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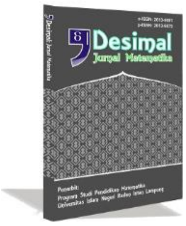

Application of graph theory and webster method in traffic light settings at the tulip intersection in kefamenanu city

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ABSTRACT

The traffic light settings at several road intersections in Timor Tengah Utara Regency have not been regulated, taking into account the width of the road and the volume of vehicles. One of the intersections in question is the Eltari–Sonbay–L. Lake intersection road (Tulip intersection). At this intersection, traffic jams often occur because traffic light settings are not optimal, so it is necessary to have traffic regulations that pay attention to road width and vehicle volume. This research aims to find out how to regulate the duration of traffic lights using graph theory and the Webster method. This research is applied research. The data used is primary data, which includes road geometry and traffic volume data. The results of calculations using a compatible graph and the Webster method obtained two-time phases. Phase 1 for the Eltari road section (north and south) has a green light duration of 22 seconds, yellow 3 seconds, and red 27 seconds. Meanwhile, Phase 2 for Sonbay Road and L. Lake Road has a green, yellow, and red-light duration of 23 seconds, 3 seconds, and 26 seconds, respectively. These results look more optimal compared to the current ones, which only consist of one-time phase.

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INTRODUCTION

The increasing mobility of society has resulted in the increasing use of vehicles as a means of transportation. Suppose the increase in the number of vehicles is not accompanied by adequate transportation infrastructure. In that case, there will be a demand-supply imbalance, which will ultimately hinder travel in the form of congestion. Traffic jams in a city are nothing new and can occur on roads and intersections. Congestion is caused by colliding movements in each direction of the intersection. To reduce these collisions, many controls are carried out by optimizing intersections with traffic lights (Nurhidayat, Indra Septiana, Nursyah Putra, Syaripudin, & Irawan Saputra, 2018).

The Tulip intersection on Eltari Road, Kefamenanu City, is one of four intersections equipped with traffic lights in Kefamenanu City. This intersection is one of the ones that many vehicles pass through because it is one of the access roads for going to schools, campuses, markets, places of worship, or work and is also an access route between districts and countries. Tulip Junction has a red duration of 75 seconds, a yellow duration of 3 seconds, and a green duration of 15 seconds. As a city located on the border of Indonesia and Timor Leste, Kefamenanu City continues to experience development in various aspects, including in terms of urban planning, economy, and transportation. Existing traffic light arrangements do not take into account the condition of road width, type, and volume of vehicles. Of course, this traffic light arrangement is no longer appropriate with the increase in the number and type of vehicles in Kefamenanu City. For this reason, it is necessary to regulate traffic lights that also take into account the condition of road width, type, and volume of vehicles.

Many methods have been applied to optimize traffic light flashing times, including the Naive Bayes Classifier method (Kasogi, Setiawan, & Syauqy, 2020), fuzzy logic (Maslim, Dwiandiyanta, & Viany Susilo, 2018; Prasetya, 2020), Goal Programming (Praditya & Anggraeni, 2016), fuzzy graphs and max-plus algebra (Kurniawan, Abadi, & Musthofa, 2017), Monte Carlo Simulation (Budianto, Amrullah, Wahidaturrahmi, & Arjudin, 2022), Simple Additive Weight (Suhartono, 2022), the concept of compatible graphs (Basriati & Wahyuni, 2016; Nisa & Muzdalifah, 2021; Sarbaini, 2022, 2023) and the Webster method (Chairani, Jaya, & Cipta, 2021). The concept of compatible graphs is the method most often used in determining traffic light waiting times. Several researchers combine the concept of compatible graphs with the concepts of vertex coloring and graph edge coloring with the Welch-Powell algorithm (Abdullah & Rahadjeng, 2022; Fakhri, Harahap, & Badruzzaman, 2021; Sari, Cipta, & Munthe, 2022; Syechah, Hairunnisa, Fadila, & Anggraeni, 2023; Utami, DS, & Intan, 2020), and there are several researchers who combine it with the Webster method (Fangelis & Ahmad, 2021; Sendow, Sulistyaningsih, & F. Monoarfa, 2023) and Anova analysis (Lusiani, Sartika, Binarto, & Habinuddin, 2020). The forms of intersections studied also varied; for example, Farida, Fanani, Purwanti, Wulandari, & Zaen (2020) calculated the optimal waiting time for traffic lights with an intersection in the form of a T-junction, and Fanani (2016) calculated the optimal waiting time for traffic with an intersection that was a combination of intersections and T-junctions, while Fikri & Triana (2016) optimized traffic signal light cycle times at two coordinated intersections. Research to optimize the length of waiting time for lights continues to develop. Several other researchers, such as Hardianti, Rochmad, & Arifudin (2013), digitized the data processing process using graph theory into a traffic light simulation application, and Nirwanda, Yenni, Anam, & Lathifah (2023) created a prototype smart time scheduler for traffic lights. Traffic using the Haar Cascade algorithm; Deshpande & Hsieh (2023) designed a cyber-physical system for smart traffic light control; and Alkhatib, Maria, AlZu'bi, & Maria (2022) designed smart traffic scheduling for crowded road networks.

This research will combine the concept of compatible graphs and the Webster method in determining the total time on which traffic lights are on at the Tulip intersection in Kefamenanu City. It is hoped that this research can provide good input for related agencies in optimizing the function of traffic lights in border areas.

METHOD

This research is applied research, with the data used being primary data in the form of road geometry data, including road names and widths, as well as traffic volume data. Data collection focused on the Tulip intersection in Kefamenanu City, East Nusa Tenggara Province, and was carried out by direct measurement and observation. Traffic volume data is recorded for one hour (peak hour), and then, in processing, it is converted to hours. Data collection was carried out for one week from May 22 to May 27, 2023, with data collection carried out three times each day at different periods, namely in the morning at 06:30–07:30 Central Indonesian Time (CIT), in the afternoon at 12:00–13:00 CIT, and in the afternoon at 16:00–17:00 CIT. The composition of traffic movements passing through the four arms of the intersection is as follows:

1. A light vehicle (LV) is a four-wheeled light vehicle that includes passenger vehicles, microbuses, and pick-ups.
2. A heavy vehicle (HV) is a heavy vehicle with more than four wheels.
3. A motorcycle (MC) is a two-wheeled motorized vehicle such as a motorbike.

The data processing stages are illustrated in Figure 1.

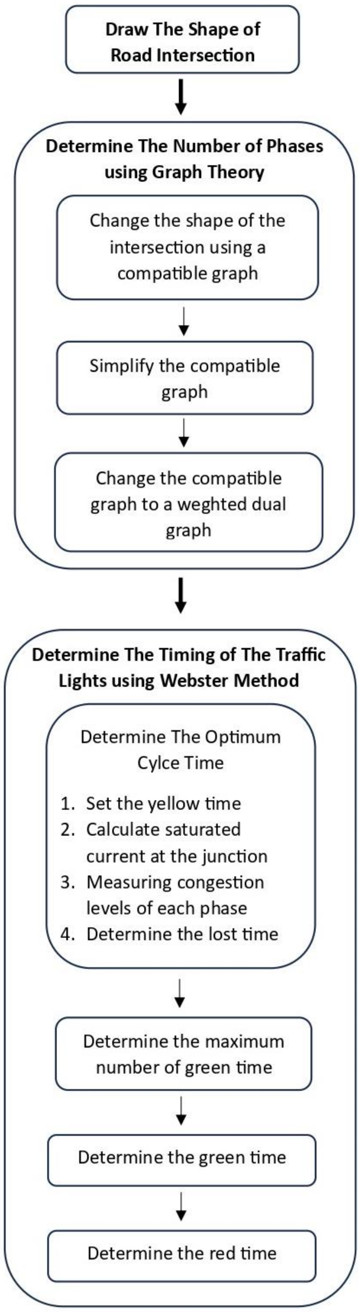

Figure 1. The Tulip Intersection

1. Draw the shape of a road intersection.
2. Change the shape of the intersection using a compatible graph with the following steps:
   a. Create nodes, with nodes representing flows.
   b. Determines the edge to connect two vertices that cross each other or are opposite each other. Sides show compatible pairs of objects.
3. Simplify the compatible graph.

4. Change the compatible graph to a weighted dual graph with the following conditions:
   The width of the road
   a. For roads under 4 meters, a value of 4 is given.
   b. Between 4 and 5 meters is given a value of 3.
   c. More than 5 to 6 meters are given a value of 2.
   d. More than 6 meters is given a value of 1.

   Vehicle volume
   a. Above 2000 vehicles/hour, value 5.
   b. 1500–2000 vehicles/hour, value 4.
   c. 999–1499 vehicles/hour, value 3.
   d. 500–998 vehicles/hour, value 2.
   e. 0–449 vehicles/hour, value 1.
5. Determine the flashing time for traffic lights using the Webster method.
   This method was developed by F. V. Webster in 1832. The steps for the process are:
   a. Determine saturation current
      The intersection saturation flow is determined based on the road width. The settings are presented in Table 1.

Table 1. Saturated Flow at Juntions

Road Width (m)	Saturated current (pcu/hour)
3.0	1850
3.5	1875
4	1975
4.5	2175
5	2550
5.5	2900

where pcu = passenger car units

Passenger car units (pcu) are vehicle units in the traffic flow that are equalized according to light vehicles or passenger cars. pcu is adjusted by the type of vehicle, vehicle dimensions, and vehicle movement patterns. Vehicle classification is very necessary to convert all vehicle volumes into passenger car units (pcu) per hour by using passenger vehicle equivalents (pve) for each approach by multiplying the total number of each type of vehicle by the conversion factor in Table 2.

Table 2. Signalized Passenger Car Unit Conversion

Transportation type	pve	
	Protected Approach	Opposed Approach
LV	1.0	1.0
HV	1.3	1.3
MC	0.2	0.4

where a protected approach is a departing flow without conflict with traffic from the opposite direction and a countered approach is a departing flow with conflict with traffic from the opposite direction.

If the width (w) exceeds the value specified in Table 2, then saturation current = w x 525 (pcu/hour).

Especially for good intersections (clear view, etc.), this number should be increased by 20%, and for bad intersections (clim, less clear view, etc.), these numbers should be reduced by 15%.

The ratio of normal current to saturation current (y) is

$$y = \frac{Q}{S} \tag{1}$$

where,
S = saturation current (pcu/h)
Q = real current (pcu/h)

The size of the congestion is expressed as the Phase Ratio (PR),

$$\text{PR} = \sum y_{max}.$$

   b. Determine the optimum cycle time.
      Phase is a change in the flashing time of red, yellow, and green lights. The factor needed to calculate the optimum cycle time setting is lost time (Lt), namely the length of time for one full cycle when there are no vehicles. This is done not only during all red times

and red/red/yellow times but also as starting-up and tailing-off times, which occur when the light color changes. The waiting time is calculated using the formula:

$$Lt = 2n + R \quad (2)$$

where,

n = number of phases
R = all red time and red/red/yellow time (2+3 = 5 seconds).
Lt can also be defined as the number of green periods minus one second for each green.
The road research laboratory in the UK provides several equations, as follows:

i. Optimum cycle time (C_0).

$$C_0 = \frac{1{,}5 \times Lt + 5}{1 - FR} \quad (3)$$

ii. Allowable waiting time for y in each direction:
The green time period for each phase is calculated using the formula:

$$\frac{FR_i}{FR_j} = \frac{q_{i+1}}{q_{j+1}} \quad (4)$$

where $i, j = 1,2,3,4,\ i \neq j$
and $g_i = \frac{y_i(C_0 - Lt)}{FR} - 1$ seconds

iii. Delay

$$d = FC_{cs} \frac{S(C_0 - g)^2}{2C_0(S - q)} \times \frac{1800 \times q \times C_0^2}{q \times S(q.S - q.C_0)} \quad (5)$$

where
d = delay (seconds/pcu)
C_0 = cycle time (seconds)
g = green light period (seconds)
q = vehicle flow (vehicle/h)
S = saturation current (vehicle/h)
FC_{CS} = capacity adjustment factor for city size.

RESULTS AND DISCUSSION

Based on the research stages, firstly, road geometry data, traffic light cycle length data, and traffic volume data are presented.

1. Intersection Geometry Data

The intersection used as the research location is called the Tulip intersection, Kefamenanu City, Timor Tengah Utara Regency. The intersection has four roads, namely Eltari Road (North), L. Lake Road (West), Eltari Road (South), and Sonbay Road (East). Data is taken at each road intersection by recording all types of vehicles with protected approach types. In this research, the direction of traffic flow will be conditioned more appropriately in the new design. This new design will change the traffic light arrangement at the Tulip intersection, which previously consisted of one phase, to two phases. An overview of the geometry of the four-way intersection can be seen in Figure 2.

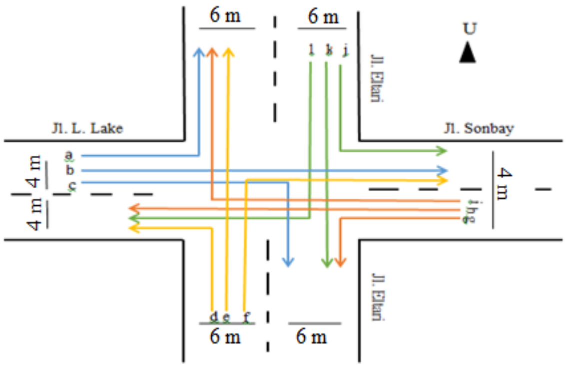

Figure 2. The Tulip Intersection

Figure 2 has the following information:

a. The northern part is Eltari Road which has 2 lanes, with the width of the entry and exit lanes each being 6 m.
b. The southern part is Eltari Road which has 2 lanes with an entry and exit width of 6 m each.
c. The western part is L. Lake Road, which has 2 lanes with an entry and exit width of 4 m each.
d. The eastern part is Sonbay Road, which has an entry and exit lane width of 4 m.

2. Data on the length of the traffic cycle at the Tulip Intersection.

Table 3. Traffic Light Cycle Time Data

Roads	Red (seconds)	Yellow (seconds)	Green (seconds)
Eltari (Utara)	75	3	15
L. Lake	75	3	15
Eltari (Selatan)	75	3	15
Sonbay	75	3	15

Based on Table 3, it is known that data on the length of the traffic light cycle at the Tulip intersection, Eltari Road (North) – Eltary Road (South) - L. Lake - Sonbay, uses one phase where for each traffic flow the red duration is 75 seconds, yellow is 3 seconds, and green is 15 seconds. These traffic light settings do not take into account road width and vehicle volume. At the Tulip intersection, traffic jams often occur due to the high volume of vehicles.

3. Traffic volume

Based on the recording results, the peak flow was obtained, namely on Monday, May 22, 2023, which is the data for the volume and composition of traffic in this research. Data from observations of traffic volume at peak flow for each road section are presented in Tables 4, 5, 6, and 7.

Table 4. Traffic Volume on the Eltari (South) Road Section

Time	LV		HV		MC		Amount	
	pve = 1.0		pve = 1.3		pve = 0.2			
	Vehi.	pcu	Vehi.	pcu	Vehi.	pcu	Vehi./hour	pcu/hour
1	2	3	4	5	6	7	8=2+4+6	9=3+5+7
06:30 – 07:30	386	386	4	5.2	728	145.6	1118	536.8
12:00 – 13:00	452	452	8	10.4	896	179.2	1356	641.6
16:00 – 17:00	762	762	10	13	1384	276.8	2156	1015.8

Based on Table 4, on the Eltari (South) road section, the peak traffic volume occurs in the afternoon at 16:00–17:00 CIT, with the number of light vehicles at 762 vehicles/hour, heavy vehicles at 10 vehicles/hour, and motorbikes at 1384 vehicles/hour. All types of vehicles are converted to passenger car units (pcu), so that we get 762 pcu/hour for light vehicles, 13 pcu/hour for heavy vehicles, and 276.8 pcu/hour for motorbikes, and then we get a peak flow volume of 1015.8 pcu/hour.

Table 5. Traffic Volume on the Eltari (North) Road Section

Time	LV		HV		MC		Amount	
	pve = 1.0		pve = 1.3		pve = 0.2			
	Vehi.	pcu	Vehi.	pcu	Vehi.	pcu	Vehi./hour	pcu/hour
1	2	3	4	5	6	7	8=2+4+6	9=3+5+7
06:30 – 07:30	249	249	2	2.6	694	138.8	945	390.4
12:00 – 13:00	486	486	6	7.8	873	174.6	1365	662.2
16:00 – 17:00	695	695	12	15.6	1296	259.2	2003	969.8

Based on Table 5, on the Eltari (North) road section, the peak traffic volume occurs in the afternoon at 16:00–17:00 CIT, with the number of light vehicles at 695 vehicles/hour, heavy vehicles at 12 vehicles/hour, and motorbikes at 1296 vehicles/hour. All types of vehicles are converted to passenger car units (pcu), so that we get 695 pcu/hour for light vehicles, 15.6 pcu/hour for heavy vehicles, and 259.2 pcu/hour for motorbikes, and then we get a peak flow volume of 969.8 pcu/hour.

Table 6. Traffic Volume on the L. Lake Road Section

Time	LV		HV		MC		Amount	
	pve = 1.0		pve = 1.3		pve = 0.2			
	Vehi.	pcu	Vehi.	pcu	Vehi.	pcu	Vehi./hour	pcu/hour
1	2	3	4	5	6	7	8=2+4+6	9=3+5+7
06:30 – 07:30	220	220	4	5.2	579	115.8	803	341
12:00 – 13:00	476	476	8	10.4	882	176.4	1366	662.8
16:00 – 17:00	325	325	4	5.2	680	136	1009	466.2

Based on Table 6, on the L. Lake Road section, peak traffic volume occurs during the day at 12:00–13:00 CIT, with the number of light vehicles at 476 vehicles/hour, heavy vehicles at 8 vehicles/hour, and motorbikes at 882 vehicles/hour. All types of vehicles are converted to passenger car units (pcu), so that we get 476 pcu/hour for light vehicles, 10.4 pcu/hour for heavy vehicles, and 176.4 pcu/hour for motorbikes, and then we get a peak flow volume of 662.8 pcu/hour.

Table 7. Traffic Volume on the Sonbay Road Section

Time	LV		HV		MC		Amount	
	pve = 1.0		pve = 1.3		pve = 0.2			
	Vehi.	pcu	Vehi.	pcu	Vehi.	pcu	Vehi./hour	pcu/hour
1	2	3	4	5	6	7	8=2+4+6	9=3+5+7
06:30 – 07:30	173	173	2	2.6	448	89.6	623	265.2
12:00 – 13:00	384	384	6	7.8	727	145.4	1117	537.2
16:00 – 17:00	290	290	4	5.2	524	104.8	818	400

Based on Table 7 on the Sonbay Road section, peak traffic volume occurs during the day from 12:00 to 13:00 CIT, with the number of light vehicles at 384 vehicles/hour, heavy vehicles at 6 vehicles/hour and motorbikes at 727 vehicles/hour. All types of vehicles are converted to passenger car units (pcu), so that we get 384 pcu/hour for light vehicles, 7.8 pcu/hour for heavy vehicles, and 145.4 pcu/hour for motorbikes, and then we get a peak flow volume of 537.2 pcu/hour.

Based on data collected in the field, the vehicle volume on Eltari (North) Road, Eltari (South) Road, Sonbay Road, and L. Lake Road, the most heavily traveled road section is Eltari (South) Road where the vehicle volume intensity increases quite significantly in the afternoon at 16:00–17:00 CIT, with the number of light vehicles at 762 vehicles/hour, heavy vehicles at 10 vehicles/hour and motorbikes at 1384 vehicles/hour. This can happen because the Eltari (South) route is one of the road accesses for going to schools, campuses, markets, places of worship, and activities for shopping, coming home from work, and is an access point between districts.

Next, we proceed to the data processing stage.

1. Changing the shape of the road intersection into a compatible graph.
   a. Making the Nodes

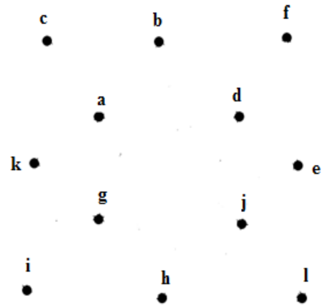

Figure 3. Nodes

b. Determine the Edges

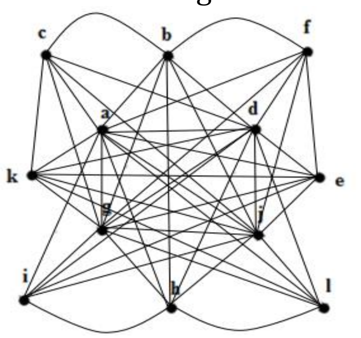

Figure 4. Tulip Intersection Graph

In Figure 3, the intersection of Eltari Road (North), L. Lake Road, Eltari Road (South), and Sonbay Road consists of 12 lanes with the respective names a, b, c, d, e, f, g, h, i, j, k, and l. Node a shows the traffic flow at a, node b shows the traffic flow at b, node c shows the traffic flow at c, and the same goes for nodes d, e, f, g, h, i, j, k, and l. For more details, it can be seen in Table 8.

Table 8. Compatible and Incompatible Currents

Traffic Flow	Compatible with	Incompatible with
a	b,c,d,e,f,g,h,i,j,k, and l	-
b	a,c,d,f,g,h, and j	e,i,k, and l
c	a,b,d,g,j, and k	e,f,h,i, and l
d	a,b,c,e,f,g,h,i,j,k, and l	-
e	a,d,f,g,i,j, and k	b,c,h, and l
f	a,b,d,e,g, and j	c,h,i,k,and l
g	a,b,c,d,e,f,h,i,j,k, and l	-
h	a,b,d,g,i,j, and l	c,e,f, and k
i	a,d,e,g,h, and j	b,c,f,k, and l
j	a,b,c,d,e,f,g,h,i,,k, and l	-
k	a,c,d,e,g,j, and l	b,f,h, and i
l	a,d,g,h,j, and k	b,c,e,f, and i

Based on Table 8, nodes a, d, g, and j are compatible with all nodes, while nodes b, c, e, f, h, i, k, and l are not compatible with several other nodes.

c. Simplifying Compatible Graphs

Because nodes a, d, g, and j are compatible with all lanes, from Figure 4, nodes a, d, g, and j are removed so that Figure 4 changes to Figure 5.

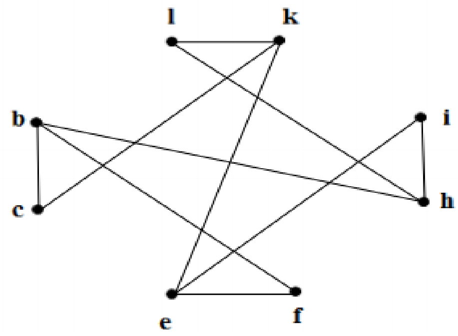

Figure 5. Compatible Graph

d. Converts a Compatible Graph to a Weighted Directed Dual Graph

i. Nodes k and l for Eltari (North) Road have a road width of 6 m and peak hour volume (in the afternoon at 16:00–17:00 CIT with a number of vehicles of 2003 vehicles/hour, so the road width is given a weight value of 2 and the vehicle volume is given a weight value of 5, then nodes k and l have a weight value of 7.

ii. Nodes e and f for the Eltari (South) road have a road width of 6 m and peak hour volume in the afternoon at 16:00–17:00 CIT with a number of vehicles of 2156 vehicles/hour, so the road width is given a weight of 2 and the vehicle volume is given a weight value of 5, then nodes e and f have a weight value of 7.

iii. Nodes b and c for L. Lake Road have a road width of 4 m and peak hour volume during the day at 12:00–13:00 CIT, where the number of vehicles is 1366 vehicles/hour, so the road width is given a weight of 3 and the vehicle volume is given a weight value of 3, then nodes e and f have a weight value of 6.

iv. Nodes h and i for Sonbay Road have a road width of 4 m and peak hour volume during the day at 12:00–13:00 CIT, where the number of vehicles is 1117 vehicles/hour, so the road width is given a weight of 3 and the vehicle volume is given a weight of 3, then nodes e and f have a weight value of 6.

Hence, the weighted double-directed graph for the intersection of four Tulip roads can be seen in Figure 6.

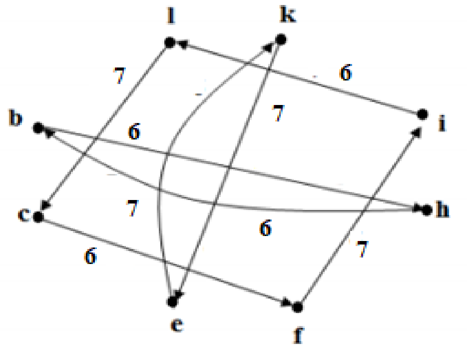

Figure 6. Weighted Double-Directed Graph

In Figure 6, nodes k and l represent the traffic flow on Eltari (North) Road, which has a weight of 14. Nodes i and h are the traffic flow on Sonbay Road, which has a weight of 12. Nodes e and f are the traffic flow on Eltari Road (South), which has a weight of 14. Nodes b and c are the traffic flow on L. Lake Road, which has a weight of 12. Because Eltari Road (North) and Eltari Road (South) have the same weight and Sonbay Road and L. Lake Road also have the same weight, the number of phases at the Tulip intersection is 2.

After getting the number of phases, the next step is to determine the optimum cycle time (C_0).

2. Determine the optimum cycle time

To obtain the optimum cycle time, first determine:

a. Yellow time (R) = 5 seconds
It is set at 5 seconds with the assumption that 2 seconds is lost time when vehicles wait in line and 3 seconds is yellow time at the traffic light.

b. Saturated current at the junction
Eltari Road (North) = 6 m × 525 = 3150 $\frac{pcu}{hour}$
Eltari Road (South) = 6 m × 525 = 3150 $\frac{pcu}{hour}$
Sonbay Road = 4 m = 1975 $\frac{pcu}{hour}$
L. Lake Road = 4 m = 1975 $\frac{pcu}{hour}$

c. Measuring Congestion Levels
To determine the level of congestion at the intersection, a calculation is carried out to determine the ratio of normal flow to saturated flow in each phase, which is determined using Equation (1). A measure of congestion is then obtained, which is expressed as the Phase Ratio. (PR = $\sum y_{max}$).

i. Phase 1

Eltari Road (North) = $\frac{970}{3150}$
= 0.3079 $\frac{pcu}{hour}$

Eltari Road (South) = $\frac{1016}{3150}$
= 0.3225 $\frac{pcu}{hour}$

y_{max} = 0.3225 $\frac{pcu}{hour}$

ii. Phase 2

Sonbay Road = $\frac{537}{1975}$ = 0.2718 $\frac{pcu}{hour}$

L. Lake Road = $\frac{663}{1975}$ = 0.3356 $\frac{pcu}{hour}$

y_{max} = 0.3356 $\frac{pcu}{hour}$

Thus, the size of the congestion is:
$FR = \sum y_{max}$
= 0.3225 + 0.3356
= 0.6581 $\frac{pcu}{hour}$

d. Determine the lost time (Lt)
Lt = 2n + R = 2(2) + 5= 9 seconds
Thus, the optimum cycle time is:

$$C_0 = \frac{1.5 \times Lt + 5}{1 - FR} = \frac{1.5 \times 9 + 5}{1 - 0.6581} = 54 \text{ seconds}$$

3. Determine the maximum number of green time cycles

The maximum number of green time cycles is obtained by subtracting the optimum cycle time from the lost time, thus obtaining

$C_0 - Lt = 54 - 9 = 45$ seconds.

4. Determine green time

The green time for each phase is obtained by multiplying y_{max} for each phase by the maximum number of green time cycles and dividing by the phase ratio. Then, we get:

a. Phase 1 = $\frac{0.3225 \times 45}{0.6581} = \frac{14.5125}{0.6581} = 22$ s
b. Phase 2 = $\frac{0.3356 \times 45}{0.6581} = \frac{15.102}{0.6581} = 23$ s

5. Determine red time

The red time for each phase is obtained by subtracting the optimum cycle time minus the green time and yellow time. Then we get:

a. Phase 1 = C_0 − green time – yellow time
$= 54 - 22 - 5 = 27$ seconds.
b. Phase 2 = C_0 − green time – yellow time
$= 54 - 23 - 5$
= 26 seconds

Based on the results of calculations using the Webster method and the duration of the red, yellow, and green lights, the new design of the Tulip intersection traffic system is presented in Table 9.

Table 9. New Tulip Intersection Traffic Light Duration

Roads	Red (seconds)	Yellow (seconds)	Green (seconds)
Eltari (North)	22	3	27
L. Lake	23	3	26
Eltari (South)	22	3	27
Sonbay	23	3	26

Based on Table 9, the application of graph theory and Webster method to create a new design for the Tulip intersection traffic light settings obtains optimal results where all flows can run simultaneously without experiencing any intersection of currents and the duration of the traffic light is in accordance with the recommended length of time.

This research is similar to previous research by Fangelis & Ahmad (2021), Sendow et al. (2023), and Chairani et al. (2021) because they also combine the Webster method and graph theory in determining the optimal time for traffic lights. The research of Fangelis & Ahmad (2021) calculated the flashing time for traffic lights at each interconnected intersection and T-junction. The final results show that the intersection has four phases and the T-junction has three phases. In their research, the node coloring technique was also used. The research of Chairani et al. (2021) focuses on intersections that produce three-time phases. In this study, the edge coloring technique was also used. The research of Sendow et al. (2023) is similar to the research of Chairani et al. (2021). The research of Sendow et al. (2023) focuses on intersections, which then produce three-time phases. The difference is that in this study, graph coloring techniques were not used, either node coloring or edge coloring. Meanwhile, for our research, we only use a combination of the Webster method and graph theory, especially the concept of compatible graphs without graph coloring techniques. Our research focuses on intersections and produces only two-time phases.

CONCLUSIONS AND SUGGESTIONS

By taking into account the width of the road and the volume of vehicles, we calculate the optimal duration of traffic lights using graph theory and the Webster method. We obtained the results for phase 1, that is, the Eltari (North) and Eltari (South) roads have durations of green, yellow, and red lights of 22 seconds, 3 seconds, and 27 seconds, respectively. For phase 2 of Sonbay and L. Lake roads, the duration of the green, yellow, and red lights is 23 seconds, 3 seconds, and 26 seconds, respectively. The difference with the previous arrangement, which only had 1 phase, for which each road had the same duration for green, yellow, and red lights, was 15 seconds, 3 seconds, and 75 seconds.

The suggestions for future researchers to improve the compatible graph at the Tulip intersection by adding nodes and edges coloring using the Welch Powel algorithm and developing a computer application to simulate traffic lights so the timing can be more effective and efficient (saves time) when there is an increase in vehicle volume in the future.

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