or clashes between courses, lecturers, or lecture rooms at a certain time slot. This can be caused by several things, including: (a) a lecturer teaching several different subjects, (b) using the same room for different subjects, (c) the limited number of lecture rooms available, (d) needs certain rooms (specifically) for several courses, and (e) the request of the lecturer concerned not to teach at a certain time slot. The preparation of the lecture schedule in the Informatics study program and study program of the Faculty of Science and Technology Information System, Musi Charitas Catholic University (MCCU) also still faces obstacles in the occurrence of clashes and the failure of lecturers' requests not to be scheduled at certain time slots. Scheduling is done by placing certain subjects in a certain space and time slot, then for other courses by looking for time slots that are still empty. Scheduling carried out by trial and error like this will certainly be difficult and requires a long time because they have to make repetitions repeatedly.

2. Literature Review

There are various scheduling methods that have been developed before. Burke & Sanja [5] state that there are at least four groups of methods that have been used in various studies, including sequential methods, cluster methods, constructional based methods, and meta-heuristics. One method that is often used for lecture scheduling problems is the graph coloring method. This technique is included in the group of sequential methods.

Graph coloring places the occurrence of each event sequentially into a valid time period such that there is no conflict between events. This technique uses graph representation, where events are represented as vertices and conflict is represented as a path / node (Burke & Petrovic, 2002). Some previous studies have shown that the algorithm often used in graph coloring is the Welch-Powell algorithm [2, 6, 7, 8, 9, 10, 11, 12]. Graph (graph) is a discrete structure consisting of vertices and edges, or in other words, a graph is a set of pairs (V, E) with V is a non-empty set of vertices and E is a set of sides connecting a pair node in the graph. Figure 1 is an example of drawing vertices, sides and calculation of degrees. In picture 1, there are 4 subjects (01, 02, 03, and 04) with connecting lines (sides) between subjects which show the similarity of lecturers and semesters. The degree of node is calculated based on the number of sides a node has. The degree of vertex 01 is 2, node 02 is 3, node 03 is 2, and node 04 is 3.

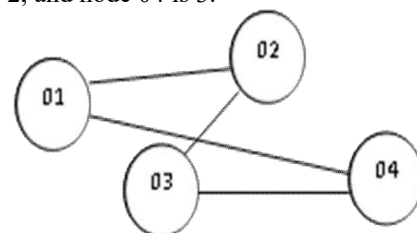


Figure 1: Sample of Graph

In graph theory, the term graph coloring is known as a method for labeling a graph. The label can be given to vertices, sides or regions (Astuti, 2011). The vertex coloring of a graph is to color the vertices of a graph so that no two neighboring nodes have the same color. We can give any color to the nodes as long as they are different from the neighboring nodes.

Welch Powell algorithm is one of the graph coloring algorithms that performs coloring based on the highest degree of vertices, called Largest Degree Ordering (LDO). The Welch Powell algorithm can be used to color a G graph efficiently and practically, although it does not always provide the minimum number of colors needed to color G. The coloring stages with Welch Powell algorithm are as follows:

- 1) Sort the vertices of G in decreasing degrees
- 2) Use one color to color the first node (which has the highest degree) and other vertices (in sequential order) that are not adjacent to this first node.
- 3) Start again with the next highest degree node in the sorted list that has not been colored and repeat the node coloring process using the second color.
- 4) Repeat using colors until all the vertices have been colored.

3. Research Methodology

The stages to be carried out in this study are (1) data collection and codification, (2) graph coloring process, (3) time slot allocation, and (4) optimization analysis. The stages in scheduling begin collecting and codifying data. In the next stage, identification of relationships between vertices in this case is conducted, based on the similarity of lecturers, study programs and semesters. The relationship formed becomes the basis for calculating the degree of courses used in graph coloring. Next the results of graph coloring become the basis for allocating time and space slots on the schedule. Allocations are carried out with due regard to predetermined constraints. At this stage, the allocation process is carried out in two scenarios. The final step is to compare the results of allocations based on predetermined scenarios to see the most optimal results.

4. Analysis and Result

4.1 Data Collections

The data used in this study are 2016/2017 semester semester lecture data on Informatics study programs and Information Systems study programs, Catholic University of Musi Charitas (Table 2). There are 39 courses with 18 lecturers. The total credits for all courses are 112 credits or 56 lecture sessions, where 2 credits will be held in each lecture session. The total courses that use the laboratory are 48 credits or 24 sessions that need to be carried out in the laboratory (Table 2). There are 4 laboratories used. The remaining 32 lecture sessions were held in the lecture hall. Lecture rooms are available in 3 rooms.

To facilitate data processing, data codification is first done.

Each data will be represented numerically based on the provisions provided (Table 1).

Table 1: Data Codification

Criteria Representation	Code	Description
Course	1 to 39	each subject of course are represented by a number. For example MK001 will be coded 1, and so on.
Lecturer	1 to 18	each lecturer is represented by a number. For example lecturer D001 will be coded 1, and so on.
Credit	2 or 4	2 = courses with a load of 2 credits, 4 = courses with a load of 4 credits
Department	1 to 3	1 = informatics department (IF), 2 = information systems department (SI), 3 = joint class of IF and SI
semester	1 to 8	1 = the first semester 1, 2 = the second semester and so on.

4.2 Graph Coloring Process

After the data codification is done, the next step is to do graph coloring. In this case, the course is the vertex of the graph, while the lecturer, study program and semester become the edge connecting one node with another node. Each subject taught by the same lecturer is considered to have a related side. Likewise if the subject is in one study program and the same semester will be considered to have a related side.

The first stage in graph coloring is to calculate the number of sides or degrees of each vertex. For example, MK001 will have a side connected to MK009 and MK016 because it is administered by the same lecturer, namely D007. MK001 will also have sides connected with MK023, MK024, MK025 and MK039 because the five subjects are in one department (SI) in the same semester (semester 1). In addition MK001 will also be connected to MK006, MK007, MK014, and MK015 because the four subjects are IF and SI combined courses. Thus MK001 will have 10 sides that are connected to another node or given a degree value = 7. Another example, MK002 is a joint course of IF and SI department in semester 3. Thus MK002 will be connected to MK001, MK010, MK018, MK019 courses, as well as joint IF / SI courses (MK006, MK007, MK014, MK015). Thus MK002 will have a degree value = 8.

Table 2: Data Collection

No	Course	Lecture	Department	credits	Semester	Node of graph
1	01	07	2	4	1	01/07/2/4/1
2	02	08	3	2	3	02/08/3/2/3
3	03	13	2	4	5	03/13/2/4/5
4	04	13	1	4	5	04/13/1/4/5
5	05	14	1	4	7	05/14/1/4/7
6	06	10	3	2	7	06/10/3/2/7
7	07	01	3	2	7	07/01/3/2/7
8	08	09	1	4	5	08/09/1/4/5
9	09	07	1	4	5	09/07/1/4/5
10	10	05	2	2	3	10/05/2/2/3
11	11	06	1	4	3	11/16/1/4/3
12	12	02	2	2	5	12/02/2/2/5
13	13	10	2	2	6	13/10/2/2/6

No	Course	Lecture	Department	credits	Semester	Node of graph
14	14	10	2	4	1	14/10/2/4/1
15	15	14	2	2	6	15/14/2/2/6
16	16	07	1	4	8	16/07/1/4/8
17	17	11	2	4	5	17/11/2/4/5
18	18	11	1	4	5	18/11/1/4/5
19	19	06	2	2	3	19/06/2/2/3
20	20	06	1	2	3	20/06/1/2/3
21	21	06	3	2	3	21/06/3/2/3
22	22	17	3	2	3	22/17/3/2/3
23	23	03	2	2	1	23/03/2/2/1
24	24	15	2	4	1	24/15/2/4/1
25	25	10	2	2	1	25/10/2/2/1
26	26	02	2	2	5	26/02/2/2/5
27	27	09	2	2	7	27/09/2/2/7
28	28	10	2	2	3	28/10/2/2/3
29	29	04	1	4	5	29/04/1/4/5
30	30	02	2	4	5	30/02/2/4/5
31	31	14	1	2	6	31/14/1/2/6
32	32	18	2	2	5	32/18/2/2/5
33	33	02	2	2	7	33/02/2/2/7
34	34	10	2	2	3	34/10/2/2/3
35	35	15	1	2	3	35/15/1/2/3
36	36	05	2	4	3	36/05/2/4/3
37	37	16	1	4	3	37/16/1/4/3
38	38	09	3	2	3	38/09/3/2/3
39	39	12	2	4	1	39/12/2/4/1

17	17	6	5
18	18	9	5
19	19	10	5
20	20	6	6
21	21	6	6
22	22	7	6
23	23	7	6
24	24	8	6
25	25	8	7
26	26	8	5
27	27	4	6
28	28	10	6
29	29	5	5
30	30	7	6
31	31	3	5
32	32	4	6
33	33	3	6
34	34	5	9
35	35	5	10
36	36	5	5
37	37	6	5
38	38	7	5
39	39	4	6

4.3 Slot Allocations

The first step in the allocation process is to determine the lecturer time preference and course preference. What is meant by lecturer time preference is the time available for a lecturer. While the subject space preferences are courses that need or must be carried out in certain spaces, for example practicum courses must be carried out in the laboratory. Preference determination is needed to determine slot allocation priorities. Table 4 shows the lecturer time preference. While Table 5 shows the preferences of the course space.

After the degree of each subject is calculated, the next step is to give color to each subject starting from the subject with the highest degree. After that, the same color will be given to all courses that do not have sides with courses that have been colored. For example, MK006 is a node with the highest degree, then MK006 will be colored 1. After that all nodes that have no side are connected to MK006. All nodes that do not have a side connected to MK006 will be the same color as MK006, i.e. color 1. The next step selects the node with the next highest degree that has not been colored. In this case MK014 will be selected as the node to be colored. MK014 will be given color 2. Then all nodes that are not side by side with MK014 will be searched for given the same color. The process is done repeatedly until all the vertices get color. Table 3 presents the degrees of each course and the results of the coloring.

Table 3: Degree and Color of Node

No	Course	Degree	Color
1	01	10	5
2	02	8	5
3	03	5	8
4	04	6	5
5	05	7	5
6	06	17	1
7	07	12	4
8	08	3	5
9	09	7	5
10	10	10	5
11	11	6	5
12	12	8	5
13	13	12	5
14	14	17	2
15	15	14	3
16	16	5	5

Table 4a: Lecturer Preferences

No	Lecturer	Monday			Tuesday			Wednesday		
		1	2	3	1	2	3	1	2	3
1	01		v	v			v		v	v
2	02	v	v	v	v	v	v	v	v	v
3	03		v	v		v	v		v	v
4	04									
5	05	v	v	v	v	v	v	v	v	v
6	06	v	v	v	v	v	v	v	v	v
7	07	v	v	v	v	v	v	v	v	v
8	08	v	v		v	v		v	v	
9	09	v	v	v	v	v	v	v	v	v
10	10	v	v	v	v	v	v	v	v	v
11	11	v	v	v	v	v	v	v	v	v
12	12	v	v		v	v		v	v	
13	13									
14	14	v	v	v	v	v	v	v	v	v
15	15	v	v		v	v		v	v	
16	16	v	v	v	v	v	v	v	v	v
17	17									
18	18	v	v	v	v	v	v	v	v	v

Table 4b: Lecturer Preferences

No	Lecturer	Thursday			Friday			Saturday		
		1	2	3	1	2	3	1	2	3
1	01			v		v	v			
2	02	v			v	v	v			
3	03	v	v		v	v				
4	04	v	v	v						
5	05	v			v	v	v			
6	06	v			v	v	v			
7	07	v			v	v	v			
8	08				v	v				
9	09	v			v	v	v			
10	10	v			v	v	v			
11	11				v	v				
12	12	v	v		v	v				
13	13	v	v	v				v	v	
14	14				v	v	v			
15	15	v			v	v				
16	16	v			v	v				
17	17	v			v			v	v	v
18	18				v	v	v			

Courses will be allocated into time slots based on constraints or specified scheduling limits. There are two types of constraints that are determined, namely hard constraint and soft constraint. Hard constraint is a limitation that must be met or may not be violated at the time of preparing the schedule. While soft constraints are boundaries that are fulfilled as much as possible. Hard constraints in this study are as follows.

- 1) A lecturer cannot be scheduled at the same time for two or more courses.
- 2) A course cannot be scheduled together with other courses that coincide with the semester in the same study program
- 3) A course scheduled for a particular space can only be carried out in that space.

Table 5: Room Preferences

Course	Room
01	L1
03	L4
04	L4
08	L5
09	L5
10	L2
11	L2
16	L5
17	L1
18	L1
21	L5
36	L4
37	L4
38	L5

While soft constraints are used as follows.

- 1) A lecturer is tried to be scheduled according to the available time preferences
- 2) Courses with the same semester are scheduled for a maximum of 2 courses per day.

At the time of allocation, data is placed in priority based slots. The allocation priority is as follows.

- 1) The combined course will be scheduled in advance.
- 2) Lecturers with the least time preference will be scheduled

first.

- 3) Courses with preferences for specific space requirements will be scheduled in advance.
- 4) Courses with a higher semester will be scheduled in advance.
- 5) Courses with a higher number of credits will be scheduled in advance.

Because the process of filling courses into slots is a sequential process, the next step is to determine the order of subjects to be allocated into the time slot. Determination of the sequence of courses is carried out by the following steps: (1) starting from the smallest color, for example starting from color = 1 and so on, (2) for all courses selected in step (1), select the subject with the smallest lecturer preference, (3) for all courses selected in step (2), select the subject with a specific space preference, (4) for all courses selected in step (3), select the highest semester course, (5) for all courses selected in step (4), select the subject with the highest score, (6) for all courses selected in step (5), select the course with the smallest course code, (7) place the chosen course in step (6) in the first order and so on, (8) go back to step (2) until all courses with color = 1 are finished sorting, (9) back to step (1). Sorting results can be seen in Table 3.

During the slot filling process, the first step is to design a slot scenario. In this analysis two scenarios were used (Table 6). Determination of this scenario is based on the amount of data that must be allocated. Of the 56 lecture sessions there are 18 sessions that must be allocated to special rooms, while the remaining 38 sessions need to be allocated in the classroom. Therefore, the time slot provided is at least 56 slots, with a minimum of 18 special space slots and 38 slots for classrooms.

Table 6: The Scenarios

Scenario	Number of Days	Number of Class Rooms	Number of Specific Rooms	Number Session/day
1	5	4	4	2
2	5	3	4	3

The process of allocating data into slots is the process of filling session and space matrix cells. The cell filling process is carried out sequentially starting from the first cell and so on by paying attention to the lecturer preferences, space preferences and defined constraints. The results of the subject allocation can be seen in Table 7 and Table 8.

Table 7: The Result of First Scenario

Slots		T1	T2
Monday	R1	06/10/3/2/3	14/10/3/2/3
	R2	31/14/2/2/6	39/12/1/4/5
	R3	39/12/1/4/5	33/02/1/4/8
	R4	27/09/1/4/7	35/15/3/2/7
	L1	17/11/2/4/1	17/11/2/4/1
	L2	11/16/2/2/5	
	L4		37/16/2/2/5
	L5	16/07/2/2/7	08/09/2/2/6
Tuesday	R1	15/14/3/2/3	02/08/2/2/3
	R2	12/02/2/4/5	05/14/2/2/1
	R3	32/18/1/4/5	12/02/2/4/5
	R4	27/09/1/4/7	34/10/1/2/6

Slots		T1	T2
	L1		
	L2		
	L4	36/05/2/2/1	03/13/3/2/7
	L5		21/06/1/4/5
Wednesday	R1	26/02/2/4/5	07/01/3/2/3
	R2	24/15/1/4/3	26/02/2/4/5
	R3	32/18/1/4/5	20/06/1/4/5
	R4	25/10/2/2/7	
	L1	18/11/2/2/3	
	L2		
	L4		
	L5	38/09/2/4/1	38/09/2/4/1
Thursday	R1	29/04/2/4/1	29/04/2/4/1
	R2	22/17/1/4/3	23/03/1/2/3
	R3	33/02/1/4/8	20/06/1/4/5
	R4	28/10/2/4/5	
	L1		01/07/2/2/3
	L2	10/05/2/2/3	
	L5	21/06/1/4/5	
Friday	R1	19/06/2/4/3	19/06/2/4/3
	R2	22/17/1/4/3	24/15/1/4/3
	R3	30/02/1/4/5	28/10/2/4/5
	R4	13/10/1/2/3	30/02/1/4/5
	L4	04/13/2/4/1	04/13/2/4/1
	L5	09/07/2/2/5	

	L1	01/07/2/2/3		
	L2			
	L4	03/13/3/2/7		04/13/2/4/1
	L5			
Friday	R1	22/17/1/4/3	30/02/1/4/5	25/10/2/2/7
	R2	20/06/1/4/5	34/10/1/2/6	
	R3	35/15/3/2/7	35/15/3/2/7	

Based on these two scenarios, optimization analysis is then carried out. Analysis is based on the number of constraint violations and time slot utilization. The results of the analysis (Table 9) show that scenario 1 is more optimal compared to scenario 2. This shows that although soft constraints occur in scenario 1, time slots utilization is more efficient.

Table 9: Utilization Analysis

Scenario	hard constraints violations	soft constraints violations	utilization
1	0%	7,1%	36,8%
2	0%	3,6%	29,5%

4.4 Optimization Analysis

Table 7 shows the results of slot allocation for scenario 1. Based on Table 7, it appears that there are violations of soft constraints which are indicated by the existence of courses placed not in accordance with the lecturers' time preferences (20/06/1/4/5, 01/07/2 / 2/3, 04/13/2/4/1, 04/13/2/4/1). In scenario 2 (Table 8), it can be seen that soft constraint violations occur in one course (04/13/2/4/1).

Table 8: The Result of Second Scenario

Slots		T1	T2	T3
Monday	R1	06/10/3/2/3	14/10/3/2/3	15/14/3/2/3
	R2	31/14/2/2/6	39/12/1/4/5	05/14/2/2/1
	R3	39/12/1/4/5	33/02/1/4/8	12/02/2/4/5
	L1	17/11/2/4/1	17/11/2/4/1	
	L2	11/16/2/2/5		
	L4		37/16/2/2/5	
	L5	16/07/2/2/7	08/09/2/2/6	21/06/1/4/5
Tuesday	R1	02/08/2/2/3	12/02/2/4/5	07/01/3/2/3
	R2	26/02/2/4/5	24/15/1/4/3	26/02/2/4/5
	R3	13/10/1/2/3	32/18/1/4/5	23/03/1/2/3
	L1		18/11/2/2/3	
	L2			
	L4	36/05/2/2/1		
	L5	21/06/1/4/5	38/09/2/4/1	38/09/2/4/1
Wednesday	R1	19/06/2/4/3	32/18/1/4/5	19/06/2/4/3
	R2	24/15/1/4/3	27/09/1/4/7	27/09/1/4/7
	R3	30/02/1/4/5	28/10/2/4/5	28/10/2/4/5
	L1			
	L2			
	L4	04/13/2/4/1		
Thursday	L5	09/07/2/2/5	10/05/2/2/3	
	R1	29/04/2/4/1	29/04/2/4/1	
	R2	22/17/1/4/3		
	R3	20/06/1/4/5		

5. Conclusions

The results of the study show that graph coloring with the Welch Powell algorithm can be used to produce class schedules. Further research needs to be done to optimize the scheduling results that have been obtained. Thus, it is expected that all the constraints set can be fulfilled. This research will continue with scheduling with a wider scope and software will be made for scheduling with graph coloring using the Welch-Powell algorithm.

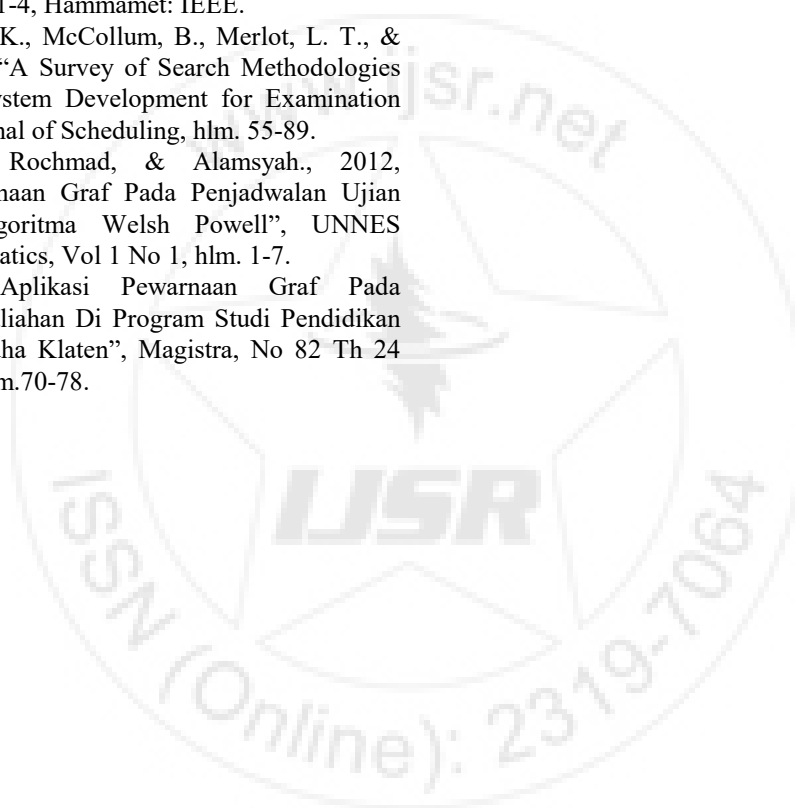
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