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Optimization of smart traffic lights to prevent traffic congestion using fuzzy logic

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Abstract
One of the main causes of traffic congestion, especially at intersections, is because traffic lights have not been able to show the right time according to the existing traffic conditions. Time settings based on peak/off-peak traffic lights are not enough to handle unexpected situations. The fuzzy mamdani method makes decisions with several stages, the criteria used are the number of vehicles, the length of the queue and the width of the road to be able to optimize the time settings based on the real-time conditions required so that unwanted green signals (when there is no queue) can be avoided. The purpose of this research is to create a simulator to optimize traffic time management, so that the timers on each track have the intelligence to predict the right time, so that congestion at the intersection can be reduced by adding up to 15 seconds of green light from the previous time in the path of many vehicles.

Keywords: *congestion, fuzzy mamdani, intersection, smart, traffic light*

1. Introduction

Traffic congestion is one of the main problems in Indonesia's major cities, such as Jakarta, Bandung, Medan, and Yogyakarta. The number of vehicles that is increasing year by year, the growing population, the imbalance between traffic demand and transportation infrastructure [1], and the inability of the traffic management to control and reduce traffic are the main causes of the congestion. According to the Indonesian Central Statistics Agency (BPS, *Badan Pusat Statistik*), the number of four-wheeled cars and motorcycles in 2016 reached more than 14 million and 105 million each. Compared to 10 years earlier, the number of cars has increased approximately 58.6%, while the increase in the number of motorcycles reaches 223.25% [2]. Inrix, a company that specializes in connected car services and transportation analytics, releases Global Traffic Scorecard that analyzed and ranked the impact of congestion in 1,360 cities in 38 countries annually. In its list of the most congested cities in the world, based on 2017 statistics, Jakarta is ranked 17th, after Bangkok and before Washington DC. In Jakarta, Indonesian drivers spend about 63 extra hours per year driving in congestion or 20% of their driving time [3].

To address the traffic issues, it is required more than just infrastructure expansion and buliding new roads. Managing of traffic flow should be a combination of infrastructure, new technologies, and new ways of thinking [1]. Traffic light, as part of the traffic control infrastructure, needs to be be able to predict its timing of red, yellow, and green periods based on current situation, Some studies have been conducted to make traffic lights become smart. With the help of sensors and cameras, as well as the implementation of various technologies, such as artificial intelligence and image processing, the traffic light controller is able to make time setting decision based on real time data.

Hsieh et al [4] introduce smart traffic optimization using a genetic algorithm that allows automatic adjusment of the time setting of the traffic ight based on sensor and camera inputs. If the congestion level at an intersection surpasses a preset threshold, the currect traffic statistics are sent to the AI system for time setting optimization. Other study measures the area on the road covered by a vehicle. A web camera is placed in a lane to capture images of the road to be controlled. The images are, then, processed to know the traffic density. The controller will send the command to the timer, based on the traffic density, to set particular time to manage

traffic [5]. The image processing technique is also employed by Hasan et al. for determining traffic congestion [6]. Smart traffic control with proposed algorithm that gives emergency vehicles, such as ambulance,to get the green light every time they pass through an intersection, is proposed by M.A.Tank et al [7] and A.S. Abdul Munem and M.S.Croock [8]. But in the latter, the ambulance is also guided to the optimal path depending on crowd sensor readings.

Fuzzy Logic has been widely used for making decision in many researches and projects. This method, for example, can be implemented for navigating the AR Drone Quadrotor [9], scheduling the accumulator charging [10], helping the ship maneuvering [11], and controlling indoor lighting [12]. As it can be implemented in many different areas, Fuzzy Logic is considered one of the promising options to control traffic in big cities.Smart traffic light control based on Fuzzy Logic is proposed in [13-15]. Hawi et al. describe the smart traffic light for an isolated for-way junction that incorporates Wireless Sensor Network (WSN) for collecting road traffic data, fuzzy logic control (FLC) for decision making, and a routing algorithm that assigns green light (period) based on data retrieved from FLC. One of the differences offered in [14] from other related works is that data from sensors is stored, and then reviewed and analysed by experts over period of time to identify traffic patterns. In [16], fuzzy logic is used to predict traffic flow in different parts of the city at different times.

In this paper, we develop the traffic light control design that is more optimal and dynamic using Fuzzy Mamdani logic method. The analysis is based on the length of queue at each lane in an intersection, the width of each lane, number of vehicles heading to the traffic, and vehicles' speed.

2. Research Method

In this research, surveys were conducted in busy hours to examine the maximum length of the queue (at the intersection) and other parameters needed. Figure 1 shows the stages to determine the red/green period of the smart traffic light using Fuzzy Mamdani method.
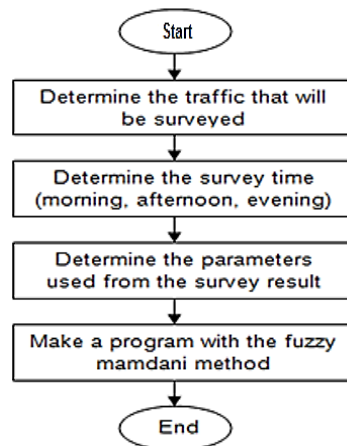

Figure 1. Research flow stage

According to research conducted by D. Hartanti et al about crossroads using algorithms and data structures programmed in the Arduino control device system, with the input of maximum speed and length of vehicles it is known that traffic density is seen to increase in the morning and evening [17], Simulation experiments on scale models in detecting the length of the vehicle queue using the help of infrared sensors placed in each intersection path, then applying the Greedy algorithm to help speed up the movement of the green light duration for the path that needs [18], simulation applications of movement and traffic control are used for monitoring queue length and duration of green light in traffic [19]. In a study conducted by Siswipraptini et al. [20], TSP (Travelling Salesman Problem) is used to minimize the total length of the trip and the detection results are used for input to the traffic regulation system. Other traffic simulation study uses fuzzy criteria based on the number of cars, the motor and the green

light duration [21, 22]. Other researcher uses the Fuzzy Mamdani method to design automated parking systems using fuzzy controls [23] and to control electric vehicle speed and torque, developing an adaptive cruise control to adjust the vehicle speed [24, 25].

The purpose of this research is to developa more optimal and dynamic traffic light control system using Fuzzy Mamdani logic method based on several criterias. Data used in this study is obtained from observation at Cengkareng Intersection, West Jakarta. As in most traffic lights, the traffic lights in Cengkareng are static. The timing is preset based on peak / busy hours and off peak/non busy hours. Figure 2 shows the stages in the Fuzzy Mamdani method.
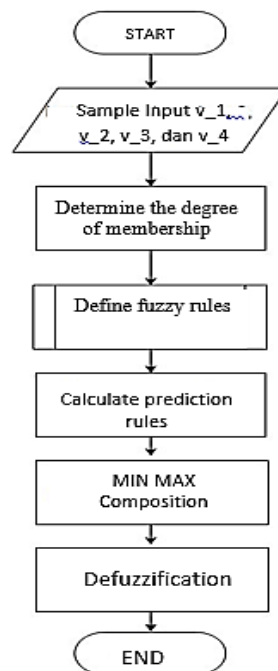

Figure 2. Fuzzy mamdani method

3. Results and Analysis

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

3.1. Fuzzification

At the fuzzification stage, the domain based on the data obtained from observation is created. Here is the table that shows the determination of the domain. The Criteria Domain that is used for the Analysis Shown in Table 1.

Table 1. Criteria Domain that is used for the Analysis

Criteria	Domain	Information
Number of Vehicle	0,10,25	Quiet
	20,30,45	Normal
	40,50	Crowded
Length of Queue	0,70,150	Short
	100,200,300	Normal
	230,350,450	Long
	400,550	Very Long
Width of Road	0,5,8	Narrow
	6,15	Wide

3.1.1. Number of Vehicles

Number of vehicles is classified into three categories: quiet (ranged until 25), normal (ranged from 20 to 45 vehicles) and crowded (ranged from 40). Figure 3 shows the membership function of this vehicle number.
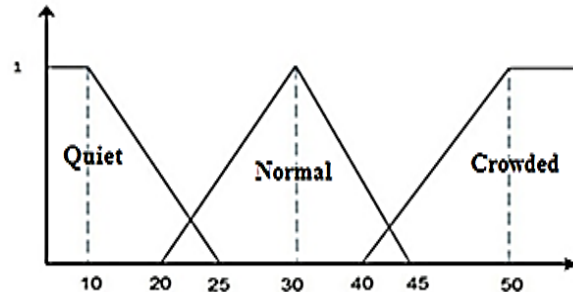

Figure 3. Graph of membership function of the vehicles number

$$\mu\ quiet \begin{cases} 1; & x \le 10 \\ (25 - x):(25 - 10); & 10 < x < 25 \\ 0; & x \ge 25 \end{cases}$$

$$\mu\ normal \begin{cases} 1; & x = 30 \\ (x - 20):(30 - 20); & 20 < x < 30 \\ (45 - x):(45 - 30); & 30 < x < 45 \\ 0; & 20 \le x \le 45 \end{cases}$$

$$\mu\ crowded \begin{cases} 1; & x \ge 50 \\ (50\text{-}x):(50\text{-}40); & 40 < x < 50 \\ 0; & x \le 40 \end{cases} \tag{1}$$

3.1.2. Length of Queue

The length of the queue is grouped into 4 categories: short, normal, long, and very long. Short is 150 metres and less, normal is ranged between 100 and 300 metres, long is between 230-450 metres and very long is from 400 and above. The membership function of the queue's length is shown in figure 4 below.
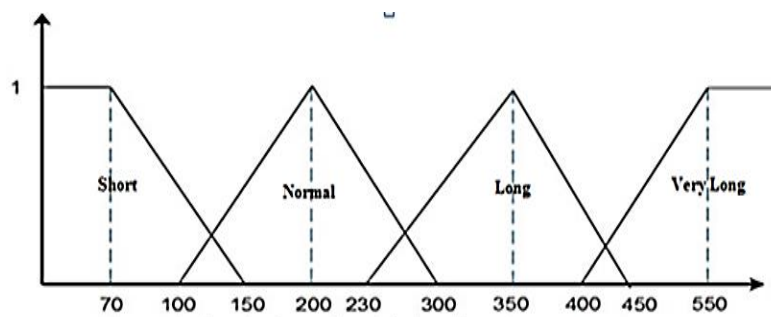

Figure 4. Graph of membership function of the Queue's length

$$\mu\ short \begin{cases} 1; & x \le 70 \\ (150\text{-}x):(150\text{-}70); & 70 < x < 150 \\ 0; & x \ge 150 \end{cases}$$

$$\mu\ normal \begin{cases} 1; & x = 200 \\ (x\text{-}100):(200\text{-}100); & 100 < x \leq 200 \\ (300\text{-}x):(300\text{-}200); & 200 < x < 300 \\ 0; & 100 \leq x \leq 300 \end{cases}$$

$$\mu\ long \begin{cases} 1; & x = 350 \\ (x - 230):(350 - 230); & 230 < x \leq 350 \\ (450 - x):(450 - 350); & 350 < x \leq 450 \\ 0; & 230 \leq x \leq 450 \end{cases}$$

$$\mu\ very\ long \begin{cases} 1; & x \geq 550 \\ (x - 400):(550 - 400); & 400 < x < 550 \\ 0; & x < 400 \end{cases} \tag{2}$$

3.1.3. The Width of Road

The width of road consists of 2 groups, i.e. narrow (up to 9 metres) and wide (more than 9 metres). Figure 5 shows the membership of the road's width.
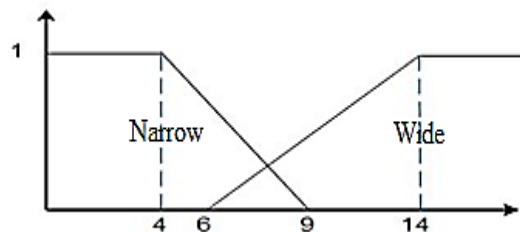

Figure 5. Graph of membership function of the road's width

$$\mu\ \mu\ narrow \begin{cases} 1; & x \leq 4 \\ (9 - x):(9 - 4); & 4 < x < 9 \\ 0; & x \geq 6 \end{cases}$$

$$\mu\ wide \begin{cases} 1; & x \geq 14 \\ (x - 6):(14 - 6); & 4 < x < 10 \\ 0; & x < 6 \end{cases} \tag{3}$$

3.2. Knowledge Base Formation

The μ values that have been obtained from the fuzzification stage will be applied for the rulecalculation. As some of the rules are as follows:
a) IF number of vehicles is small and the queue length is short and the road width is narrow then duration of green light is short.
b) IF number of vehicles is small and the queue length is short and and the road width is wide then duration of green light is short.
c) IF number of vehicles is small and the queue length is normal and the road width is narrow then duration of green light is short.
d) IF number of vehicles is small and the queue length is normaland the road width is wide then duration of green light is short.
e) IF number of vehicles is small and the queue length is longand the road width is narrow then duration of green light is short.
f) IF number of vehicles is small and the queue length is short and the vehicles speed is fast and the road width is wide then duration of green light is short.

g) IF number of vehicles is small and the queue length is short and the vehicles speed is slow and the road width is wide then duration of green light is short.
h) IF number of vehicles is small and the queue length is normal and the vehicles speed is fast and the road width is wide then duration of green light is short.
i) IF number of vehicles is small and the queue length is normal and the vehicles speed is normal and the road width is narrow then duration of green light is short.
j) IF number of vehicles is small and the queue length is normal and the vehicles speed is normal and the road width is wide then duration of green light is short

From the research, it is found that data obtained from observation is different from the application's result, that is calculated using Fuzzy Mamdani. The difference between green light period from observation and data from application in the morning on lane 1 (West Outer Ring Road to the north) is shown in the Table 2.

Table 2. Data from Observation

	Green Light Period (second)	Red Light Period(second)	Number of vehicles heading to the queue	Length of Queue (metre)
Road lingkar luar (West Outer Ring Road) to the North	38	88	29	110
	38	88	20	130
	38	88	31	140
	38	88	28	120
	38	88	24	120
	38	88	26	110
	38	88	27	130
	38	88	33	140
	38	88	30	140
	38	88	31	140

On the width of the road the data from observations are all 7. In the data in the application of the number of vehicles going to the queue, the queue length and the width of the road value are the same, without using red light data when data is entered into the application using fuzzy mamdani method can produce green lights that are not static/can be different and this can be seen in Figure 6. Figure 6 shows the comparison between the duration/period of the green light in lane 1 at 6-8 am from observation and application results using fuzzy mamdani method.

In the application fuzzy inputs are presented in the form of four rows, i.e. the number of vehicles, the length of the queue, the width of the road and the duration of green lights, (as shown in Figure 7). The resulting green light period in second shown on the application is obtained from the calculation based on Fuzzy Mamdani method
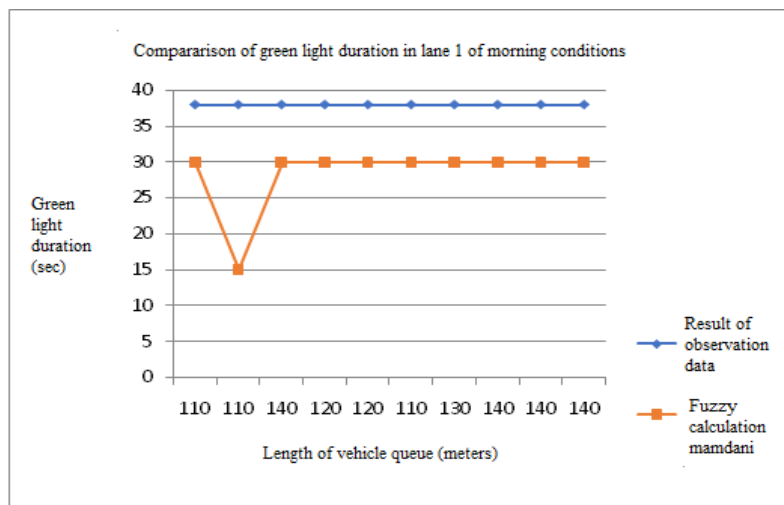

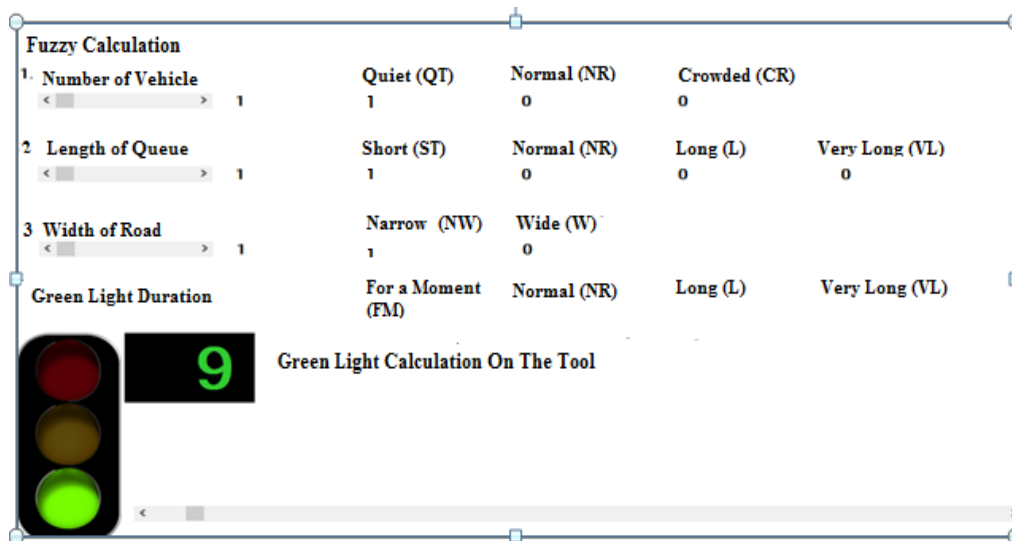Figure 6. Graph of the comparison of green light periods in the morning

Figure 7. Fuzzy calculation on the application

4. Conclusion

In this study, Fuzzy Mamdani logic is used to optimize traffic light control at intersections. The duration or green light period for each row can be optimized based on several real-time parameters, such as queue length in each row, number of vehicles going to the queue, vehicle speed, and width of each lane. The duration of the green light in each row may be different, based on the conditions on each path. Lines with longer lines can get longer green periods than other lines with fewer vehicles. The green light application period must reduce traffic congestion.

In the graph, how to use data on the data of fuzzy mamdani calculations in this application can be seen when the green light can vary several tens of seconds, in contrast to our previous research that uses the help of infrared sensors placed in each intersection path and the use of greedy algorithms to help accelerate the duration of movement the green light for the required path, but can only add two seconds to the green light. With this research is expected to reduce the stack of vehicles to prevent traffic congestion, especially at intersections

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