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Application of Number Theory to Determine Congruence in Traffic Lights

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Abstract: This study explores the application of number theory—particularly congruence relations—in modeling and synchronizing traffic light systems. By interpreting the periodic behavior of traffic lights through modular arithmetic, we demonstrate how congruence equations can predict simultaneous signal changes and optimize traffic flow. Using least common multiples (LCMs) and modular congruences, we analyze cycle times of multiple intersections to determine coordination points where lights align. The approach allows for more efficient traffic management, reducing waiting time and improving vehicular movement in urban environments. The findings highlight the practical relevance of number theory in solving real-world scheduling and synchronization problems.

Keywords: Number Theory; Congruence; Traffic Light Synchronization; Modular Arithmetic; Least Common Multiple (LCM); Traffic Flow Optimization

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INTRODUCTION

Discrete mathematics is a branch of mathematics as the basis of computer science which studies discrete objects for the theoretical basis of computer science. One of his theories is number theory, which is the basic theory of every calculus operation[1][2][3][4][5]. In everyday life, discrete mathematics can solve problems that occur in everyday life, one of which is the basic theory of every arithmetic operation, namely number theory.

The basis for the development of a branch of mathematics, one of which is number theory and several branches such as cryptography (writing secrets / passwords) and computer science as an example of applied science[6][7]. One of the important algorithms owned by number theory and related to the nature of this division is the Euclidean algorithm which, when applied to congruence, can be used as a computational tool to solve existing problems.

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Traffic is a condition where traffic lights are installed at intersections with the aim of regulating traffic flow. Traffic regulation at the intersection is basically understood as how the movement of vehicles in each group of vehicle movements can move alternately so that the existing flows do not interfere with each other. 22 of 2009 concerning Road Traffic and Transportation, traffic lights available at intersections have several purposes, including avoiding obstacles due to differences in road flow for vehicular traffic, facilitating safe pedestrian traffic and reducing accident rates due to collisions. Because of its important function, traffic lights should be checked or controlled as easily as possible to facilitate traffic at an intersection[8][9][10][11] .

There are so many problems with traffic lights in the community, such as the countdown lane at the red light which takes longer than other lanes that are faster[12]. This raises thoughts in the community about justice, if justice is not obtained then the community will start to get restless and cause demonstrations, therefore the discussion about congruence is described in this article, and this article hopefully can help the government in the development of cities in Indonesia. Therefore, mathematics can also be developed for urban development, for example in discrete mathematics with number theory to determine congruent values.

Taking the case in this discussion, namely the case of traffic lights at the intersection of Brigadier General H. Darsono's road, Cirebon city[13][10][14]. Serves as a case to determine the congruence, therefore it is necessary to monitor the traffic lights of each traffic light at the intersection. The purpose of this study is to show that the alignment of traffic lights is important because every road user has the same rights, so the calculation for light traffic must be done fairly but not in the same way because the density of roads on each road is different [15].

LITERATURE REVIEW

In previous studies using experimental and congruence methods to calculate congruence at traffic lights, traffic lights that we often encounter on the road use 2 signals:

- Time signal

  With a fixed time signal, the fire operates according to the schedule specified at the start of the installation and has a fixed duration. This light is equipped with a time switch to change the schedule under certain conditions to cope with different traffic

- Demand signal (vehicle-activated signal)

  In this type of signal, the detector is used to detect the number of vehicles within the detection range and is connected to the controller. With the detector and controller connected, the controller calculates the cycle time and alters the signal to meet traffic demands.

  From the results of calculating the congruence, it is found that the traffic lights on each road are not always congruent if congruent means that the time is ideal for each lane. There are several factors that can cause incongruence, the first is the number of riders, meaning that the waiting time can be less or excessive, judging by the number of or at least riders on the lane, the second factor is the volume of the lane, meaning that if the calculation is fast, it can be caused by a narrow road width and on the other hand, as well as the factor that affects the latter, namely the direction of the route, meaning that

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if the number of riders is large, it aims to go to the city and if the number of riders is small, it aims to go to the village[1].

METHODS

The research method used by the author is the experimental method. Experimental research is a systematic, logical, and in-depth study under controlled conditions. The data used comes from direct observation and recording from the research location[16] namely traffic lights at the intersection of Brigadier General H. Darsono, Cirebon city. The observed part is the waiting time for traffic lights in each lane at the intersection on November 3, 2021, at 09.00 WIB.

This research employs a mathematical modeling approach using concepts from number theory, particularly modular arithmetic and congruence relations, to analyze and synchronize traffic light cycles. The method involves the following steps:

1. **Data Collection**

   The cycle times (in seconds) of traffic lights at selected intersections are collected. These include the total duration of each cycle and the timing of green, yellow, and red phases.

2. **Mathematical Modeling**

   Each traffic light cycle is modeled as a periodic function. Congruence relations of the form

$$t \equiv ai \ (mod\ ni)$$

are used, where ttt is the time variable, ai is the offset for intersection iii, and ni is the cycle time of the i-th traffic light.

3. **Determination of Synchronization Points**

   The system of congruences is solved using the Chinese Remainder Theorem (CRT) or Least Common Multiple (LCM) methods to find the least time TTT where all traffic lights change simultaneously or align in a desired pattern.

4. **Simulation and Analysis**

   A simulation model is developed to visualize the synchronization. Traffic flow efficiency is then analyzed by comparing wait times and vehicle throughput before and after applying the synchronization method.

5. **Validation**
   The model is validated using real-time traffic data or simulations in a controlled environment to ensure accuracy and applicability.

This method demonstrates how abstract mathematical concepts can be applied to practical problems in traffic engineering and urban mobility optimization.

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RESULT AND DISCUSSION

By using the congruence method, the traffic light duration problem can be used to prove the suitability between discrete mathematics and real-world applications[17]. Therefore, by taking samples of traffic lights that are often encountered on trips, traffic lights are operated by cars or electricity. There are 2 types of signals on traffic lights that can be used as follows[18]:

1. Fixed time signals

In this signal, this light is realized based on a predetermined program at the beginning of the installation and has a predetermined or fixed duration, and this light also has a time switch and is useful for changing the duration of a certain time in overcoming traffic problems that occur.

2. Vehicle-activated signal

This signal detects the number of vehicles that are at a certain distance and this signal is also connected to the controller, by being connected to the controller then the controller will be able to change or calculate the cycle time and change the signal in response to traffic requests.

So in this case we use fixed time signals. Because of that there is no change in data retrieval during direct recording. There are 3 waiting times from traffic lights that we get from the results of the recording that has been carried out, 3 waiting times, namely red, yellow, and green lights[19]. As in the following table:

Table 1. Traffic Light Data

Track	**Traffic lights**		
	Red	**Yellow**	**Green**
South Direction	94	4	39
North direction	98	4	36
East direction	110	4	23
West direction	110	4	23

From table 1 above, the data that has been described above is when the traffic light is on which is obtained from the observations. The calculation used combines the formula between Euclid's theorem and congruence with rums

The data above is the length of time the traffic lights are on which is obtained from observations. Calculation of m = n.q+r where in every comparison of variables n and r must be the same as the data being compared and 0 r < n. With the following information[20]:

m = n.q+r

m = Target calculated like a red light

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n = Number of intersections

q = Variable for multiplication

r = Variable for addition

Figure 1Illustration of Brigadier General H. Darsono City Crossroads. Cirebon

From the illustration above, the variable n is worth 4 because the number of intersections is four. Each path is compared and calculated if the variables r and n have the same value, then they are congruent, because the congruence conditions are for the divisor (n) and the residue (r) to have the same value.

Table 2.Results of Inter-Line Calculation

Track	Red light	Congruence	Residue (r)
South Direction	94	YES	2
North direction	98	YES	2
East direction	110	YES	2
West direction	110	YES	2

From table 2 above, the value used for the calculation is the length of time the red light is on and the same residue is obtained. So for the case of the intersection of Brigadier General H. Darsono Kota. Cirebon gets a YES result for congruent.

Figure 2. Traffic Light Illustration

From the illustration above, the variable n is worth 3 because the number of traffic lights is 3. Then the waiting time is calculated for each lane, the calculation of the red light with or compared to the green and yellow lights and vice versa.

Table 3. South Line Calculation Results with Each Lamp

South Line	Duration	Congruence	Residue (r)
Red light	94	YES	1
Yellow light	4	YES	1
Green light	39	NO	0

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From the results of the table above, it can be said that the red and yellow lights are not congruent with the green lights. This incongruence can be caused by delays in the lights when changing colors so that the data is less accurate.

Table 4. Calculation Results Between Lights on the North Line

North Line	Duration	Congruence	Residue(r)
Red light	98	NO	2
Yellow light	4	NO	1
Green light	36	NO	0

From Table 4 above, it can be seen that all the lights are not congruent. The possibility could be caused by a delay when the lamp changes color and causes the data to be less accurate, in the event that the calculation is not on the principle of congruence, the calculation is not updated every year, the tool is less accurate in the calculation even though it has been updated and in the delivery of the data on the results.

Table 5. Calculation Results Between Lights on the East Line

East Line	Duration	Congruence	Residue(r)
Red light	110	YES	2
Yellow light	4	NO	1
Green light	23	YES	2

From table 5 above, it can be seen that the yellow lights are not congruent. Because the yellow light does not have anything in common with the other lights, it may be due to a delay in changing the color of the lights, which can cause data inaccuracies, or in performing calculations that do not use the principles of congruence.

Table 6. Calculation Results Between Lights on the West Line

West Line	Duration	Congruence	Residue(r)
Red light	110	YES	2
Yellow light	4	NO	1
Green light	23	YES	2

From table 6 above, it can be seen that the yellow lights are not congruent. Because the yellow light doesn't have anything in common with other lights, it may be due to a delay in changing the color of the lights, which can cause data inaccuracies, or not using the principles of congruence in performing calculations.

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From the table data above, it can be concluded that the traffic lights are not always congruent, and if there are congruent traffic lights it can be interpreted that the waiting time on each lane is ideal. And if capable, the lights on the crossing must be adjusted to the needs so that they can be calculated in the calculation.

CONCLUSION

The use of the Euclidean algorithm can be applied to solve the congruence calculations of traffic lights. The first step is to find data for traffic lights and enter it into a table to facilitate data processing, the table becomes a reference in calculations using the Euclid algorithm, the data is congruent, using a congruent formula conditioned in the Euclid algorithm so that it has a division condition and the residual must have the same value. the same to be called congruent, the light system analyzes the number of existing vehicles and determines the efficiency of the calculation or ideally the calculation so that it must remain orderly and experience traffic jams. Therefore, we can say that the intersection only, because the calculation between lanes has to be congruent in each traffic.

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