PENERAPAN TEORI GRAF DAN METODE WELCH - POWELL PADA PENGATURAN LAMPU LALU LINTAS

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ABSTRAK

Lampu lalu lintas adalah sarana prasarana milik negara yang digunakan untuk penanda kendaraan harus berhenti secara bergantian dari berbagai arah. Lampu lalu lintas banyak ditemui di persimpangan jalan, seperti pada lampu lalu lintas di Jl. Margerejo dengan durasi lampu merah yang lama dan lampu hijau yang singkat. Penelitian ini bertujuan untuk memperoleh graf arus lalu lintas pada persimpangan 4 Jalan Demak-Dupak Surabaya. Optimasi pengaturan durasi lampu lalu lintas sangat diperlukan dijalan tersebut, karena durasi lampu merah yang panjang sedangkan durasi lampu hijau yang singkat menyebabkan penumpukan kendaraan di persimpangan Jalan Demak-Dupak Surabaya. Pada penelitian ini diperoleh durasi lampu lalu lintas baru yaitu pada Jl. Demak (Utara) lampu merah 112.5 detik dan lampu hijau 37.5 detik. Untuk Jl. Dupak lampu merah 84 detik dan lampu hijau 28 detik. Jl. Demak (Selatan) lampu merah 135 detik dan lampu hijau 45 detik. Dan untuk poros Jl. Surabaya-Gresik lampu merah 84 detik dan lampu hijau 28 detik. Tingkat keefektivitasan nyala lampu hijau didapatkan nilai sebesar 21,77% dan tingkat keefektivitasan nyala lampu merah sebesar 6,62%.

***Kata Kunci**: Welch-Powell, Pengaturan Lalu Lintas, Pewarnaan Graf.*

APPLICATION OF GRAPH THEORY AND WELCH-POWELL METHOD AT TRAFFIC LIGHT REGULATION

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ABSTRACT

Traffic lights are state-owned infrastructure facilities that are used to mark vehicles that must stop alternately from various directions. Traffic lights are often found at crossstreets, such as at the traffic lights on Jl. Margerejo with a long duration of red light and short green light. This study aims to obtain a traffic flow graph at the intersection of 4 Jalan Demak-Dupak Surabaya. Optimization of traffic light duration settings is very necessary on this street, because the long duration of the red light while the short duration of the green light causes the accumulation of vehicles at the intersection of Jalan Demak-Dupak Surabaya. In this study, the duration of the new traffic light was obtained, namely on Jl. Demak (North) red light 112.5 seconds and green light 37.5 seconds. For Jl. Dupak red light 84 seconds and green light 28 seconds. Jl. Demak (South) red light for 135 seconds and green light for 45 seconds. And for the axle Jl. Surabaya-Gresik red light for 84 seconds and green light for 28 seconds. The level of effectiveness of the green light is obtained by a value of 21.77% and the level of effectiveness of the red light is 6.62%.

***Keywords**: Welch-Powell, Traffic Management, Graph Coloring.*

I. INTRODUCTION

Congestion is one of the main problems faced by almost all countries in the world, including Indonesia. Indonesia is included in the 10 countries with the highest levels of congestion in the world. The cause of the congestion is the increase in the number of vehicles and the lack of awareness and discipline of street users [1]. If the increase in the number of vehicles is not balanced with transportation facilities and infrastructure adequate supply, there will be an imbalance of demand (demand) with supply (supply) and will eventually lead to congestion [2]. Traffic light installed in Crossstreets serve to control the flow of traffic. Currently, many traffic lights do not operate optimally and the problem that often occurs is the duration of the red light being too long and the duration of the green light being too short, resulting in a buildup of vehicles [3].

The city of Surabaya is the second largest city in Indonesia which has various problems, one of which needs to get more attention is the problem of traffic. City of Surabaya also ranks second as the city with the highest congestion rate in Indonesia. The more an increase in the volume of vehicles that is not proportional to the width of the street, and also coupled with the non-optimal duration of setting traffic lights at intersections, so that resulting in the accumulation of vehicles and long traffic jams [4]. One of the intersection with the duration of the traffic light is not optimal, namely the intersection of four on Demak-Dupak's street, namely with a long red light duration and a short green light duration. Mathematically, problems related to traffic can be solved using graph theory.

Graph theory is a branch of discrete mathematics which in its application can be used in various fields of science and everyday life [5]. The uniqueness in graph theory is simplicity in the subject matter being studied, because it can be presented as a point (vertex) and an edge [6]. One application of graph theory is in graph coloring. Graph coloring is one part of graph theory, which is represented as an ordered number starting at 1, or can be represented directly by using red, blue, green, and other colors. There are 3 kinds of graph coloring, namely point coloring, edge coloring and plane coloring [7]. Graph theory is a theory that studies diagrams containing certain information [8]. The traffic light problem which is viewed from a graph perspective, namely by representing the intersection in the form of a graph. Direction of travel from street X to Y is assumed to be the vertex of the graph, while the direction of travel that cannot run simultaneously is assumed to be the edge of the graph, so that traffic problems in graph theory solved using point staining [9].

In graph theory, there are several algorithms that can be used in graph coloring. Based on previous research by Ezekiel Ermanto and Yosefina Riti (2022) in Comparison of Welch-Powell and Recursive Largest First algorithms in course scheduling Informatics study program, Darma Cendika Catholic University. It was found that the Welch-Powell algorithm is 0.083 seconds faster in solving problems and has a low level of complexity or is more concise in scheduling courses, so the Welch-Powell algorithm is considered to be faster and more efficient in solving problems [10]. So that the method considered in this study is the Welch-Powell algorithm. The Welch-Powell algorithm in this study is used to determine which currents can run simultaneously and determine the duration of the green and red lights with a certain time cycle using numbers chromatic [11].

Welch-Powell algorithm consists of vertex coloring and edge coloring, vertex coloring in a graph is to color each vertex so that no neighboring vertices have the same color [12]. The advantage of the Welch-Powell algorithm is that this algorithm can handle the number of nodes is large and only searches that lead to the solution are developed, so it can save search time [13]. Research on the application of the Welch-Powell algorithm in regulating traffic lights at crossstreets has been carried out previously. In a study conducted by Wika Dianita Utami., et al (2020) on the optimization of waiting time for traffic lights at the intersection of five in Krian-Sidoarjo that uses an algorithm Welch-Powell results obtained effectiveness up to 13.63% with a chromatic number of 5 [14].

Previous research conducted by Erna Lus Diana., et al (2016) on traffic light settings traffic at the intersection of Giant Ahmad Yani's street, Surabaya using the Welch-Powell algorithm, obtained a chromatic number of 3 with the level of effectiveness of the duration of the green light increasing by 47.12%, and the effectiveness of the duration of the red light decreasing by 25.62% [15]. Another study conducted by Dina Ulfa Mafuza, et al (2020) in the application of the algorithm welch-powell on traffic light regulation at Glugur Intersection, the duration effectiveness is obtained green light flame increased by 5.37% and the effectiveness of red light duration decreased by 1.55% [16].

Based on this background, the authors are interested in conducting research on the optimization of traffic light settings at the intersection of four Demak-Dupak's street Surabaya uses an algorithm welch-powell, which aims to obtain a new traffic light duration setting on Demak-Dupak's street Surabaya, which is expected to prevent the accumulation of too many vehicles and optimize traffic light settings so that congestion problems at intersections do not occur too often in Surabaya.

II. LITERATURE REVIEW

A. *Graph Teory*

The use of graphs was first used in 1739 to solve problems Königsberg Bridge, there is a river pregal which flows around the island of Kneiphof then branched off into two islands. The problem is finding the route which crosses once on each correct bridge and returns to the starting point, but does not found a route that passes through each bridge exactly one [17].

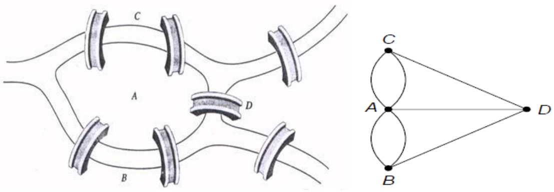


Figure 1. The Königsberg Bridge Problem

A graph is a collection of several vertices or nodes that are connected to each other through edges or arcs (edges).

A graph G = (V, E) V is a non-empty set of vertices (point or vertex) and E is the set of edges (edge). Graphs can be used for representation of discrete objects and the relations between these objects [18].

B. Graph Coloring

One of the applications of graph theory is graph coloring or graph coloring. There are 3 kinds graph coloring, namely vertex coloring, edge coloring, and area or field coloring. On vertex coloring is by giving color to the vertices in the graph so that there are no 2 connected vertices that have the same graph color. On the side coloring is done with assigns a color to an k-edge of graph G with some of the color of k or all of assigns color to all edges of graph G so that all pairs of edges have vertices associations that have different colors. In area coloring, the coloring focuses on planes, so that no adjacent planes have the same color. Region coloring can be done by converting the graph to planar, a planar graph is a graph that depicted on a flat plane with non-crossing edges [14].

Chromatic Number is the minimum number of colors needed to give color to a graph [19]. In a graph G the chromatic number is denoted by $\chi(G)$, here is "chi" which comes from the Greek letters. A graph G is said to be k-chromatic if $\chi(G) = k$ for a $k \in \mathbb{N}$ [20].

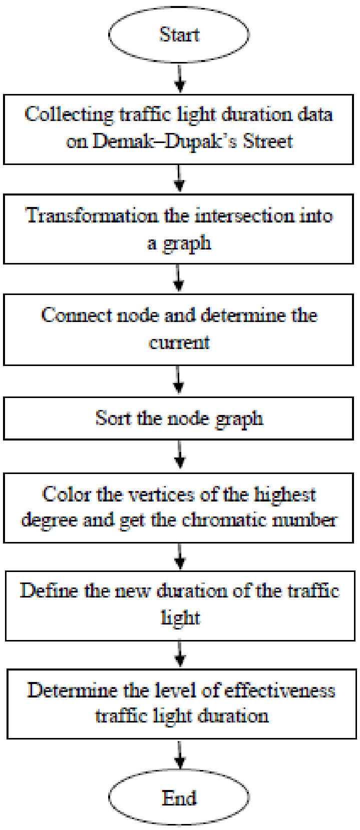
C. Welch-Powell Algorithm

The Welch-Powell algorithm can be used to color the vertices of a graph based on the highest degree of its vertices. Welch-Powell doesn't always give the number of colors minimal on graph coloring, but can provide a limit to the number of colors that can be used in coloring a graph [1]. Steps in Welch-Powell Algorithm as follows [21].

a. Sorts the vertices of graph G in descending degrees (from the highest vertex degree to the lowest).
b. Colors the first vertex (with the highest degree) as well as other vertices in the sequence (which are not next to the starting vertex) with the same first color.
c. Repeat the coloring again with the vertex of the highest degree in the sequence with the second color.
d. Repeat coloring until all vertices have finished coloring.

III. RESEARCH METHODS

The data that will be used in this study is field data for the duration of each traffic light cross at the intersection of Demak-Dupak's street, Surabaya which was collected by researchers on 3 June 2021 at 06.30 – 08.30 WIB. The following is a flow chart in this research.



Welch-Powell algorithm graph coloring method that will be used in this study, with the first stage is to transform the intersection into a graph, then connect each node formed and determine the current from which direction can be traversed by the vehicle at the same time. The next step is to sort the vertices of the graph formed into decreasing degrees (from the highest degree to the lowest degree). Coloring vertex highest degree and other non-adjacent vertices on the first vertex with the same color the same, then repeats the coloring on the next highest degree node in the sequence until all the vertices have been colored. At this stage, the chromatic number will also be obtained. Stage The next step is to divide one cycle by the chromatic number obtained and determine duration in a new cycle. The last stage, determining the level of effectiveness of the new duration traffic lights.

IV. RESULT AND DISCUSSION

The results of the study of field data collection in the form of the duration of traffic lights at the intersection of Demak-Dupak's street, Surabaya in the morning can be seen in Table 1 as follows.

TABLE I
TRAFFIC LIGHT CYCLE DURATION

Street Name	**Red (second)**	**Green (second)**	**Total**
North Demak	120	30	150
Surabaya-Gresik	90	22	112
South Demak	145	35	180
Dupak	90	22	112
Total	445	109	554

The direction of traffic is formed from each individual movement of the rider in interacting between one driver and another on a street segment and its environment. This is due to differences in the ability and nature of driving by each individual, then the driving behavior cannot be uniformed and the flow of traffic will be have different characteristics. There will be differences in the flow of traffic on a street segment characteristics will vary by time. The following is an illustration of the direction of the intersection current four of Demak–Dupak's street.

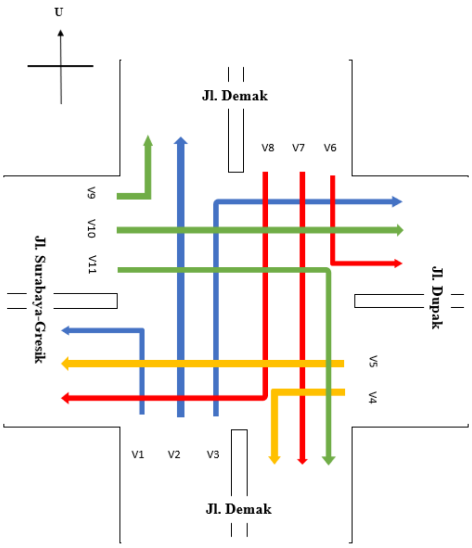


Figure 2. Traffic direction of Demak-Dupak intersection

Information:

v_1 = current from South Demak's street to Surabaya-Gresik's street
v_2 = current from South Demak to North Demak's street
v_3 = current from Demak Selatan to Dupak's street
v_4 = current from Dupak to Demak Selatan's street
v_5 = current from Dupak to Surabaya-Gresik's street
v_6 = current from Demak Utara to Dupak's street
v_7 = current from Demak Utara to Demak Selatan's street
v_8 = current from Demak Utara to Surabaya-Gresik's street
v_9 = current from Surabaya-Gresik to Demak Utara's street

v_{10} = current from Surabaya-Gresik to Dupak's street
v_{11} = current from Surabaya-Gresik to Demak Selatan's street
Uncompatible currents (must not run together) are as follows:

a. Current v_2 must not run at the same time as v_5, v_8, v_{10}, and v_{11}.
b. Current v_3 must not run at the same time as v_5, v_7, v_8, v_{10}, and v_{11}.
c. Current v_5 must not run at the same time as v_2, v_3, v_7, v_8, and v_{11}.
d. Current v_7 must not run at the same time as v_3, v_5, v_{10}, and v_{11}.
e. Current v_8 ti must not run at the same time as v_2, v_3, v_5, v_{10}, and v_{11}.
f. Current v_{10} must not run at the same time as v_2, v_3, v_7, and v_8.
g. Current v_{11} must not run at the same time as v_2, v_3, v_5, v_{10}, and v_8.

Solving graph coloring using the Welch-Powell algorithm and optimization duration settings traffic lights, the first is to transform the four-way intersection of Demak–Dupak's street to form graph as follows:

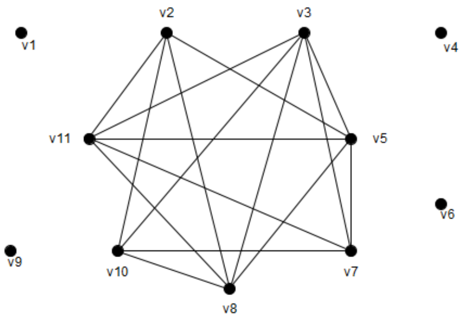


Figure 3. The Graph of the intersection Demak-Dupak's street

Based on the graph transformation above, it is known that $v_1, v_4, v_6,$ and v_9 are foreign vertices, it means the current expressed in $v_1, v_4, v_6,$ and v_9 can run concurrently with other current. So for the currents represented by $v_1, v_4, v_6,$ and v_9 the green light always applies.

Furthermore, the remaining vertices will be colored according to the Welch-Powell algorithm and to find the chromatic number. By using the Welch-Powell algorithm, we get graph coloring as follows:

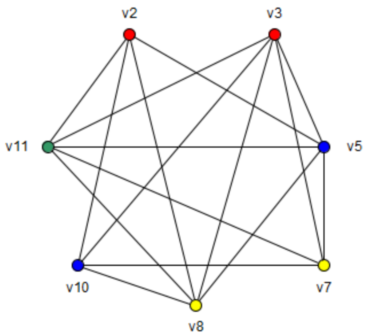


Figure 4. The result of coloring intersection of Demak-Dupak's street

Based on the coloring of the graph above, the chromatic number is 4 and the currents that can be run concurrently as follows:

TABLE II
GRAPH NODE COLORING AT THE INTERSECTION OF DEMAK-DUPAK'S STREET

Color	**Node**
Red	v_2, v_3
Blue	v_5, v_{10}
Yellow	v_7, v_8
Green	v_{11}

Based on Table 2, a traffic flow regulation partition can be formed, namely the first partition, current v_2 can run along with current v_3. The second partition, the current v_5 will run together with v_{10}. The third partition, the current v_7 will run together with the current v_8. The last partition, the current v_{11} will run on its own.

The next step is to determine alternative solutions for the duration of the red and green lights. Based on field data, the duration of the traffic light at the intersection of four Demak-Dupak's street the currents have different durations of time in one cycle. Then the total duration of each current is divided by with a chromatic number of 4. On North Demak's street obtained the duration of traffic lights in one cycle is 150, after dividing by the chromatic number, the duration of the green light is 37.5 seconds and the duration of the red light is 112.5 seconds. On Surabaya-Gresik's street and Dupak's street, the duration of the traffic light in one cycle is 112 seconds, after dividing by the number chromatic, the duration of the green light is 28 seconds and the duration of the red light is 84 second. On South Demak's street, the duration of traffic lights in one cycle is 180 seconds, after dividing by the chromatic number, the duration of the green light is 45 seconds and the duration of the red light is 135 seconds. Table 3 shows the data from the new calculation of traffic light duration.

TABLE III
SETTLEMENT OF THE DURATION OF TRAFFIC LIGHT IN DEMAK-DUPAK'S STREET

Node	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}
Red	180	135	135	112	84	150	112.5	112.5	112	84	84
Green	0	45	45	0	28	0	37.5	37.5	0	28	28

Furthermore, for the new data, the traffic lights of the four-way intersection on Demak-Dupak's street as follows:

TABLE IV
NEW DURATION OF TRAFFIC LIGHT

Street Name	Red (second)	Green (second)	Total
North Demak	112.5	37.5	150
Surabaya-Gresik	84	28	112
South Demak	135	45	180
Dupak	84	28	112
Total	**415.5**	**138.5**	**554**

Based on the duration of the traffic light at the intersection of four Demak-Dupak's street can be seen that the data of the new duration of graph coloring results using the Welch-Powell algorithm is more effective than field observation data. The following is a comparison of the new data and the observation data for the duration of traffic lights.

TABLE V
COMPARISON OF DATA TRAFFIC LIGHTS IN DEMAK-DUPAK'S STREET

Street Name	Preliminary Data		New Data	
	Red	**Green**	**Red**	**Green**
North Demak	120	30	112.5	37.5
Dupak	90	22	84	28
South Demak	145	35	135	45
Surabaya-Gresik	90	22	84	28
Total	**445**	**109**	**415.5**	**138.5**

The total duration of the green light flash in the initial data is 109 seconds, while after node coloring the total duration of the green light is 138.5 seconds. The level of effectiveness of the green light is:

$$hijau = \frac{138.5 - 109}{135.5} \times 100\% = 21.77\%$$

The total duration of the red light on the initial data is 445 seconds, while after node coloring the total duration of the red light is 415.5 seconds. The level of effectiveness of the red light is:

$$merah = \frac{445 - 415.5}{445} \times 100\% = 6.62\%$$

So, in the problem of the intersection of Demak-Dupak's street, Surabaya, the duration of green lights on will increase by 21.77%, while the duration of red lights on will increase by 6.62%.

V. CONCLUTION

Based on the research and discussion that has been described above, the traffic light settings on Demak-Dupak's street using the welch-powel method has obtained the optimal duration, namely North Demak's street the red light is 112.5 seconds and the green light is 37.5 seconds. For Jl. 84 red light seconds and green light 28 seconds. South Demak's street red light 135 seconds and green light 45 seconds. And for axle Surabaya-Gresik's street red light for 84 seconds and green light for 28 seconds. The level of effectiveness of the green light increased by 21.77% and the effectiveness of the flame of the lamp red by 6.62% both of these values indicate the percentage increase in the duration of new traffic lights traffic from the data of the initial duration of the traffic lights obtained.

REFERENCES

[1] C. H. Meiliana and D. Maryono, "Aplikasi Pewarnaan Graf untuk Optimalisasi Pengaturan Traffic Light di Sukoharjo," *JIPTEK*, vol. VII, no. 1, pp. 25–34, 2014.

[2] Y. E. Kurnia, Mulyono, and Rochmad, "Algoritma Bee Colony dengan Metode Fuzzy Mamdani untuk Pengaturan Lampu Lalu Lintas," *UNNES J. Math.*, vol. 9, no. 2, pp. 64–73, 2020.

[3] S. R. P. W. Pramesthi, "Graf Sistem Arus Lalu Lintas Bundaran Dolog - Jalan jemur Andayani Surabaya," vol. 7, no. 1, pp. 119–128, 2020.

[4] K. M. D. Pertiwi and R. Anggoro, "Modifikasi Metode Pemilihan Forwarding Node Berdasarkan Faktor Arah dan Kecepatan Kendaraan pada Protokol Routing GPSR dalam Lingkungan Vanets," *JUTI J. Ilm. Teknol. Inf.*, vol. 18, no. 1, pp. 39–47, 2020, doi: http://dx.doi.org/10.12962/j24068535.v18i1.a976.

[5] V. A. Nawagusti, A. Nurdin, and Aryanti, "Penentuan Rute Terpendek pada Optimalisasi Jalur Pendistribusian Barang di PT.X dengan Menerapkan Algoritma Floyd-Warshall," *Semin. Nas. Inov. dan Apl. Teknol. di Ind.*, pp. 57–64, 2018.

[6] R. Annisa and Anna, "Pemanfaatan Graf Dalam Pengaturan Warna Lampu Lalu Lintas Menggunakan Algoritma Welch Powell," *TEKNIKA*, vol. 13, no. 1, pp. 18–23, 2019.

[7] Niarma, B. Pramono, and L. Tajidun, "Aplikasi Penjadwalan menggunakan Algoritma Welch Powell (Studi Kasus: SMA Muhammadiyah Kendari)," *semanTIK*, vol. 4, no. 1, pp. 1–6, 2018.

[8] S. Andayani and E. W. Perwitasari, "Penentuan Rute Terpendek Pengambilan Sampah di Kota Merauke Menggunakan Algoritma Dijkstra," vol. 2014, no. November, pp. 164–170, 2014.

[9] F. Merpaung, "Optimalisasi Pengaturan Traffic Light di Persimpangan Kota Medan," *J. Kel. Sehat Sejah.*, vol. 17, no. 1, 2019.

[10] Y. V. Ermanto and Y. F. Riti, "Comparison of Welch-Powell and Recursive Largest First Algorithm Implementation in Course Scheduling," *J. Manag. Sci.*, vol. 5, no. 1, pp. 5–12, 2022.

[11] A. Mardiatus, N. Saif, and M. Mussafi, "Pewarnaan Simpul Dengan Algoritma Welch-Powell Pada Traffic Light di Yogyakarta," *J. Fourier*, vol. 2, no. 2, pp. 73–79, 2013.

[12] V. Sagala and F. M. Sari, "Optimasi Pengaturan Lalu-lintas Jalan Raya Gedangan dengan Penerapan Algoritma Pewarnaan Graf," *LIMITS J. Math. its Appl.*, vol. 15, no. 1, pp. 79–88, 2018.

[13] R. Munarto and E. Permata, "Perancangan Sistem Penjadualan Kuliah di Jurusan Teknik Elektro FT Untirta menggunakan Teknik Pewarnaan Graph Algoritma Backtracking Welch-Powell," *Semin. Nas. Inov. Teknol.*, pp. 277–282, 2017.

[14] W. D. Utami, A. N. Ds, and P. K. Intan, "Optimasi Waktu Tunggu Lampu Lalu Lintas pada Simpang Lima Krian-Sidoarjo menggunakan Algoritma Welch-Powell," *Math Vis.*, vol. 02, no. 01, pp. 1–6, 2020.

[15] E. L. Diana, W. Suryaningtyas, and E. Suprapti, "Pengaturan Lampu Lalu Lintas di Pesimpangan Jalan Ahmad Yani Giant dengan Aplikasi Pewarnaan Teori Graf," *MUST J. Math. Educ. Sci. Technol.*, vol. 1, no. 1, pp. 1–2, 2016.

[16] D. U. Mahfuza and Mulyono, "Penerapan Pewarnaan Graf menggunakan Algoritma Welch-Powell untuk Keefektifan pada Pengaturan Lampu Lalu Lintas," *Karismatika*, vol. 6, no. 2, pp. 52–65, 2020.

[17] I. Poernamasari, R. Tumilaar, and C. E. J. C. Montolalu, "Optimasi Pengaturan Lampu Lalu Lintas dengan menggunakan Metode Webster (Studi Kasus Persimpangan Jalan Babe Palar)," *d'CartesiaN J. Mat. dan Apl.*, vol. 8, no. 1, pp. 27–35, 2019.

[18] I. B. G. W. A. Dalem, "Penerapan Algoritma A* (Star) menggunakan Graph untuk Menghitung Jarak Terpendek," *J. Resist.*, vol. 1, no. 1, pp. 41–47, 2018.

[19] D. A. Setiawan, "Penerapan Graf pada Persimpangan menggunakan Algoritma Welsh-Powell untuk Optimalisasi Pengaturan Traffic Light," Universitas Negeri Semarang, 2015.

[20] A. P. Rahadi, "Penjadwalan Mata Kuliah menggunakan Pewarnaan Graf dengan Algoritma Largest First," *J. Padegogik*, vol. 2, no. 1, pp. 1–13, 2019.

[21] N. L. Azizah and M. Suryawinata, "Aplikasi Pewarnaan Graf untuk Optimalisasi Distribusi Raskin di Kabupaten Sidoarjo," *J. Ris. dan Apl. Mat.*, vol. 2, no. 1, pp. 31–40, 2018.