

Comparison of the Implementation of the Mamdani Method and the Sugeno Method in Predicting Green Time at Intersections Based on Vehicle Volume and Lane Width

Khikmatussolekhah*, Isnaini Rosyida

Department of Mathematics, Faculty of Mathematics and Natural Sciences
Universitas Negeri Semarang, Semarang, 50229, Indonesia

Article Info

Article History:

Received 18-06-2025

Accepted 20-04-2026

Published 30-04-2026

Keywords:

Fuzzy Mamdani, Fuzzy Sugeno, MAPE, MATLAB, Green time

Abstract

Traffic congestion is a major problem in big cities, and Semarang City has the largest number of vehicles in Central Java Province. One cause is green time that is not adjusted to the vehicle volume of each approach. This study compares the Mamdani and Sugeno fuzzy methods in predicting green time at the Prince Diponegoro Statue intersection, with vehicle volume and lane width as inputs, green time as output, and MATLAB as software. Data were observed on four approaches in the morning (06.30–07.30 WIB) and the afternoon (16.00–17.00 WIB). Both methods use fuzzification, implication, rule composition, and defuzzification with nine rules. The Mamdani method predicts green times of 33.7 to 63.8 seconds, and the Sugeno method 30 to 70 seconds. The Sugeno method is more accurate, with a MAPE of 7.5% in the morning and 9.5% in the afternoon, against 15.5% and 10.25% for the Mamdani method, although the difference in the afternoon is small. The results show that the Sugeno method can serve as the basis for green time planning at this intersection, that both methods give the same output for high volumes, and that the afternoon green time of Jl. Setia Budi Utara should be reviewed. The Sugeno method should be tested at other intersections.

How to cite:

Khikmatussolekhah, & Rosyida, I. (2026). Comparison of the implementation of the Mamdani method and the Sugeno method in predicting green time at intersections based on vehicle volume and lane width. *UNNES Journal of Mathematics*. 15(1): 43-54

1. Introduction

With the development of technology and the times, the interest in choosing a motorized vehicle is increasing. If not accompanied by the development of transportation infrastructure in the growing number of vehicles, there will be a mismatch between demand and availability, which will eventually lead to congestion. According to the Federal Highway Administration (2005), there are seven main factors that contribute to congestion, one of which is the traffic flow management system with traffic lights installed along the highway (Kurnia et al., 2020).

Traffic lights are indicators that are commonly used as a reference for all people who use the road. It has been regulated in Law No. 22 of 2009, which explains that traffic lights are devices that can regulate and control the movement of vehicle flows at road intersections in order to maintain smoothness and safety while on the road. The existence of traffic lights is very crucial, especially in urban areas, where at certain times the volume of vehicles increases, so an efficient traffic light management system is needed so that traffic remains orderly and smooth (Warni, 2024).

The Central Bureau of Statistics (BPS) in 2021 informed that the data on the number of vehicles in Semarang City occupies the first position in Central Java Province with 1,875,781 vehicles (Statistics, 2024). With the large number of vehicles in Semarang City, congestion conditions often occur. Some intersections in Semarang City are still not running optimally, one of the areas in the Tembalang area. After conducting observations at the Prince Diponegoro Statue intersection, it was found that the conditions that occur on the road are very congested, and congestion often occurs. One of the causes of heavy vehicle queues is the traffic system at the intersection which has a green time that is not balanced with the volume of vehicles and does not pay attention to road conditions. Another cause of congestion in the Diponegoro statue area is that this road is the access for students to the UNDIP and POLINES campuses. Vehicle volume increases during peak hours, such as in the morning between 06.30 - 07.30 WIB people go to work and in the afternoon at 16.00 - 17.00 WIB people go home from work. Therefore, it is necessary to apply mathematical solutions to optimize traffic light timing, especially for green time which is divided into categories (short, medium, and long) by taking into account the volume of vehicles grouped into categories (few, medium, and many) and the condition of the vehicle lane width which is divided into categories (narrow, medium, and wide).

One mathematical approach that can be applied in overcoming traffic light signal optimization is by using fuzzy logic. Fuzzy logic itself can be applied in supporting decision making, especially in conditions involving uncertainty and complexity (Ismiatul K et al., 2019). The beginning of fuzzy logic was introduced by Prof. Lotfi A. Zadeh in 1965 (Amni et al., 2023). The reason for choosing fuzzy logic is because of the simplicity and ease of understanding basic mathematical concepts, fuzzy logic is very flexible, and is able to tolerate data that is less precise or inaccurate (Ismiatul K et al., 2019).

Fuzzy logic means vague or unclear. Therefore, fuzzy logic is vague, or contains aspects of uncertainty. The truth in fuzzy logic is measured based on the level or degree of truth, which is in the range of 0 to 1 (Hignasari, 2021). The basic concept of fuzzy logic is based on fuzzy set theory, which emphasizes the importance of membership degrees in determining whether an element belongs to a particular set. The use of fuzzy logic to predict traffic volume on weekdays aims to improve the accuracy and precision of predictions. Fuzzy logic is applied to create a more efficient and effective traffic forecasting method.

According to Trivusi (2022), Fuzzy Inference System (FIS) is an important component in fuzzy logic. Based on fuzzy set rules, the FIS system processes input data values and produces output values. In general, fuzzy inference systems are useful for transforming input areas to output areas in a non-linear manner by utilizing fuzzy logic. There are several methods that can be applied, such as Mamdani-type, Sugeno-type, and Tsukamoto-type methods. The process involved in the fuzzy inference system consists of several stages, the first stage is fuzzification (converting from clear values into fuzzy sets), the second stage is the application of the implication function, the third stage is rules composition, and the last stage is defuzzification (converting fuzzy sets into clear values) (Septiani et al., 2020).

Of the three methods, significant differences lie in the fuzzy consequence values, aggregation process, and defuzzification process. The advantages of the three methods include that the Mamdani type has the advantage of describing knowledge more intuitively, while the Sugeno type is known for its efficiency in calculation and its ability to perform good optimization and adaptivity. The Tsukamoto type offers advantages in terms of output accuracy and precision, thanks to the use of membership functions that are more specific to each input condition. This method tends to provide sharper and more detailed calculation results (Septiani et al., 2020).

The Mamdani method is a thought process applied to handle problems related to uncertainty and inaccuracy. The basic rules of Mamdani logic are simple and easy to understand, making this method tolerant of inaccurate data (Hardianto & Nurhasanah, 2020). With a simple structure, and using Min - Max or Max - Product operations, Mamdani type methods are widely applied in various applications. This Mamdani type will be more suitable and relevant in solving green time optimization problems because it is not too complex. On the other hand, the Sugeno method uses a fuzzy inference technique with IF - THEN rules, where the output produced is a constant value or linear equation, not a fuzzy set. Sugeno's method is very interesting to be used as one of the methods in green time optimization research because it has the expertise that can produce estimates close to the true value of a function that is not fixed.

Based on the background above, the research that will be carried out by researchers is to use Mamdani type methods and Sugeno type methods to predict green time. Research on traffic has been conducted by several researchers such as Muzaroah et al. (2019), Karyaningsih & Robby (2020), Saleh et al. (2017), Rosyida et al. (2020), Prasetya (2020), Cahyani

& Rosha (2023), Juniana & Hakim (2019), Maslim Martinus (2020), Sharma et al. (2014) and many other researchers. Related to the prediction of vehicle volume and green time has been done by Suprayogi et al. (2021) using the Mamdani method to predict traffic volume and green light duration. In this research, modifications will be made from previous research by Suprayogi by adding input variables and using the Sugeno method. Therefore, this research study will discuss the comparison of the Mamdani method with the Sugeno method to predict green time based on vehicle volume and lane width. It is hoped that this research study can determine the most accurate method between the two methods by using the value of forecasting results as an indicator of accuracy in predicting green time.

2. Method

This research method is carried out using the method of literature study, data collection, data processing and conclusion drawing. Data obtained through direct observation on the Tembalang road at the intersection of four Prince Diponegoro Statues. Data collected in the form of vehicle volume and lane width for 1 week in the morning at 06.30 - 07.30 WIB and in the afternoon at 16.00 - 17.00 WIB.

This research involves two input and output variables. The input variables consist of vehicle volume and lane width, while the output variable is green light duration. Green light duration data was obtained from four approach directions, namely Jl. Soedarto, Jl. Setia budi selatan, Jl. Ngesrep barat, and Jl. Setia budi utara, both in the morning and afternoon. This research uses fuzzy Mamdani and fuzzy Sugeno methods with the support of MATLAB software.

1. Mamdani Method

There are four stages to get the output value, namely (Muflihunna & Mashuri, 2022):

- Fuzzification, this process involves determining the fuzzy set for each input and output variable using membership functions.
- Compilation of fuzzy basic rules, this process uses an implication function in the form of min. Fuzzy basic rules are formed 9 rules based on each input variable.
- Rule composition, the inference process is carried out using the maximum method to combine the results of each applicable rule.
- Defuzzification, in the Mamdani fuzzy method the defuzzification used is the center of gravity method.

2. Sugeno Method

In this research, the zero-order Sugeno fuzzy method is applied through several stages with the help of MATLAB.

- In the Sugeno method, the fuzzy set for input is determined in the same way as in the Mamdani method. The difference lies in the output, where the Sugeno method produces output in the form of a constant equation.
- Compilation of basic fuzzy rules, fuzzy rules in the Sugeno method are arranged in the same way as the Mamdani method, forming 9 rules.
- Rule composition, the inference process is carried out using the maximum method.
- Defuzzification, the defuzzification process is carried out using the center of gravity method.

After performing calculations on the Mamdani and Sugeno methods using MATLAB, after that calculate the mean absolute percentage (MAPE) value to assess the level of accuracy in each method. MAPE is an indicator of the accuracy of the prediction technique that shows the accuracy of the prediction results with the actual results (astuti & mashuri, 2020). MAPE is formulated as follows:

$$MAPE = \frac{\sum_{i=1}^n \frac{|X_i - F_i|}{X_i} \times 100\%}{n}$$

Where:

X_i = original data results of period - i

F_i = predicted results of period - i

n = number of data

A low MAPE indicates that the prediction technique has good accuracy. Forecasting ability is excellent if the MAPE value is < 10%, good forecasting if the MAPE is 10% - 20%, decent/adequate forecasting if the MAPE value is 20% - 50%, and poor forecasting if the MAPE value is > 50%.

The last step in the research is drawing conclusions. Based on the calculation of the MAPE value, a more accurate method will be selected by considering the lower MAPE percentage value.

3. Results and Discussion

In this study, the data taken in the form of vehicle volume and lane width in the morning at 06.30 - 07.30 WIB and in the afternoon at 16.00 - 17.00 WIB. There are two variables, namely input variables in the form of vehicle volume and lane width, and output variables in the form of green time duration. Vehicle volume data has been calculated based on the

average of each approach on Monday - Friday can be seen in Table 1 and Table 2, and lane width data and green time (actual) can be seen in Table 3.

Table 1 Average Vehicle Volume (smp/h) in the Morning

Approach	Average Vehicle Volume
Jl. Soedarto	980
Jl. Setia Budi Selatan	2,248
Jl. Ngesrep Barat	123
Jl. Setia Budi Utara	1,463

Table 2 Average Vehicle Volume (smp/h) in the Afternoon

Approach	Average Vehicle Volume
Jl. Soedarto	848
Jl. Setia Budi Selatan	1,815
Jl. Ngesrep Barat	102
Jl. Setia Budi Utara	2,160

Table 3 Lane Width and Green Time (actual)

Approach	Lane Width	Morning Green Time	Afternoon Green Time
Jl. Soedarto	6.5 m	30	35
Jl. Setia Budi Selatan	8.5 m	70	70
Jl. Ngesrep Barat	3.5 m	35	30
Jl. Setia Budi Utara	8.5 m	40	55

Each input and output will be given a fuzzy set and its domain which can be seen in Table 4 below.

Table 4 Fuzzy Sets

Function	Variables	Fuzzy Set	Universe of Discourse	Domain
Input	Vehicle Volume	Few	[100, 2,300]	[100, 1,200]
		Medium		[700, 1,600]
		Many		[1,500, 2,300]
Output	Lane Width	Narrow	[2,10]	[2, 6]
		Medium		[4,8]
		Wide		[6, 10]
	Green Time	Short	[25,75]	[25,45]
		Medium		[40,55]
		Long		[50,75]

From the data that has been obtained, a membership function can be formed for each input and output variable, following the membership function of each variable.

a. Vehicle Volume

Table 5 Vehicle Volume Membership Function

Fuzzy Set	Domain
Few	[100, 1200]
Medium	[700, 1,600]
Many	[1,500, 2,300]

$$\mu_{Few}(x) = \begin{cases} 1, & 100 \leq x \leq 700 \\ \frac{1,200-x}{500}, & 700 \leq x \leq 1,200 \\ 0, & x \geq 1,200 \end{cases} \quad \mu_{Medium}(x) = \begin{cases} 0, & x \leq 700 \\ \frac{x-700}{500}, & 700 \leq x \leq 1,200 \\ \frac{1,600-x}{400}, & 1,200 \leq x \leq 1,600 \\ 0, & x \geq 1,600 \end{cases} \quad \mu_{Many}(x) = \begin{cases} 1, & 1,600 \leq x \leq 2,300 \\ \frac{x-1,500}{100}, & 1,500 \leq x \leq 1,600 \\ 0, & x \leq 1,500 \end{cases}$$

Membership functions using triangular and trapezoidal representations can be seen in Figure 1 below

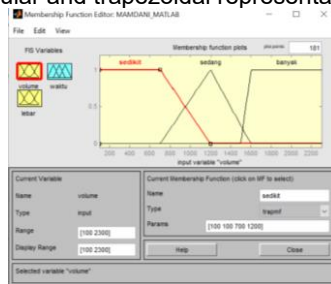


Figure 1 Vehicle Volume Fuzzy Set

b. Lane Width

Table 6 Lane Width Membership Function

Fuzzy Set	Domain
Narrow	[2,6]
Medium	[4,8]
Wide	[6,10]

$$\mu_{Narrow}(x) = \begin{cases} 1, & 2 \leq x \leq 4 \\ \frac{6-x}{2}, & 4 \leq x \leq 6 \\ 0, & x \geq 6 \end{cases} \quad \mu_{Medium}(x) = \begin{cases} 0, & x \leq 4 \text{ or } x \geq 8 \\ \frac{x-4}{1}, & 4 \leq x \leq 5 \\ 1, & 5 \leq x \leq 7 \\ \frac{8-x}{1}, & 7 \leq x \leq 8 \end{cases} \quad \mu_{Wide}(x) = \begin{cases} 1, & 8 \leq x \leq 10 \\ \frac{x-6}{2}, & 6 \leq x \leq 8 \\ 0, & x \leq 6 \end{cases}$$

The membership function using trapezoidal representation can be seen in Figure 2 below.

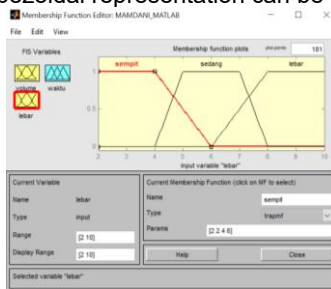


Figure 2 Lane Width Fuzzy Set

c. Green Time

Table 7 Green Time Membership Function

Fuzzy Set	Domain
Short	[25,45]
Medium	[40,55]
Long	[50,75]

$$\mu_{Short}(z) = \begin{cases} 1, & 25 \leq z \leq 40 \\ \frac{45-z}{5}, & 40 \leq z \leq 45 \\ 0, & z \geq 45 \end{cases} \quad \mu_{Medium}(z) = \begin{cases} 0, & z \leq 40 \text{ or } z \geq 55 \\ \frac{z-40}{5}, & 40 \leq z \leq 45 \\ 1, & 45 \leq z \leq 50 \\ \frac{55-z}{5}, & 50 \leq z \leq 55 \end{cases} \quad \mu_{Long}(z) = \begin{cases} 0, & z \geq 50 \\ \frac{z-50}{5}, & 50 \leq z \leq 55 \\ 1, & 55 \leq z \leq 75 \end{cases}$$

The membership function using trapezoidal representation can be seen in Figure 3 below.



Figure 3 Green Time Fuzzy Set

A. Green Time Prediction of Mamdani Method and Sugeno Method

In this study, we will predict the length of green time at the intersection of four Prince Diponegoro Statues using two methods, namely the Mamdani method and the Sugeno method, to compare which method is more accurate and good to apply to predict the length of green time at the intersection.

I. Solution Using Mamdani Method

The following is the solution of the Mamdani method on **Jl. Soedarto** in the morning.

1. Fuzzification

Vehicle volume (980) has a membership value of 2 with the following equation conditions.

$$\mu_{Few}(x) = \begin{cases} 1, & 100 \leq x \leq 700 \\ \frac{1,200-x}{500}, & 700 \leq x \leq 1,200 \\ 0, & x \geq 1,200 \end{cases} \quad \mu_{Medium}(x) = \begin{cases} 0, & x \leq 700 \\ \frac{x-700}{500}, & 700 \leq x \leq 1,200 \\ \frac{1,600-x}{400}, & 1,200 \leq x \leq 1,600 \\ 0, & x \geq 1,600 \end{cases}$$

$$\text{Membership value: } \mu_{Few}(980) = \frac{1,200-980}{500} = \frac{220}{500} = 0.44 \approx 0.4 \text{ and } \mu_{Medium}(980) = \frac{980-700}{500} = \frac{280}{500} = 0.56 \approx 0.6$$

The lane width (6.5) has a membership value of 2 under the following equation.

$$\mu_{Medium}(x) = \begin{cases} 0, & x \leq 4 \text{ or } x \geq 8 \\ \frac{x-4}{1}, & 4 \leq x \leq 5 \\ 1, & 5 \leq x \leq 7 \\ \frac{8-x}{1}, & 7 \leq x \leq 8 \end{cases} \text{ and } \mu_{Wide}(x) = \begin{cases} 1, & 8 \leq x \leq 10 \\ \frac{x-6}{2}, & 6 \leq x \leq 8 \\ 0, & x \leq 6 \end{cases}$$

$$\text{Membership value: } \mu_{Medium}(6.5) = 1 \text{ and } \mu_{Wide}(6.5) = \frac{6.5-6}{2} = 0.25$$

2. Inference

The next stage forms the basic fuzzy rules, considering that the method used is Mamdani, the implication rule applied is the Min function. there are 9 fuzzy rules formed based on the number of fuzzy sets of each input variable. The fuzzy rules are presented in Table 8.

Table 8 Basic Rules of the Mamdani Method

Fuzzy Implication	Vehicle Volume	Lane Width	Green Time
R1	Few	Narrow	Short
R2	Few	Medium	Short
R3	Few	Wide	Short
R4	Medium	Narrow	Long
R5	Medium	Medium	Medium
R6	Medium	Wide	Medium
R7	Many	Narrow	Long
R8	Many	Medium	Long
R9	Many	Wide	Long

[R2] If the vehicle volume is **few** and the lane width is **medium**, the green time duration is **short**.

$$\mu_2 = \mu_{Few} \cap \mu_{Medium} = \min(\mu_{Few}(980), \mu_{Medium}(6.5)) = \min(0.4, 1) = 0.4$$

[R3] If the vehicle volume is **few** and the lane width is **wide**, the green time duration is **short**.

$$\mu_3 = \mu_{Few} \cap \mu_{Wide} = \min(\mu_{Few}(980), \mu_{Wide}(6.5)) = \min(0.4, 0.25) = 0.25$$

[R5] If the vehicle volume is **medium** and the lane width is **medium**, the green time duration is **medium**.

$$\mu_5 = \mu_{Medium} \cap \mu_{Medium} = \min(\mu_{Medium}(980), \mu_{Medium}(6.5)) = \min(0.6, 1) = 0.6$$

[R6] If the vehicle volume is **medium** and the lane width is **wide**, the green time duration is **medium**.

$$\mu_6 = \mu_{Medium} \cap \mu_{Wide} = \min(\mu_{Medium}(980), \mu_{Wide}(6.5)) = \min(0.6, 0.25) = 0.25$$

3. Rule Composition

In the Mamdani method of performing fuzzy inference, the Max method is used. The value of a can be determined based on the following calculation.

$$a_1 = \frac{a_1-40}{5} = 0.4 \leftrightarrow a_1 - 40 = 2 \leftrightarrow a_1 = 42, \quad a_2 = \frac{45-a_2}{5} = 0.25 \leftrightarrow 45 - a_2 = 1.25 \leftrightarrow a_2 = 43.75$$

$$a_3 = \frac{a_3-40}{5} = 0.25 \leftrightarrow a_3 - 40 = 1.25 \leftrightarrow a_3 = 41.25, \quad a_4 = \frac{55-a_4}{5} = 0.25 \leftrightarrow 55 - a_4 = 1.25 \leftrightarrow a_4 = 53.75$$

$$a_5 = \frac{a_5-40}{5} = 0.6 \leftrightarrow a_5 - 40 = 3 \leftrightarrow a_5 = 43, \quad a_6 = \frac{55-a_6}{5} = 0.56 \leftrightarrow 55 - a_6 = 3 \leftrightarrow a_6 = 52$$

The results of the rule composition are presented in Figure 4 below.

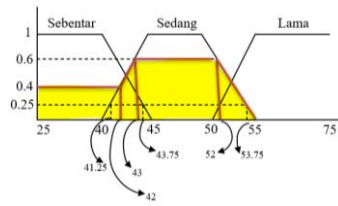


Figure 4 Green time inference for Jl. Soedarto

So the membership function of the composition above is

$$\mu_{Medium}(z) = \begin{cases} 0.4, & 25 \leq z \leq 42 \\ \frac{z-40}{5}, & 42 \leq z \leq 43 \\ 0.6, & 43 \leq z \leq 52 \\ \frac{55-z}{5}, & 52 \leq z \leq 55 \end{cases}$$

4. Defuzzification

The defuzzification used is using the center of gravity method, therefore the first thing to do is to calculate the moments in each region.

$$M1 = \int_{25}^{42} 0.4 z dz$$

$$= 0.4 \times \frac{z^2}{2} = 0.4 \left(\frac{42^2}{2} - \frac{25^2}{2} \right) = 0.4(882 - 312.5) = 227.8$$

$$M2 = \int_{42}^{43} \left(\frac{z-40}{5} \right) z dz$$

$$= \int_{42}^{43} \frac{1}{5} (z^2 - 40z) dz$$

$$= \frac{1}{5} \left[\int_{42}^{43} z^2 dz - 40 \int_{42}^{43} z dz \right] = \frac{1}{5} \left[\frac{z^3}{3} - 40 \times \frac{z^2}{2} \right]_{42}^{43}$$

$$= \frac{1}{5} \left[\left(\frac{43^3}{3} - \frac{42^3}{3} \right) - 50 \times \left(\frac{43^2}{2} - \frac{42^2}{2} \right) \right]$$

$$= \frac{1}{5} [319] = 21.26$$

$$M3 = \int_{43}^{52} 0.6 z dz$$

$$= 0.6 \times \frac{z^2}{2} = 0.6 \left(\frac{52^2}{2} - \frac{43^2}{2} \right) = 0.6(1352 - 924.5) = 256.5$$

$$M4 = \int_{52}^{55} \left(\frac{55-z}{5} \right) z dz$$

$$= \int_{52}^{55} \frac{1}{5} (55z - z^2) dz$$

$$= \frac{1}{5} \left[\int_{52}^{55} 55z dz - \int_{52}^{55} z^2 dz \right] = \frac{1}{5} \left[\frac{55}{2} z^2 - \frac{z^3}{3} \right]_{52}^{55}$$

$$= \frac{1}{5} \left[\left(\frac{55(55^2)}{2} - \frac{55^3}{3} \right) - \left(\frac{55(52^2)}{2} - \frac{52^3}{3} \right) \right]$$

$$= \frac{1}{5} [27729.17 - 27490.67] = 47.7$$

Then calculate the area of each region: $A1 = 17 \times 0.4 = 6.8$, $A2 = \frac{1 \times 0.6}{2} = 0.3$, $A3 = 9 \times 0.6 = 5.4$, $A4 = \frac{3 \times 0.6}{2} = 0.9$

The center point is obtained from: $z = \frac{227.8 + 21.26 + 256.5 + 47.7}{6.8 + 0.3 + 5.4 + 0.9} = \frac{553.26}{13.4} = 41.28$

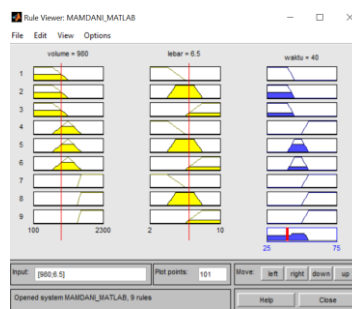


Figure 5 Defuzzification of Mamdani Method Jl. Soedarto

II. Solution Using Sugeno Method

The following is the Sugeno method solution on **Jl. Soedarto** in the morning.

1. Fuzzification

In this research, the zero-order Sugeno method with constant output is used. Fuzzification in the Sugeno method is the same as fuzzification in the Mamdani method, different only in the output. The fuzzy rules in this Sugeno method assume that the constant value is taken from the length of the longest vehicle queue, which is 72 meters. This means that the estimated length of green time is 70 seconds. Given the output membership function in the form of fuzzy points, the output variable is taken in the range of 7 fuzzy points, namely 10, 20, 30, 40, 50, 60, 70 seconds.

2. Inference

The next stage forms the basic fuzzy rules, considering that the method used is Sugeno, the fuzzy value output rules are constants. there are 9 fuzzy rules formed based on the number of fuzzy sets of each input variable. The fuzzy rules are presented in Table 9.

Table 9 Sugeno Method Basic Rules

Fuzzy Implication	Vehicle Volume	Lane Width	Green Time
R1	Few	Narrow	30
R2	Few	Medium	30
R3	Few	Wide	20
R4	Medium	Narrow	50
R5	Medium	Medium	40
R6	Medium	Wide	40
R7	Many	Narrow	70
R8	Many	Medium	60
R9	Many	Wide	70

[R2] If the vehicle volume is **few** and the lane width is **medium** then the green time duration = 30

$$\mu_2 = \mu_{Few} \cap \mu_{Medium} = \min(\mu_{Few}(980), \mu_{Medium}(6.5)) = \min(0.4, 1) = 0.4, \text{ value } z_2 = 30$$

[R3] If the vehicle volume is **few** and the lane width is **wide** then the green time duration = 20

$$\mu_3 = \mu_{Few} \cap \mu_{Wide} = \min(\mu_{Few}(980), \mu_{Wide}(6.5)) = \min(0.4, 0.25) = 0.25, \text{ value } z_3 = 20$$

[R5] If the vehicle volume is **medium** and the lane width is **medium** then the green time duration = 40

$$\mu_5 = \mu_{Medium} \cap \mu_{Medium} = \min(\mu_{medium}(980), \mu_{medium}(6.5)) = \min(0.6, 1) = 0.6, \text{ value } z_5 = 40$$

[R6] If the vehicle volume is **medium** and the lane width is **wide** then the green time duration = 40

$$\mu_6 = \mu_{Medium} \cap \mu_{Wide} = \min(\mu_{Medium}(980), \mu_{Wide}(6.5)) = \min(0.6, 0.25) = 0.25, \text{ value } z_6 = 40$$

3. Defuzzification

Next, find the z value using the centroid or center of gravity method, namely:

$$z = \frac{\mu_2 \cdot z_2 + \mu_3 \cdot z_3 + \mu_5 \cdot z_5 + \mu_6 \cdot z_6}{\mu_2 + \mu_3 + \mu_5 + \mu_6} \leftrightarrow z = \frac{(0.4 \times 30) + (0.25 \times 20) + (0.6 \times 40) + (0.25 \times 40)}{0.4 + 0.25 + 0.6 + 0.25} = \frac{51}{1.5} = 34$$

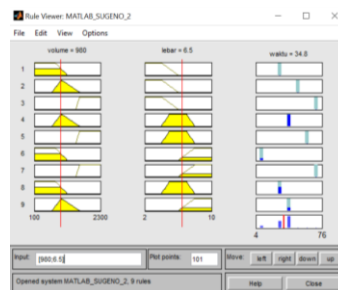


Figure 6 Defuzzification of the Sugeno Method for Jl. Soedarto

The Mamdani and Sugeno calculations for the other three approaches in the morning follow the same steps as for Jl. Soedarto (fuzzification, implication with the minimum function, rule composition, and defuzzification), and their intermediate values are summarized in Table 10. The manual Mamdani values agree with the MATLAB results in Table 11 (41.3 against 40.5, 63.6 against 63.8, 33.8 against 33.7, and 47.5 against 47.5).

Table 10 Intermediate results of the morning calculation for the four approaches

Approach	Volume (smp/h)	Lane width (m)	Active memberships	Active rules (firing strength)	Mamdan i (manual)	Sugen o
Jl. Soedarto	980	6.5	Few 0.44, Medium 0.56; Medium 1, Wide 0.25	R2 0.4, R3 0.25, R5 0.6, R6 0.25	41.3	34
Jl. Setia Budi Selatan	2,248	8.5	Many 1; Wide 1	R9 (1)	63.6	70
Jl. Ngesrep Barat	123	3.5	Few 1; Narrow 1	R1 (1)	33.8	30
Jl. Setia Budi Utara	1,463	8.5	Medium 0.3; Wide 1	R6 (0.3)	47.5	40

B. ANALYSIS OF RESULTS

Based on calculations that have been carried out using the Mamdani method and the Sugeno method, both manually and with the help of MATLAB, results are obtained that show relatively small differences between the two methods. The following presents details of the results of each method based on MATLAB. Can be seen in Tables 11 to 14 below.

Table 11 Green Time Predicted by the Mamdani Method at the Prince Diponegoro Statue Intersection in the Morning

Approach	INPUT		OUTPUT
	Vehicle Volume	Lane Width	Prediction Result
Jl. Soedarto	980	6.5	40
Jl. Setia Budi Selatan	2,248	8.5	63.8
Jl. Ngesrep Barat	123	3.5	33.7
Jl. Setia Budi Utara	1,463	8.5	47.5

Table 12 Green Time Predicted by the Sugeno Method at the Prince Diponegoro Statue Intersection in the Morning

Approach	INPUT		OUTPUT
	Vehicle Volume	Lane Width	Prediction Result
Jl. Soedarto	980	6.5	34.8
Jl. Setia Budi Selatan	2,248	8.5	70
Jl. Ngesrep Barat	123	3.5	30
Jl. Setia Budi Utara	1,463	8.5	40

Table 13 Green Time Predicted by the Mamdani Method at the Prince Diponegoro Statue Intersection in the Afternoon

Approach	INPUT		OUTPUT
	Vehicle Volume	Lane Width	Prediction Result
Jl. Soedarto	848	6.5	36.8
Jl. Setia Budi Selatan	1815	8.5	63.8
Jl. Ngesrep Barat	102	3.5	33.7
Jl. Setia Budi Utara	2160	8.5	63.8

Table 14 Green Time Predicted by the Sugeno Method at the Prince Diponegoro Statue Intersection in the Afternoon

Approach	INPUT		OUTPUT
	Vehicle Volume	Lane Width	Prediction Result
Jl. Soedarto	848	6.5	31
Jl. Setia Budi Selatan	1,815	8.5	70
Jl. Ngesrep Barat	102	3.5	30
Jl. Setia Budi Utara	2160	8.5	70

Based on the comparison results, the calculation of green time duration using Mamdani method and Sugeno method can be used as an alternative in determining green time at Prince Diponegoro statue intersection. This is because the prediction results of both methods do not show a significant difference to the actual data in the field. With relatively good accuracy, especially in the Sugeno method which on some approaches is able to produce predictions that are the same as actual conditions, the application of this method can help policy makers in optimizing green time duration in a more adaptive and data-based manner.

C. MAPE Value Calculation

After obtaining the value of the green time prediction results at the four Prince Diponegoro Statue intersections both in the morning and evening using the Mamdani and Sugeno methods, the next stage is to find the MAPE value of each approach to obtain the accuracy value of the two methods. The following are the results of the MAPE value obtained from each intersection.

Table 15 MAPE of Green Time Predicted by the Mamdani Method in the Morning

Approach	INPUT		OUTPUT		$\left \frac{y - \hat{y}}{y} \right $
	Vehicle Volume	Lane Width	Actual Data	Prediction Result	
Jl. Soedarto	980	6.5	30	40	0.33
Jl. Setia Budi Selatan	2,248	8.5	70	63.8	0.08
Jl. Ngesrep Barat	123	3.5	35	33.7	0.03
Jl. Setia Budi Utara	1,463	8.5	40	47.5	0.18
Total $\left \frac{y - \hat{y}}{y} \right $					0.62
MAPE					15.5%

Based on Table 15, the MAPE result is 15.5% which is 10%-20% so that the MAPE evaluation criteria are good.

Table 16 MAPE of Green Time Predicted by the Sugeno Method in the Morning

Approach	INPUT		OUTPUT		$\left \frac{y - \hat{y}}{y} \right $
	Vehicle Volume	Lane Width	Actual Data	Prediction Result	
Jl. Soedarto	980	6.5	30	34.8	0.16
Jl. Setia Budi Selatan	2,248	8.5	70	70	0
Jl. Ngesrep Barat	123	3.5	35	30	0.14
Jl. Setia Budi Utara	1,463	8.5	40	40	0
Total $\left \frac{y - \hat{y}}{y} \right $					0.3
MAPE					7.5%

Based on Table 16, the MAPE result is 7.5% which is <10% so that the MAPE evaluation criteria are very good.

Table 17 MAPE of Green Time Predicted by the Mamdani Method in the Afternoon

Approach	INPUT		OUTPUT		$\left \frac{y - \hat{y}}{y} \right $
	Vehicle Volume	Lane Width	Actual Data	Prediction Result	
Jl. Soedarto	848	6.5	35	36.8	0.06
Jl. Setia Budi Selatan	1815	8.5	70	63.8	0.08
Jl. Ngesrep Barat	102	3.5	30	33.7	0.12
Jl. Setia Budi Utara	2160	8.5	55	63.8	0.16
Total $\left \frac{y - \hat{y}}{y} \right $					0.41
MAPE					10.25%

Based on Table 17, the MAPE result is 10.25% which is 10%-20% so that the MAPE evaluation criteria are good.

Table 18 MAPE of Green Time Predicted by the Sugeno Method in the Afternoon

Approach	INPUT		OUTPUT		$\left \frac{y - \hat{y}}{y} \right $
	Vehicle Volume	Lane Width	Actual Data	Prediction Result	
Jl. Soedarto	848	6.5	35	31	0.11
Jl. Setia Budi Selatan	1,815	8.5	70	70	0
Jl. Ngesrep Barat	102	3.5	30	30	0
Jl. Setia Budi Utara	2160	8.5	55	70	0.27
Total $\left \frac{y - \hat{y}}{y} \right $					0.38
MAPE					9.5%

Based on Table 18, the MAPE result is 9.5% which is <10% so that the MAPE evaluation criteria are very good.

D. Discussion

The results show that both methods give usable predictions of green time, with the Sugeno method more accurate (MAPE of 7.5% and 9.5%) than the Mamdani method (15.5% and 10.25%). The advantage is clear in the morning but small in the afternoon (0.75 percentage points), and with four approaches in each period (eight comparisons in total) it should be read as a tendency and not as a proven superiority. The Sugeno method reproduces the existing green time exactly in four of the eight cases (70 s and 40 s in the morning, and 70 s and 30 s in the afternoon), which is partly explained by its design: its constants were set in steps of 10 seconds up to 70 seconds from the longest queue (72 m), so that the predictions are discrete and close to the existing values, whereas the Mamdani output is a continuous blend of the fuzzy sets, which pulls the prediction of Jl. Soedarto toward the medium set (40.5 s against the existing 30 s).

Two features limit what both methods can do. First, the membership function of many vehicles is equal to one from 1,600 to 2,300 vehicles, so the approaches with 2,248 and 2,160 vehicles obtain the same output (63.8 s for Mamdani and 70 s for Sugeno), and the models cannot separate high volumes. Second, the existing green times do not always follow the volume: in the afternoon Jl. Setia Budi Utara has the highest volume (2,160) but an existing green time of 55 s, whereas Jl. Setia Budi Selatan with 1,815 vehicles has 70 s, and both methods suggest 63.8 s or 70 s for Jl. Setia Budi Utara. The error of 27% (Sugeno) and 16% (Mamdani) there is therefore more likely to show that the existing time is short for this approach than a failure of the models, which is why MAPE against the existing times measures agreement with current practice and not optimality. The total of the predicted green times is close to the existing cycle in the morning (about 175 s for Sugeno and 185 s for Mamdani against 175 s) but longer in the afternoon (about 201 s and 198 s against 190 s), so that the predictions must be fitted to the cycle length before they are applied.

The finding that the Sugeno method is more accurate agrees with Septiani et al. (2020), who found the Sugeno method more optimal than the Mamdani method for the green light delay on Ahmad Yani Street in Bandung. This study extends the earlier work in three ways. Suprayogi et al. (2021) predicted traffic volume and green time with the Mamdani method only, and the present study adds lane width as an input and the Sugeno method as a comparison. Muzaroah et al. (2019), Rosyida et al. (2020), and Cahyani and Rosha (2023) used fuzzy graph coloring and fuzzy inference to determine phases and durations of traffic lights, whereas this study compares two inference types on the same data for the green time of each approach and reports the accuracy in both peak periods. Third, the analysis of the discrepancies shows where the existing timing deviates from the demand, which the earlier studies did not report. Because the studies differ in the intersection, the inputs, and the accuracy measure, the comparison is limited to the direction of the findings.

The novelty of the findings is therefore that, for an intersection in Semarang with two peak periods, the Sugeno method is more accurate than the Mamdani method but by a margin that depends on the period, that both methods saturate at high volume, and that the errors point to approaches whose existing green time may need to be reviewed. These findings lead to the following recommendations for the traffic agency. (1) Use the Sugeno method as the basis for green time planning at this intersection, because it is more accurate and simpler to compute. (2) Review the afternoon green time of Jl. Setia Budi Utara (55 s existing against 63.8 to 70 s predicted) and the morning green time of Jl. Soedarto (30 s against 34.8 to 40.5 s). (3) Fit the predicted green times to the cycle length before application. (4) Test the method at other intersections and compare it with field delay or queue length.

Several limitations should be noted. The data are the averages of one week for four approaches, the existing green time is used as the reference although it is not necessarily optimal, the Sugeno constants were set by judgment, the volume membership saturates at 1,600 vehicles, and no delay or queue length was measured. Future research should tune the constants with data, add a validation period, include the cycle length and the intergreen time, and use delay as the accuracy measure.

4. Conclusion

Based on the research results, the conclusions are as follows.

1. The mamdani and sugeno fuzzy methods were used to determine the green time at the prince diponegoro statue intersection with fuzzification, implication, rule composition, and defuzzification; nine rules were formed, and both methods use the centroid for defuzzification.
2. The mamdani method predicts 33.7 to 63.8 seconds and the sugeno method 30 to 70 seconds for the four approaches in the morning and the afternoon (tables 11 to 14). Both methods can be used as an alternative in determining green time, but the sugeno method is recommended because it is more accurate.
3. The sugeno method has a mape of 7.5% in the morning and 9.5% in the afternoon, and the mamdani method 15.5% and 10.25%, so the sugeno method is more accurate, although the difference in the afternoon is small. It is recommended to review the afternoon green time of jl. Setia budi utara and to test the sugeno method at other intersections.

Acknowledgements

The researchers express their gratitude to all parties who have provided support, assistance, and contributions in the process of preparing and completing this research, both directly and indirectly.

References

- Amni, D., & (2023). Penerapan metode fuzzy Mamdani pada pemilihan bidang pekerjaan sesuai kompetensi (studi kasus di Atak Kerinci). *Jurnal SIMTIKA*, 6(2).
- Astuti, P., & Mashuri. (2020). Penerapan metode fuzzy Tsukamoto dan fuzzy Sugeno dalam penentuan harga jual sepeda motor. *UNNES Journal of Mathematics*, 9(2), 74–78.
- Badan Pusat Statistik. (2024). *Jumlah kendaraan bermotor menurut kabupaten/kota dan jenis kendaraan di Provinsi Jawa Tengah (unit)*.
- Cahyani, A. W., & Rosha, M. (2023). Optimasi lampu lalu lintas simpang Tabuik Kota Pariaman menggunakan graf fuzzy berbasis FIS tipe Mamdani. *Journal of Mathematics UNP*, 8(3), 16–25.
- Hardianto, H., & Nurhasanah, N. (2020). Identifikasi penyakit pada sel darah menggunakan logika fuzzy Mamdani. *Prisma Fisika*, 7(3), 269. <https://doi.org/10.26418/pf.v7i3.38106>
- Hignasari, L. V. (2021). Kajian teoritis aplikasi logika fuzzy dalam optimasi jumlah produksi pada sebuah industri. *Jurnal Ilmiah Vastuwidya*, 4(2), 51–58. <https://doi.org/10.47532/jiv.v4i2.321>
- Ismiatul K, S., Rosyida, I., & Zaenuri. (2019). Implementasi model fuzzy-wavelet dan FIS metode Mamdani dalam prediksi nilai tukar EUR/IDR. *PRISMA, Prosiding Seminar Nasional Matematika*, 8(2), 313–322.
- Juniana, P., & Hakim, L. (2019). Kendali lampu lalu lintas dengan menggunakan metode fuzzy logic Mamdani. *Jutei*, 3(1), 1–10. <https://doi.org/10.21460/jutei.2018.31.126>

- Karyaningsih, D., & Robby, R. (2020). Implementation of fuzzy Mamdani method for traffic lights smart city in Rangkasbitung, Lebak Regency, Banten Province (case study of the traffic light T-junction, Cibadak, By Pas Sukarno Hatta Street). *Jurnal KomtekInfo*, 7(3), 176–185.
- Kurnia, Mulyono, & Rochmad, D. (2020). Algoritma bee colony dengan metode fuzzy Mamdani untuk pengaturan lalu lintas. *UNNES Journal of Mathematics*, 9(2), 64–73.
- Maslim Martinus, D. B. Y. (2020). Implementasi metode logika fuzzy dalam pembangunan sistem optimalisasi lampu lalu lintas. 14(9), 3233–3242.
- Muflihunna, K., & Mashuri, M. (2022). Penerapan metode fuzzy Mamdani dan metode fuzzy Sugeno dalam penentuan jumlah produksi. *UNNES Journal of Mathematics*, 11(1), 27–37. <https://doi.org/10.15294/ujm.v11i1.50060>
- Muzaroah, S., Mulyono, Syafaatullah, M. F., & Rosyida, I. (2019). Aplikasi pewarnaan graf fuzzy dan FIS tipe Sugeno untuk menentukan fase dan durasi tiap fase pada pengaturan lampu lalu lintas. *PRISMA, Prosiding Seminar Nasional Matematika*, 2, 516–525.
- Prasetya, R. P. (2020). Implementasi fuzzy Mamdani pada lampu lalu lintas secara adaptif untuk meminimalkan waktu tunggu pengguna jalan. *Jurnal Mnemonic*, 3(1), 24–29. <https://doi.org/10.36040/mnemonic.v3i1.2526>
- Rosyida, I., Nurhaida, Narendra, A., & Widodo. (2020). Matlab algorithms for traffic light assignment using fuzzy graph, fuzzy chromatic number, and fuzzy inference system. *MethodsX*, 7, Article 101136. <https://doi.org/10.1016/j.mex.2020.101136>
- Saleh, A., Fujiati, Rosnelly, R., Rosnelly, K., & Sanjaya, A. (2017). A comparison of Mamdani and Sugeno method for optimization prediction of traffic noise levels. In *2017 International Conference on Cyber and IT Service Management (CITSM)* (pp. 1–4). IEEE.
- Septiani, R., Novianingsih, K., & Entit, P. (2020). Optimisasi delay lampu hijau lalu lintas menggunakan fuzzy metode Mamdani dan metode Sugeno. *EurekaMatika*, 8(1), 83–99.
- Sharma, B., Katiyar, V. K., & Gupta, A. K. (2014). Fuzzy logic model for the prediction of traffic volume in week days. *International Journal of Computer Applications*, 107(17), 1–6. <https://doi.org/10.5120/18840-0026>
- Suprayogi, A., Rosyida, I., Wiyanti, D. T., & Safaatullah, M. F. (2021). Implementation of Mamdani fuzzy implication in predicting traffic volume and duration of green lights on an intersection. *Journal of Physics: Conference Series*, 2106(1). <https://doi.org/10.1088/1742-6596/2106/1/012020>
- Trivusi. (2022). *Perbedaan fuzzy inference system: Mamdani, Sugeno, dan Tsukamoto*. <https://www.trivusi.web.id/2022/10/metode-inferensi-fuzzy.html>
- Warni, N. K. (2024). *Penemuan lampu lalu lintas dan manfaatnya*. Radio Republik Indonesia.