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Optimization of Traffic Light Control Using Fuzzy Logic Sugeno Method

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Abstract

Congestion is one of the big problems around the world, especially for big cities. Intersections are the scene of congestion because the lane is the meeting point of two or more roads which has a major influence on the smooth flow of vehicles on the road network. This congestion occurs due to various factors, one of which is the statistical traffic light duration, which does not match traffic conditions. Based on this, there needs to be a development in the timing of a more adaptive green light. This study describes the design of a traffic light controller using the Sugeno method fuzzy logic. This study aims to design a green light duration calculation by applying fuzzy logic that results in adaptive traffic light duration at intersections, by entering the density of each intersection path, which is divided into 4 inputs, namely regulated lane density, opposing lane density I, and opposite lane density. II, the density of the opposite lane III, with the aim of the system being able to produce a duration that is in accordance with the current traffic situation with an output in the form of a green light duration on the regulated lane.

Keywords: Fuzzy logic, traffic light, Sugeno method

1. Introduction

Traffic congestion is an important problem in many countries. The increasing number of vehicles is a factor of traffic jams (Kulkarni and Waingankar, 2007). In addition, the number of queues that pass through the intersection often results in traffic jams. In overcoming this problem, many crossroads use traffic lights to regulate traffic flow so that traffic congestion is expected to be avoided. However, at certain times the increase in the number of vehicles results in long queues at the intersection. Furthermore, traffic light system is nonlinear, unpredictable, and uncertain problem (Zendehdel and Pishkoohi, 2018), needed artificial intelligent algorithm to control the system. Such as use advance technologies as example computer vision, image processing and intelligent control to perform task traffic light control (Hawi et al., 2017).

In Indonesia the high level of traffic congestion is caused by the increasing number of vehicles on the road and the ineffective performance of the traffic control system (Mualifah and Abadi, 2019). In Bandung city, most of the traffic lights use conventional time system, where the duration of traffic lights is fixed which refers to the Indonesian Road Capacity Manual (MKJI 1997) and is based on research and observations of traffic flows that occur at intersections (Prasetiyo, 2015). In fact, traffic flow conditions are volatile. That is because the traffic management system at the intersection is not effective. Often encountered a duration of green lights that are not in accordance with traffic conditions, there are conditions where the path with a long queue but a short duration of green lights. On the contrary, the duration of green light is long for fairly quiet lanes. Research on the traffic light control system has been widely developed with the aim of helping to solve the problem of traffic light jams. Mehan (2011) has introduction about traffic light controller with fuzzy control system at 2011.

Fuzzy logic technology allows the implementation of real-life rules similar to the way humans would think. For example, to control traffic situation at a certain junction (Khalid, 1996). Wei (2001) has created a microcontroller to control traffic lights with two techniques, namely using image processing and fuzzy logic. Hegyi et al. (2001) has developed a decision support system for fuzzy inference machines. This system uses adaptive learning features and fuzzy sets by combining heuristic knowledge about traffic lights. Kulkarni (2007) has designed and construct an adaptive traffic light controller. The decision of this system is based on the number of vehicle arrivals and also the length of the queue. Traffic flow is usually characterized by randomness and uncertainty, thus designing an intelligent controller, Fuzzy logic is known to be suited for modeling and control in such problems (Homaei et al., 2015). Then there are several fuzzy logic methods (Tsukamoto and Mamdani method) that can be used for decision support systems (Sitimorang and Rindari, 2019), or production optimization using fuzzy logic (Nasution and Prakarsa, 2020).

The purpose of study is to design an adaptive traffic light system using Fuzzy Logic with the Sugeno method. This system will take into account road traffic conditions as input to determine the duration of the green light, namely the density of vehicles on the lane with the green light phase and the density on the three other lanes on the red light phase. The purpose of this research is expected to develop a method used to determine the duration of the green light adaptively using the fuzzy logic Sugeno method. This design is implemented as a simulation. Thereafter the assessment has been completed by comparing the performance of the proposed system with the fixed traffic light control system.

2. Controller System of Traffic Light

In Indonesia, especially in Bandung, most of them still use a fixed time traffic light control system without considering the level of density. Statistical calculations are used to determine fixed time controls according to traffic conditions. The Indonesian Road Capacity Manual (MKJI) 1997 is used as a reference for calculation. The green time is calculated using Equation (1):

$$gi = (cua - LTI).FRcrit \tag{1}$$

Where variable i is the index for the phase number, the variable gi is green time display in phase (seconds), LTI is the total time lost per cycle (seconds).

3. Fuzzy Logic Sugeno Method

The fuzzy logic-based systems are one of the most important applications of the fuzzy logic and fuzzy-set theory in soft computing and applied mathematics (Alhihi and Khosravi, 2018; Mujiarto et al., 2019; Trisnawan et al., 2018; Santika et al., 2018; Trisnawan et al., 2019). Reasoning using the Sugeno method is almost the same as Mamdani reasoning, it's just that the system output (concentrations) are not in the form of fuzzy sets, but in the form of constants or linear. This method was introduced by Takagi-

Sugeno Kang in 1985. The Sugeno model use the Singleton membership function, which is a membership function that has a membership degree of 1 at a single crisp value and 0 on another crisp value. There are 2 models in the Sugeno method:

a. Zero-Order Fuzzy Sugeno Model

IF (X is A) (X is A) (X is A) (X is A) THEN z = k (2)

Where A_i is fuzzy set as antecedent, and k is a (crisp) constant as a consequence.

b. First-Order Fuzzy Sugeno Model

*IF (X is A) … (x is) THEN z = p1 * 1 x + … + p2 * 2 x + q* (3)

Where A_i is the fuzzy set as the antecedent, and *pi* is a (crisp) constant it *i* and *q* is also consequent constant.

There are 4 stages in the Sugeno fuzzy system, that is:

1. Fuzzy set becoming determining all the variables involved in the process to be determined. For each input variable, determine an appropriate fuzzification function.
2. The application of the implication function. Establishing the basis of rules, rules in the form of fuzzy implications that state the relation between input and output variable. The general rule evaluation model can be seen in Figure 1.

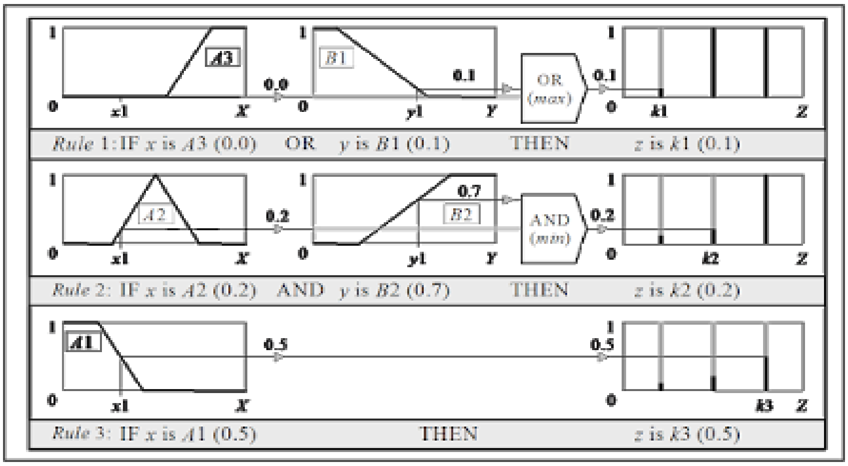

Figure 1: Rule Evaluation Model

Where *x, y, z* are linguistic variables, *A* and *B* and the *i* fuzzy sets for *x* and *y*, and *f (x, y)* are mathematical functions. The number of rules is determined by the number of linguistic values for each input variable.

3. Composition of rules If the system consists of several rules, then inference is obtained from the collection and correlation between the rules. The method used in fuzzy inference system is the Min (Minimum) method. In this method, the fuzzy set solution is obtained by taking the minimum rule value, then using that value to modify the fuzzy area and apply it to the output using the or (union) operator. In general rule composition model is Figure 2.

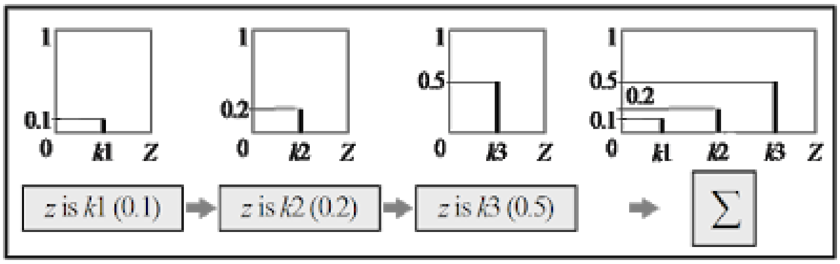

Figure 2: Rule composition model

4. Confirmation input of the affirmation process is a fuzzy set can be obtained from composition of fuzzy rules, while the resulting output is a firm real number. If the composition of the rules uses Sugeno method, defuzzification (Z *) is done by finding the central average score.

$$Z^* = \frac{\sum_{i=1}^{N} \alpha_i z_i}{\sum_{i=1}^{N} \alpha_i} \tag{4}$$

Where α_i is the output value in rule, z_i is the degree of membership output value in rule and N is the number of rules.

4. Adaptive Traffic Light Control System Design

Traffic lights at intersections require system optimization, because of fluctuating and unstable traffic conditions, so an adaptive system is needed (Prasetiyo et al., 2015). The author uses fuzzy logic to build the system. In this study, this system was built with attention to traffic conditions at the intersection, namely density. In density, there are number of vehicles, road length and road width. The design of traffic light controller system can be seen in Figure 3.

The following is adaptive control system based on traffic conditions at the intersection. This study was built using the Sugeno method. This system is used to predict the optimal green light duration and time settings for more flexible green light. This is necessary so that each intersection has the number of seconds that corresponds to the density that occurs at the intersection. That way, it is hoped that vehicle congestion at the intersection can be reduced. The decision on the duration of the green light is taken from the implications of fuzzy logic. The overall picture of this system is shown in Figure 4.

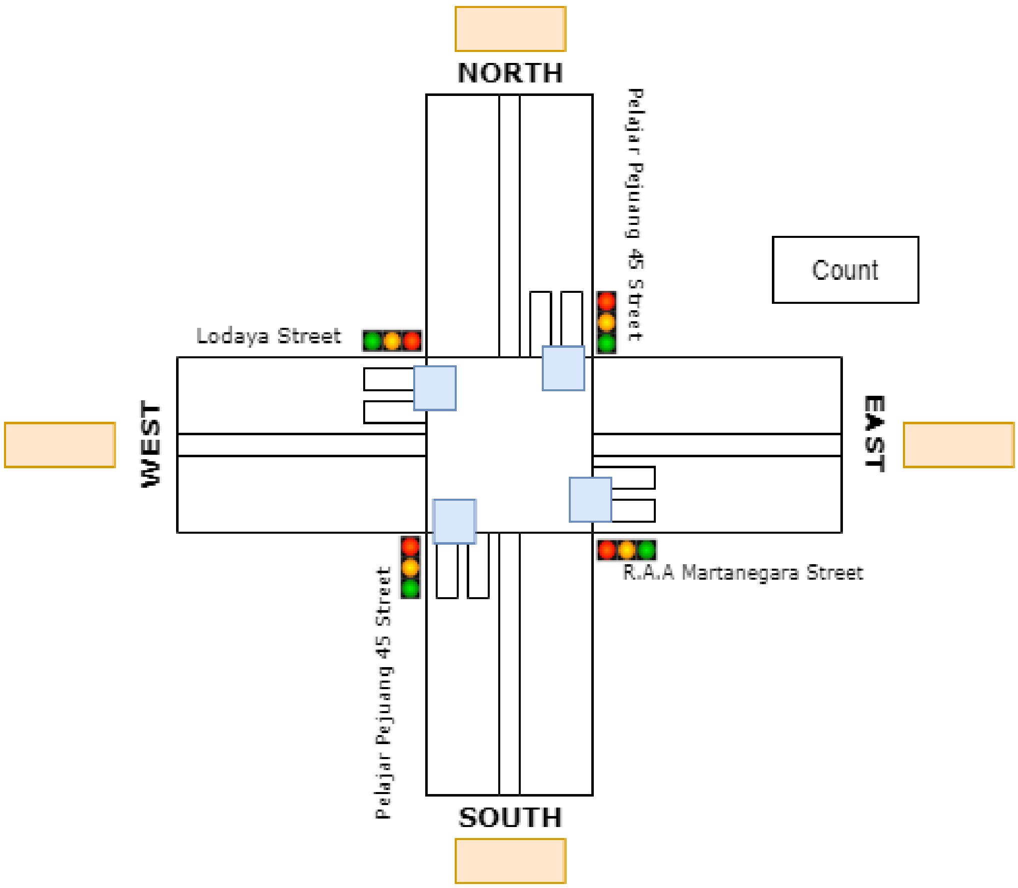

Figure 3: The Traffic Light Controller System

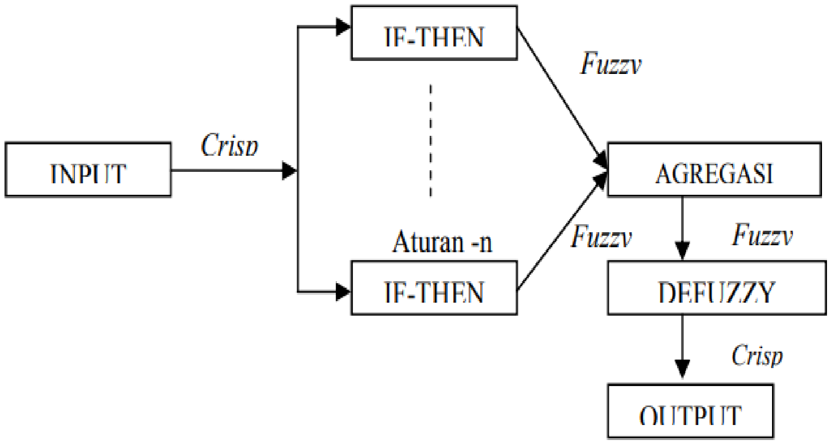

Figure 4: An Overview of This System

There are 4 inputs for this system, namely the density of the regulated lane (KJA), density of the opponent lane I (KJL I), density of the opponent lane II (KJL II) and density of the opponent lane III (KJL III). The output is green light duration for the set line. Thereupon the first input, the density of the regulated lane is divided into three urban functions, not dense (TP), dense (P), very dense (SP) with a range [0.0468: 0.4611]. The second input, the line density of Opponent I is divided into three member functions, not dense (TP), dense (P), very dense (SP) with a range of [0.0468: 0.4611]. The third input, the regulated line density is divided into three member functions, not dense (TP), dense (P), and very dense (SP) with a range of [0.0468: 0.4611]. Input Fourth, the line density of Opponent III is divided into three member functions, not dense (TP), solid (P), very solid (SP) with a range [0.0468: 0.4611]. The output of this system is in the form of constants, namely Green Light Duration (DLH) and divided into three membership functions, namely Brief (Sb), Medium (Sd) and Long (L) with a range [40: 120]. The design of this fuzzy system is can be seen Figure 5.

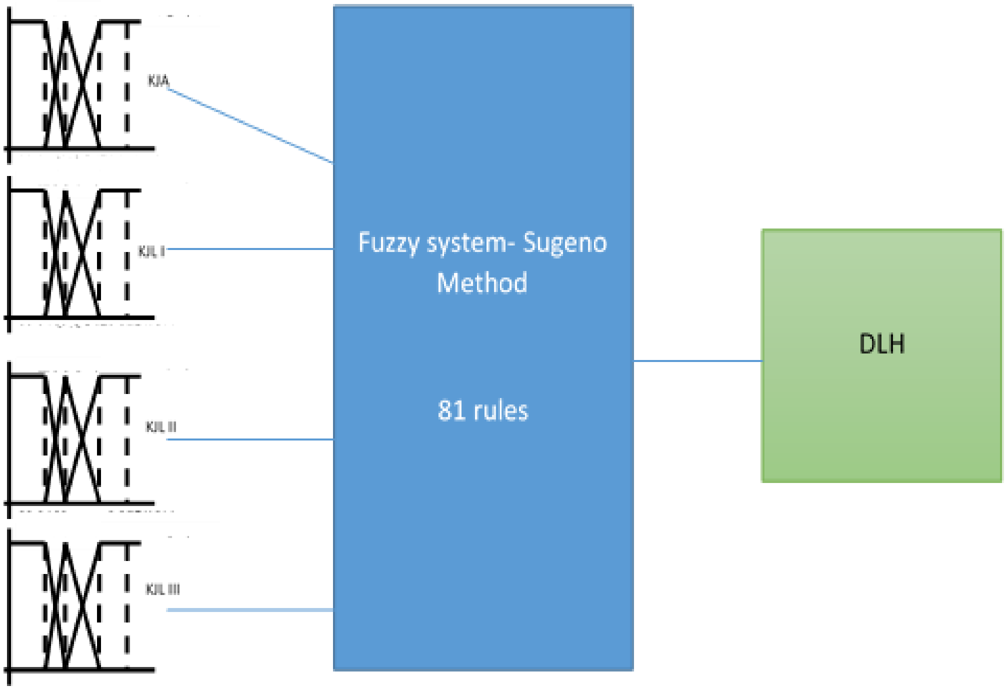

Figure 5: Fuzzy System use 4 Inputs, and use 1 Output with 81 Rules

Membership function of the Regulated Path Density (KJA) in Figure 6, Opponent I line density (KL1) as the second input is shown in Figure 7, Opponent II line density as the third input is shown in Figure 8, Opponent III line density as the third input is shown in Figure 9 and membership function of the green time as the output is shown in Figure 10.

Figure 6: Membership of Path Density the Regulated (KJA)

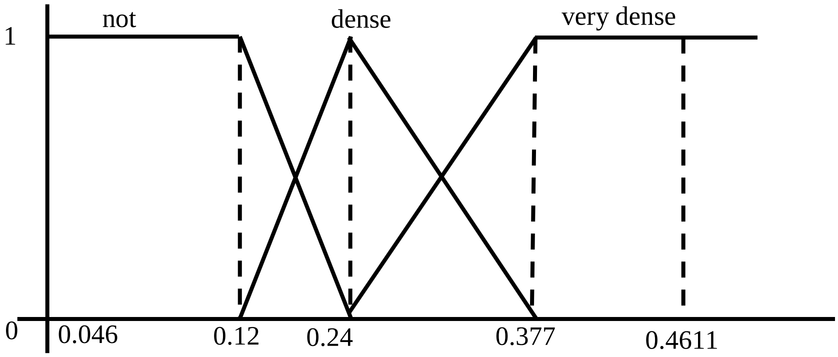

Figure 7: Opponent line density I (KL1)

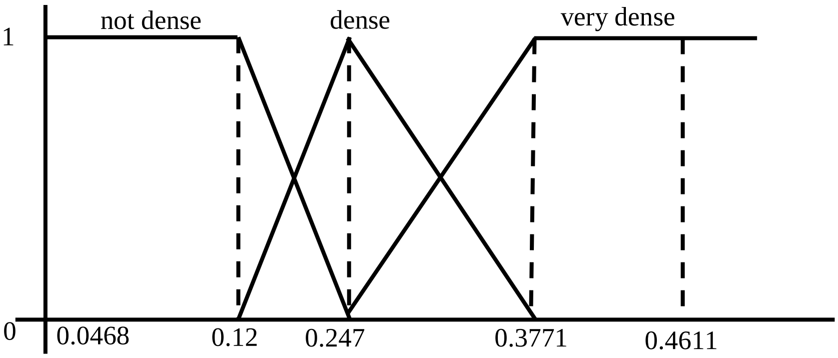

Figure 8: Opponent line density II (KL2)

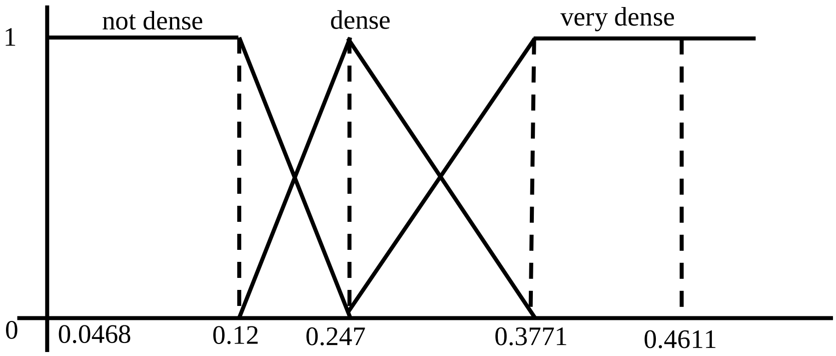

Figure 9: Opponent line density III (KL3)

Table 1: Sample of rules from 81 rules used

No		K_JYA		K_JL1		K_JL2		K_JL3		DLH
1	IF	TP	AND	TP	AND	TP	AND	TP	THEN	Short
2	IF	TP	AND	SP	AND	TP	AND	TP	THEN	Medium
3	IF	TP	AND	P	AND	P	AND	TP	THEN	Medium
4	IF	TP	AND	TP	AND	SP	AND	TP	THEN	Medium
5	IF	TP	AND	SP	AND	SP	AND	TP	THEN	Medium
6	IF	TP	AND	P	AND	TP	AND	P	THEN	Medium
7	IF	TP	AND	TP	AND	P	AND	P	THEN	Medium
8	IF	TP	AND	SP	AND	P	AND	P	THEN	Medium
9	IF	TP	AND	P	AND	SP	AND	P	THEN	Medium
10	IF	TP	AND	TP	AND	TP	AND	SP	THEN	Medium
11	IF	TP	AND	SP	AND	TP	AND	SP	THEN	Medium
12	IF	TP	AND	P	AND	P	AND	SP	THEN	Medium
13	IF	TP	AND	TP	AND	SP	AND	SP	THEN	Medium
14	IF	TP	AND	SP	AND	SP	AND	SP	THEN	Long
15	IF	P	AND	TP	AND	TP	AND	TP	THEN	Short
16	IF	P	AND	SP	AND	TP	AND	TP	THEN	Medium
17	IF	P	AND	P	AND	P	AND	TP	THEN	Medium
18	IF	P	AND	TP	AND	SP	AND	TP	THEN	Medium
19	IF	P	AND	SP	AND	SP	AND	TP	THEN	Long
20	IF	P	AND	P	AND	TP	AND	P	THEN	Medium

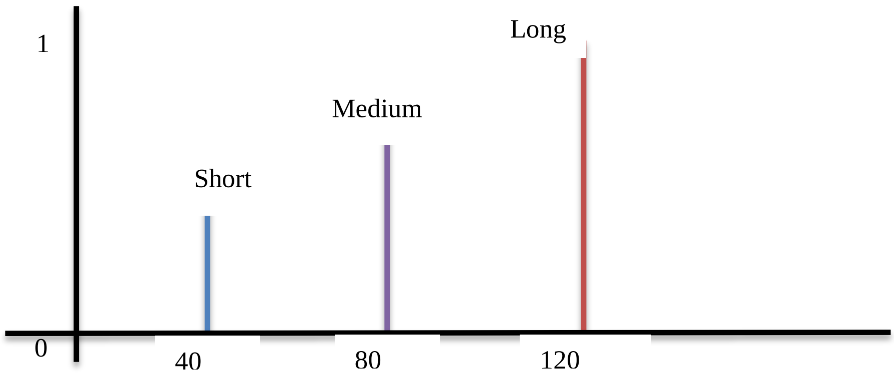

Figure 10: Membership of the green time

The fuzzy system in this research is using 81 rules. The list of rules below shows a sample of the 81 rules in use. There TP is not full, P is full, and SP is very full, where these three variables show the number of vehicles at the traffic lights. Table 1 show sample of rules from 81 rules used.

5. Result and Discussion

In this research, the simulation has been completed. Consists of a fuzzy system. This application was created to predict the optimal green light duration using the fuzzy logic Sugeno method. Applications uses the conditions as follow:

1. In this research, the traffic lights use a four-phase design.
2. Density is input of this system.
3. Density is calculated from the number of vehicles and the lane area for each intersection.
4. Data and implementation at the intersection of R.A.A Martanegara - Pelajar Pejuang 45
5. Density sample data collection is carried out at two times, i.e weekdays and weekends with a less dense and solid phase.
6. Count and generate green light only

Figure 11 present a screenshot of the simulation of this system. This adaptive system shows the results of the crossing road overview. The user can choose which lane to set or calculate the duration of the green light, after selecting the lane then the user can enter the number of vehicles that have been in the Passenger Car Equivalent (EMP) on each lane, and when pressing the Calculate button, an estimated number will be shown for the duration of the green light on the path that was set earlier.

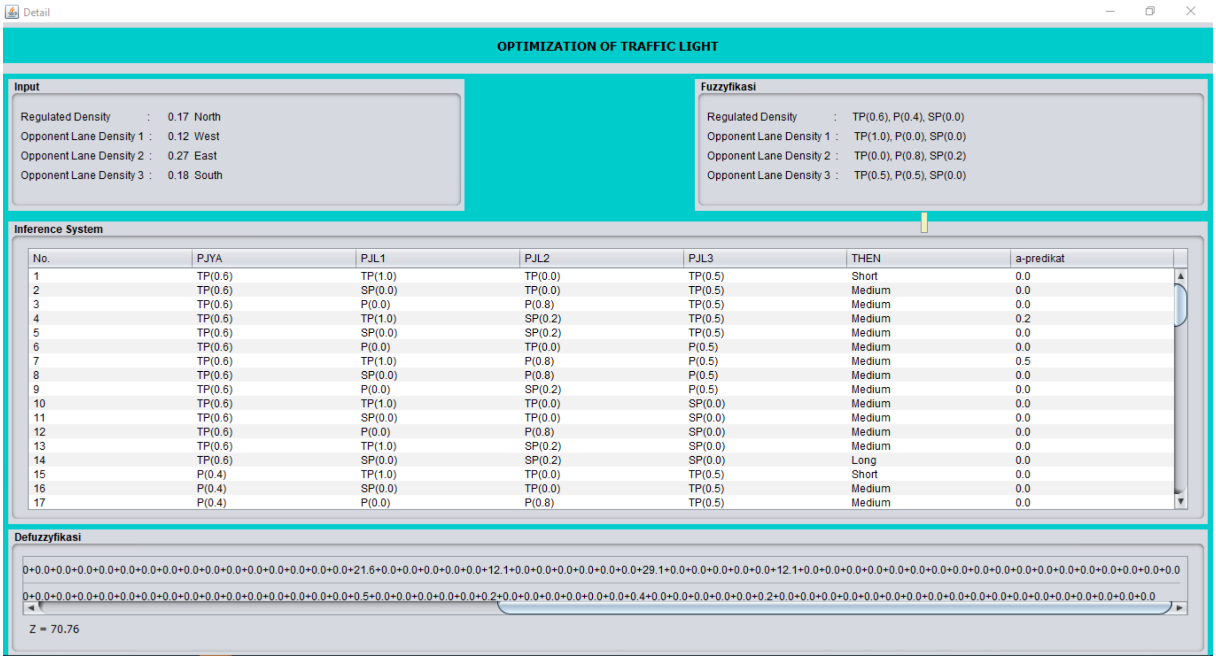

Figure 12: The Details of the Process of Calculating the Green Light Duration

The author has presented an adaptive traffic system for calculating traffic light duration. This system provides a prediction of the optimal green light duration, which is calculated based on the traffic density. This system is developed based on cases and fuzzy interpolation to predict green light duration. The knowledge base in this system is based on the current traffic situation. If this system is implemented by real control system, we can enter data based on actual situation. heuristic rules known to experienced traffic operators will be a useful addition to our system. Therefore, at the next stage of the project, we will incorporate this knowledge into our system by adding a separate fuzzy knowledge module to our system. Another interesting question is how much input is needed in a larger traffic network to make accurate predictions.

6. Conclussion

The results of this paper the Sugeno method of fuzzy logic control for traffic lights is expected to be an adaptive solution to solve problems around the intersection. So that the duration of the green light works based on the density at the four intersections. Density is the calculation result of the number of vehicles divided by the road area. From this simulation, future work can implement a tool that regulates the duration of the green light at intersections using the proposed method.

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