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Utilizing the Welch-Powell Algorithm and the IDO (Incident Degree Ordering) Algorithm in Traffic Light Settings

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ABSTRACT

The road junction needs some help with the timing of traffic lights. One method for optimizing crossroads traffic light settings is using a graph approach that applies a vertex coloring algorithm. The Welch-Powell and IDO (Incident Degree Ordering) algorithms are used to solve this problem. This case study covers two crossroads, namely: the crossroads of Prof. Dr. H.B. Jassin, Jenderal Sudirman Street, and the crossroads of Prof. Dr. H.B. Jassin, Palma, Sarini Abdullah Street. The result showed that the Welch-Powell and IDO algorithms used for vertex coloring produced XG=3 chromatic numbers for Prof. Dr. H.B Jassin, Jenderal Sudirman Street, and XG=4 for Prof. Dr. H.B Jassin, Palma, and Sarini Abdullah Street. New data shows that green-light efficiency increases by 23.85% and red-light efficiency decreases by 19.26% for crossroads of three, and new data at crossroads of four shows that data in the field is more effective than new data.

Keywords: Welch-Powell, IDO (Incident Degree Ordering), Traffic Light.

INTRODUCTION

Traffic issues are a common occurrence in daily life. An imbalance results when the number of cars increases with sufficient transportation infrastructure. This will ultimately lead to irregular traffic and congestion or accumulation of vehicles (Nugroho, 2008).

At road intersections, you can find lots of traffic lights. An intersection is a part of a road where flows from different directions will meet. Many traffic light problems are encountered at this intersection regarding monitoring vehicle flow and setting traffic light cycle times. The impact of this problem can be seen from the increase in the number and queue of vehicles at road intersections. So, a graph approach is needed to optimize traffic light settings so that vehicle queues are not at road intersections.

Generally, a graph G is a set of pairs $(V; E)$, where V is not an empty, finite object known as a vertex. The number of elements in V is called the order and is denoted by $p(g)$, while E is a set of pairs of different, unordered vertices in G, called edges. The number of elements in E is called the size, denoted by $q(g)$, (Sutarno, 2013).

Vertex coloring can be applied in various ways; one is solving traffic system problems, where nodes can involve incidents and conflict situations

Graph coloring is part of graph theory. Graph coloring is the process of adding color to a graph, which means that the object represented in it is given a specific color. The objects colored are nodes, areas, and regions. Objects will be colored if two related objects differ, (Jusuf, 2009).

The coloring of a divided graph consists of three parts, namely vertex coloring, edge coloring, and region coloring, (Gross et al, 2013). Regional coloring is also known as map coloring, (Chartrand et all 2015). Coloring graph vertices can solve problems in sets of objects so that conflicts between events do not occur. Vertices that are directly connected will have different colors because the coloring of the vertices refers to the chromatic number, namely the number of colors used to color the vertices of a graph (Purwanto, 2006).

Vertex coloring can be applied in various ways; one is solving traffic system problems, where nodes can involve incidents and conflict situations, (Sunarni, 2017). This solution produces flows that can run simultaneously and not simultaneously and provides new cycle duration options.

The Welch-Powell algorithm has been used by Setiawan et al., (2016) to optimize traffic at Intersection 3 of Jerakah and Intersection 4 of Tlogorejo. The IDO (*Incident Degree Ordering)* algorithm has been researched by Gede et al, (2019) to be used to arrange traffic lights at the intersection 5 of Ampenan Old Town by comparing the LDO, SDO, and IDO node or vertex coloring algorithms using graphs.

The difference between the author's research and previous research is that it applies two algorithms, namely the Welch-Powell algorithm and the IDO (Incident Degree Ordering) algorithm, with a case study at the intersection 3 of Prof. Dr. H.B Jassin and Jenderal Sudirman street and the intersection 4 Prof. Dr. H.B Jassin, Palma, Sarini Abdullah street. The new duration data research results will be compared with data in the field, and it is hoped that it can solve light traffic problems.

MATERIALS AND METHODS

The method used in this research is a literature study where research is carried out by searching journals and references that are relevant to the research to be carried out. The next method is the observation method, namely collecting data directly in the field. Observations were carried out for 4 days in February 2022 in the morning and evening. The data collected comes from the duration of each red and green light at each foot of the intersection. The Welch-Powell and IDO algorithms were used to process the data. The research process carried out is as follows:

1. Study literature by reviewing books or journals to obtain information, data, and problem objects.
2. Collect data in the field by recording and collecting data according to the object being studied, such as recording the duration of traffic light at the observed intersection.
3. Transforming intersection 3 of Prof. Dr. H.B. Jassin, Jenderal Sudirman Street, and intersection 4 of Prof. Dr. H.B. Jassin, Palma, Sarini Abdullah Street and their flow into the graph. In this case, the Nodes represent all paths that can be passed at the intersection, while the Edges represent flows that cannot be passed simultaneously.
4. Apply the IDO (Incident Degree Ordering) vertex coloring algorithm and the Welch-Powell Algorithm to the graph that has been created.
5. Divide one cycle (total traffic light duration) by the number of colors created previously to find an alternative solution for the traffic light duration.
6. Calculate the level of effectiveness of new data and compare it with primary data.
7. Conclude from the research results. Figure 1 illustrates the research flow.

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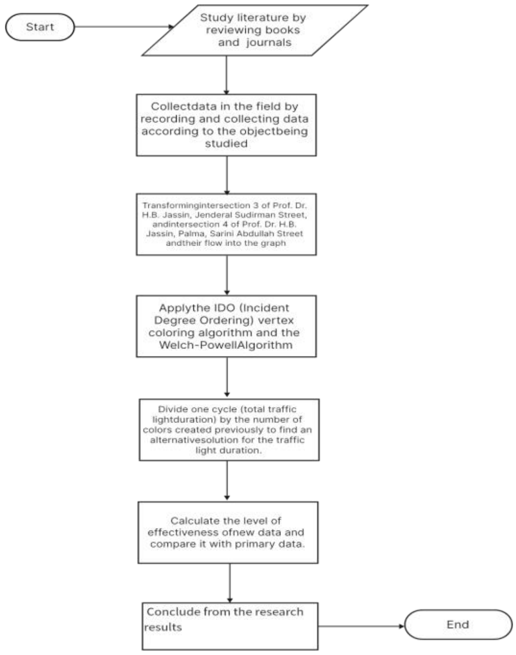

Figure 1. Research flow diagram

RESULT AND DISCUSSION

The traffic flow at the intersection used as the research location will be described first by making initial observations to determine the number of trajectories that can be passed and which cannot. The intersection used as a research location is located in Gorontalo City. Intersection 3 is near RSU Bunda, Prof. Dr. H.B. Jassin, Jenderal Sudirman Street, and intersection 4 of Prof. Dr. H.B. Jassin, Palma, Sarini Abdullah Street. The following image shows the geometric shape of the three intersections:

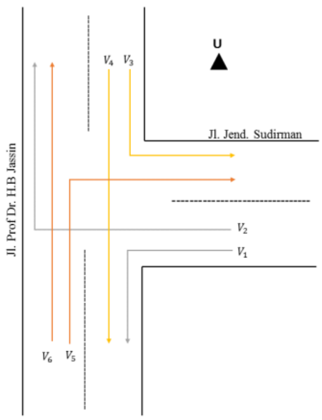

Figure 2. Illustration of the flow of an intersection 3 of Prof. Dr. H.B Jassin, Jenderal Sudirman Street.

v_1= From Jenderal Sudrman Street towards Prof. Dr. H.B Jassin Street
v_2= From Jenderal Sudirman Street towards Prof. Dr. H.B Jassin Street
v_3= From Prof. Dr. H.B Jassin Street towards Jenderal Sudrman Street
v_4= Straight towards Prof. Dr. H.B Jassin Street
v_5= From Prof. Dr. H.B Jassin Street towards Jenderal Sudrman Street
v_6= Straight towards Prof. Dr. H.B Jassin Street

Based on the illustration above, the currents that can be passed simultaneously are:
a. Current v_1 can run at the same time as v_2, v_3, v_4, v_5 dan v_6
b. Arus v_2 can run at the same time as $v_1$dan v_3
c. Current v_3 can run at the same time as v_1, v_2, v_4, v_5 dan v_6
d. Current v_4 can run at the same time as v_1, v_3, v_6
e. Currently, v_5 can run at the same time as v_1, v_3, v_6
f. Current v_6 can run at the same time as $v_1 v_3, v_4$ dan v_5

Then, the currents that are incompatible (cannot be passed simultaneously) are :
a. Current $v_2$can not run at the same time as v_4, v_5, v_6
b. Current v_4 can not run at the same time as v_2, v_5
c. Current $v_5$can not run at the same time as v_2, v_4
d. Current $v_6$can not run at the same time as v_2

The current v_1 and v_3 are foreign vertex that are not connected to the other nodes. So, vertex v_1 and v_3 can be traversed together with other currents.

Data on the duration of intersection 3 of Prof. Dr. H.B Jassin, Jenderal Sudirman Street in the morning and evening has the same duration. Data obtained from BPTD (Balai Pengelola

Transportasi Darat) Region XXI Gorontalo Province is as follows:

Table 1. Data on the duration of the intersection 3 of Prof. Dr. H.B Jassin, and Jenderal Sudirman Street.

Street Name	Red (seconds)	Green (seconds)
Prof. Dr. H.B Jassin Street (from the direction of RSU Bunda)	52	68
Jenderal Sudirman Street	68	52
Prof. Dr. H.B Jassin Street (Directions to RSU Bunda)	52	68

The steps to complete the traffic light arrangements at intersection 3 of Prof. Dr. H.B Jassin Street, and Jenderal Sudirman Street are as follows :

1) Transform the intersection 3 into a graph as follows :

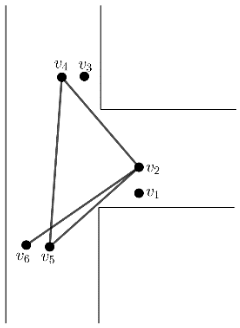

Figure 3. Transformation of Intersection 3 into a graph

Based on the graph transformation above, it can be seen that there are 6 vertex that represent the number of flows and 4 edges that represent flows that cannot be passed simultaneously. Vertex v_1 and v_3 are remote nodes, namely vertex that are disconnected. So flows v_1 and v_3 can run together with other flows or turn left and continue. For other vertex, such as vertex v_2, it is connected to vertex v_4, v_5 and v_6. Vertex v_4 is connected to nodes v_2 and v_5. Vertex v_5 is connected to vertex v_2 and v_4. As well as vertex v_6 which is connected to vertex v_2.

2) Color the graph vertex to find the chromatic number, namely the number of colors used to color the vertex in the graph. By using the Welch-Powell Algorithm, the graph coloring is produced as follows :

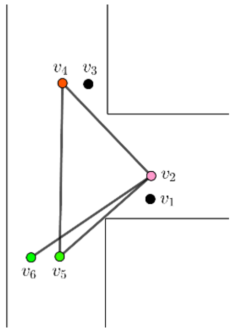

Figure 4. Intersection 3 with Coloring using the Welch-Powell Algorithm

Based on the coloring of the vertex shown in Figure 4, it can be concluded that the Welch-Powell algorithm produces a chromatic number equal to 3 or can be written $X(G) = 3$. Vertex v_1 and v_3 are not colored because vertex v_1 and v_3 are foreign or unrelated vertex with other vertex. Vertex v_5 and v_6 are given the same color because vertex v_5 and v_6 are not neighbors.

By using the IDO *(Incident Degree Ordering)* coloring algorithm, the resulting graph coloring is as follows :

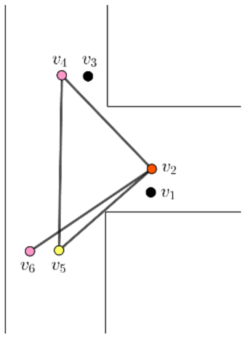

Figure 5. Intersection 3 with coloring using the IDO algorithm

Based on the coloring of the vertex shown in the graph above, it can be concluded that the IDO *(Incidental Degree Ordering)* algorithm produces a chromatic number equal to 3 or can be written as $X(G) = 3$. Vertex v_1 and v_3 are not colored because vertex v_1 and v_3 are foreign or unrelated to another vertex. Vertex v_4 and v_6 are given the same color because vertex v_4 and v_6 are not neighbors.

3) Determine alternative solutions for the duration of traffic lights.

Based on secondary data, the total duration of one cycle is 109 seconds. Referring to research (Meiliana, C. H., Maryono, 2017). The next step is to divide the time of one cycle by the chromatic number that has been obtained, namely lights up for 36.33 seconds, then the duration of the red light is 72.67 seconds.

In Figure 3, current v_6 can run simultaneously with currents v_4 and v_5, while current v_6 cannot run simultaneously with current v_2. So with current v_6 (direction towards RSU Bunda) and current v_4 (from the direction of the RSU Bunda), the duration of the green light will increase to 72.67 seconds and the duration of the red light will decrease to 36.33 seconds. Meanwhile, on current v_2 (Jenderal Sudirman Street) the duration of the red light is 72.67 and the duration of the green light is 36.33 seconds. Furthermore, new data on the duration of green and red lights at intersection 3 of Prof. Dr. H.B Jassin, Jenderal Sudirman Street, can be seen in Table 2.

Table 2. New data on the duration of the intersection 3 of Prof. Dr. H.B Jassin, Jenderal Sudirman Street

Street Name	Red (seconds)	Green (seconds)	Total (seconds)
Prof. Dr. H.B Jassin Street (from the direction of RSU Bunda)	36.33	72.67	109
Jenderal Sudirman Street	72.67	36.33	109
Prof. Dr. H.B Jassin Street (Directions to RSU Bunda)	36.33	72.67	109
Total	145.33	181.67	

Based on secondary data and new data obtained, there is a difference in the total time the green and red lights are on. The total green light time from secondary data is 147 seconds, while the new data's total green light time is 181.67 seconds. The level of effectiveness is:

$$effectiveness = \frac{181.67 - 147}{147} X\ 100$$

$$= 23.58\%$$

The total duration of the red light from secondary data is 180 seconds, while the total duration is 145.33 seconds from the new data. The level of effectiveness is:

$$effectiveness = \frac{145.33 - 180}{145.33} X\ 100\%$$

$$= -19.26\%$$

In this case, the total time the red light is on is negative, meaning the duration of the red light is reduced by 19.26%, and the total time the green light is on is positive, meaning the duration of the green light is increased by 23.58%. Based on the calculations above, the level of effectiveness using the Welch-Powell Algorithm node coloring and IDO (Incident Degree Ordering) is more effective than data in the field. This new data will be more effective because it increases the duration of the green light at the two legs of the intersection, namely currents v_6 and v_4.

The intersection 4 of Prof. Dr. H.B Jassin, Palma, and Sarini Abdullah Street

The geometric depiction of the intersection can be seen in Figure 6.

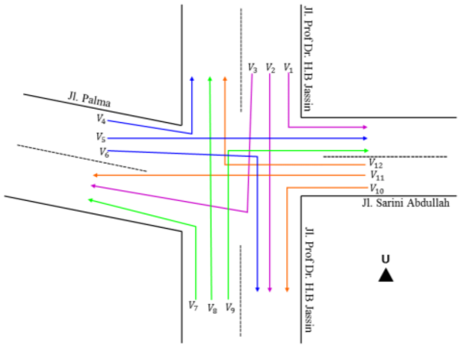

Figure 6. Illustration of the current of intersection 3 of Prof. Dr. H.B Jassin, Palma, and Sarini Abdullah Street

v_1= From Prof. Dr. H.B Jassin Street towards Sarini Abdullah Street
v_2= Straight towards Prof. Dr. H.B Jassin street
v_3= From Prof. Dr. H.B Jassin Street towards Palma Street
v_4= From Palma Street towards Prof. Dr. H.B Jassin street
v_5= From Palma Street towards Sarini Abdullah Street
v_6= From Palma Street towards Prof. Dr. H.B Jassin Street
v_7= From Prof. Dr. H.B Jassin Street towards Palma Street
v_8= Straight towards Prof. Dr. H.B Jassin street
v_9= From Prof. Dr. H.B Jassin Street towards Sarini Abdullah Street
v_{10}= From Sarini Abdullah street towards Prof. Dr. H.B Jassin Street
v_{11}= From Sarini Abdullah Street towards Palma Street
v_{12}= From Sarini Abdullah Street towards Prof. Dr. H.B Jassin Street

Based on the illustration above, the currents that can be passed simultaneously are :

a. Current $v_1$can run at the same time as $v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}, v_{11}, v_{12}$
b. Current v_2 can run at the same time as $v_1, v_3, v_4, v_7, v_8, v_{10}$
c. Current v_3 can run at the same time as $v_1, v_2, v_4, v_7, v_{10}$
d. Current v_4 can run at the same time as $v_1, v_2, v_3, v_5, v_6, v_7, v_8, v_9, v_{10}, v_{11}, v_{12}$
e. Current v_5 can run at the same time as $v_1, v_4, v_6, v_7, v_{10}, v_{11}$
f. Current v_6 can run at the same time as $v_1, v_4, v_5, v_7, v_{10}$
g. Current v_7 can run at the same time as $v_1, v_2, v_3, v_4, v_5, v_6, v_8, v_9, v_{10}, v_{11}, v_{12}$
h. Current v_8 can run at the same time as $v_1, v_2, v_4, v_7, v_9, v_{10}$
i. Current v_9 can run at the same time as $v_1, v_4, v_7, v_8, v_{10}$
j. Current v_{10} can run at the same time as $v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{11}, v_{12}$
k. Current v_{11} can run at the same time as $v_1, v_4, v_5, v_7, v_{10}, v_{12}$
l. Current v_{12} can run at the same time as $v_1, v_4, v_7, v_{10}, v_{11}$

Then, the currents that cannot be passed together are :

a. Current v_2 can not run at the same time as $v_5, v_6, v_9, v_{11}, v_{12}$
b. Current v_3 can not run at the same time as $v_g, v_6, v_8, v_9, v_{11}, v_{12}$
c. Current v_5 can not run at the same time as $v_2, v_3, v_8, v_9, v_{12}$
d. Current v_6 can not run at the same time as $v_2, v_3, v_8, v_9, v_{11}, v_{12}$
e. Current v_8 can not run at the same time as $v_3, v_5, v_6, v_{11}, v_{12}$
f. Current v_9 can not run at the same time as $v_2, v_3, v_5, v_6, v_{11}, v_{12}$
g. Current v_{11} can not run at the same time as v_2, v_3, v_6, v_8, v_9
h. Current v_{12} can not run at the same time as $v_2, v_3, v_5, v_6, v_8, v_9$

The Current v_1, v_4, v_7, and v_{10} are foreign vertex that are not connected to the other vertex. So the vertex s v_1, v_4, v_7, and v_{10} can pass simultaneously with other currents.

Data on the duration of intersection 4 of Prof. Dr. H.B Jassin, Palma, Sarini Abdullah Street in the morning and evening has the same duration. Data obtained from BPTD Region XXI Gorontalo is as follows:

Table 3. Data on the duration of the intersection 4 of Prof. Dr. H.B Jassin, Palma, Sarini Abdullah street

Street Name	Red (seconds)	Green (seconds)
Prof. Dr. H.B Jassin Street (from the direction of RSU Bunda)	41	33
Palma Street	41	33
Prof. Dr. H.B Jassin Street (Directions to RSU Bunda)	41	33
Sarini Abdullah Street	41	33

Steps for completing traffic arrangements at the intersection of four roads, Prof. Dr. H.B Jassiin, Palma, Sarini Abdullah streets as follows:

1) Transform the intersection 4 into a graph as follows :

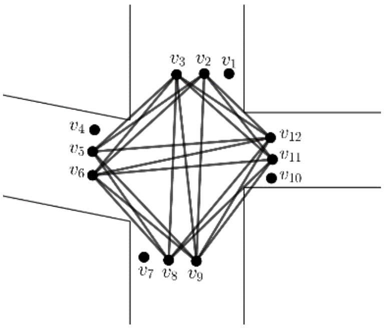

Figure 7. Transformation of Intersection 4 into a graph

Based on the graph transformation, it can be seen that there are 12 vertex that represent the number of current and 22 edges that represent current that cannot run together. Vertex v_1, v_4, v_7, and v_{10} are remote vertex, namely vertex that are not connected to each other. So, currents v_1, v_4, v_7, and v_{10} can be passed together with other currents.

2) Color the graph vertex to find the chromatic number, which is the number of colors used to color the vertex. Graph coloring using the Welch-Powell Algorithm is as follows: :

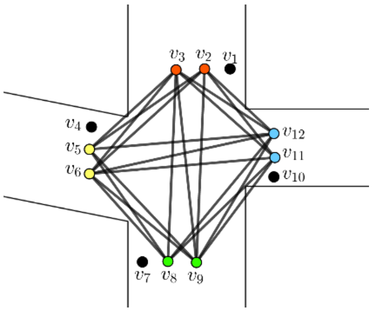

Figure 8. Intersection 4 with coloring using the Welch-Powell algorithm

Based on the image's coloring above, coloring the graph vertex using the Welch-Powell Algorithm produces a chromatic number equal to 4 or can be written as $X(G) = 4$. Vertex v_1, v_4, v_7, and v_{10} are not colored because nodes v_1, v_4, v_7, and v_{10} are foreign or unrelated to another vertex. Vertex v_2 and v_3 are colored red, nodes v_5 and v_6 are colored yellow, vertex v_8 and v_9 are colored green, and vertex v_{11} and v_{12} are colored blue. Vertex, given the same color, are close together but not neighbors.

By using the IDO *(Incident Degree Ordering)* coloring algorithm, the resulting graph coloring is as follows :

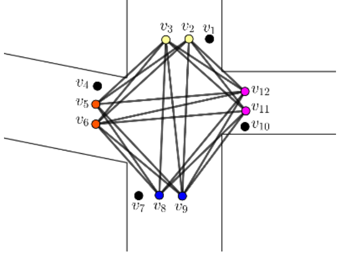

Figure 9. Intersection 4 with coloring using the IDO algorithm

3) Determine alternative solutions for traffic light duration.

Based on the image's coloring above, coloring the graph vertex using the Welch-Powell Algorithm produces a chromatic number equal to 4 or can be written as $X(G) = 4$So, in this case, the duration of the green light is 18.5 seconds, and the duration of the red light is 55.5 seconds. Because, in this case, the purpose of creating new data is to increase the time the green light is on and reduce the time the red light is on. If the duration of the green light on is made to 18.5 seconds for all intersection legs, then the total duration of the green light on will decrease, and the total duration of the red light on will increase.

Table 4. New data on the duration of intersection 4 of Prof. Dr. H.B Jassin, Palma, and Sarini Abdullah street

Street Name	Red (seconds)	Green (seconds)	Total (seconds)
Prof. Dr. H.B Jassin **Street** (from the direction of RSU Bunda)	55.5	18.5	74
Palma **street**	55.5	18.5	74
Prof. Dr. H.B Jassin **Street** (Directions to RSU Bunda)	55.5	18.5	74
Sarini Abdullah street	55.5	18.5	74
Total	222	74	

Based on secondary data and new data obtained, there are differences in the total duration of traffic lights. Secondary data shows that the total green light time is 132 seconds, while new data shows the total green light time is 74 seconds. The level of effectiveness is as follows:

$$effectiveness = \frac{74 - 132}{132} X\ 100\%$$

$$= -43.93\%$$

Secondary data shows that the total duration of the red light is 164 seconds, while new data shows the total time the red light is on is 222 seconds. The level of effectiveness is:

$$effectiveness = \frac{222 - 164}{164} X\ 100\%$$

$$= 35.36\%$$

In this case, the time the red light is on is positive, meaning the duration of the red light is increased by 35.36%, and the duration of the green light is negative, meaning the duration of the green light is reduced by 43.93%. Based on the calculations above, the level of effectiveness using the Welch-Powell and IDO algorithm vertex coloring is less effective than data in the field. The factor influencing this is that every leg of intersection 4 of Prof. Dr. H.B. Jassin, Palma, and Sarini Abdullah Street has the same green and red light duration.

CONCLUSION

1) Graph vertex coloring using the Welch-Powell and IDO algorithms at intersection 4 of Prof. Dr. H.B Jassin, Palma, Sarini Abdullah Street produced the chromatic number $X(G) = 4$, while at intersection 3 of Prof. Dr. H.B Jassin, Jenderal Sudirman Street produced the chromatic number $X(G) = 3$.
2) The effectiveness of new data from vertex coloring using the Welch-Powell and IDO algorithms is more effective at intersections 3 of Prof. Dr. H.B. Jassin, Jenderal Sudirman Street. The results show that the red light duration decreased by 19.26%, and the

green light duration increased by 23.58%.

3) The effectiveness of new data from vertex coloring using the Welch-Powell and IDO algorithms is less effective at intersections 4 of Prof. Dr. H.B. Jassin, Palma, Sarini Abdullah Street. The results show that the red light duration increased by 35.36%, and the green light duration decreased by 43.93%.

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