Implementation of mamdani fuzzy implication in predicting traffic volume and duration of green lights on an intersection

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Abstract. Traffic congestion at an intersection could be caused by the volume of vehicles that exceed the road capacity, the duration of the green light that is fixed, and so on. The volume of vehicles per unit time at an intersection cannot be known with certainty. Therefore, we need to predict it using fuzzy logic, specifically the Mamdani fuzzy implications. The problems are as follows: how are the input variables to be analyzed with Mamdani fuzzy implications; how are the prediction results, and how is the accuracy based on MAPE. The case study was conducted at two intersections in Semarang City. The tests were carried out using Matlab and manual calculations. The input variables in traffic volume prediction are MC, LV, HV, and time. While the input in the prediction of the duration of the green light is the number of motorcycles and cars. Based on the predictions, there are 74 vehicles (per hour) at the Kaligarang intersection in the east-north direction, there are 111 vehicles at the Kariadi intersection in the south-north direction, and the predictions are good and very accurate (measured by MAPE). The duration of the green light at the Kaligarang intersection on the west approach is 86 seconds, the duration on the Kariadi intersection on the north approach is 81 seconds, and the predictions are good and very accurate.

Keywords: Fuzzy logic, Mamdani fuzzy implication, Traffic volume, Greenlight duration, Intersection, Matlab

1. Introduction
Transportation is utilized to move goods or people from one place to another. Alhadar [1] states if transportation no longer exists, then it can be said that life has ceased to exist because everything in the world does not move. More people use public or private transportation every day, which will lead to more potential for congestion. According to Zadobrischi et al. [2], the long queue of vehicles is caused by the obstruction of traffic flow which consists of two factors, namely limited road capacity or too many vehicles. Traffic jams cause negative impacts such as increased air pollution, more fuel consumption, losses in the economic sector, and so on. Therefore, it is necessary to predict the volume of vehicles at an intersection during peak hours to determine whether there is a traffic jam at the intersection.

Traffic volume is defined as the vehicles that pass at a point on the road segment [3]. According to Rosyida et al. [4], volume is the set of the number of vehicles for all traffic flows. Traffic volume can be expressed in terms of annual, daily, hourly, or smaller units. Menurut Nego et al. [5], unit of volume in simple is the vehicle. Although it can be expressed in another way is unit car passengers (SMP) per unit time. In the traffic system, signals or traffic lights have an important role. According to
Law no. 22/2009 concerning road traffic and transportation in Indonesia, the traffic light is a traffic signaling device or (APIILL) that controls traffic flow installed at road intersections, pedestrian crossings (zebra crosses), and other areas [6]. According to Kunia [7], the purpose of traffic lights at intersections is to provide pedestrian facilities to cross, reduce accident rates, and avoid obstacles, etc. According to Rosyida et al. [4], there are several terms in the problem of traffic lights, namely a phase and a traffic flow. The phase at an intersection is part of the signal cycle when the green light is assigned to a certain combination of traffic movements. Traffic flow is the study of the movement of conveyances between two locations.

In the congestion problems, not all answers can be concluded with a “Yes” or “No” answer. For example, in predicting the volume of vehicles and calculating the duration of the green light, it is possible for concluding the answers into some categories, i.e., few, medium, many, or short, medium, long, etc. Therefore, we need a solution to the problem using fuzzy set theory, especially fuzzy logic. Kusumadewi and Purnomo [8] said that fuzzy logic was first developed by Prof. Lotfi A. Zadeh in 1965. Fuzzy logic is developed from theories in the fuzzy sets, i.e., a logic that contains indeterminate phenomena where an element has a degree of truth between 0 and 1. In fuzzy logic, there are 3 methods, one of which is the Mamdani method. The Mamdani method or often known as the Max-Min method was introduced by Ebrahim Mamdani in 1975. According to Cox 1995 in Rosyida [9], the reason for using fuzzy logic in this research is that the mathematical concepts underlying fuzzy reasoning are very simple and easy to understand. Another reason is fuzzy logic is very flexible and has tolerance for incomplete data.

Traffic cases have been resolved by Septyanto, et al. [10], Juniana [11], and Sharma [12]. In the research of Septyanto, et al., [10] traffic jam monitoring was carried out using a fuzzy algorithm combined with an RFID (Radio Frequency Identification) innovation with the input of vehicle speed and road width. Juniana [11] conducted a study on the implementation of the Mamdani fuzzy method in improving the program of traffic signal control by developing a prototype, namely an infrared sensor. It is used to detect the density of vehicles on three lanes or one-third of the road. In Sharma's research [12], predictions of traffic volumes on weekdays have been conducted using fuzzy logic where the accuracy of predictions was done using MAPE (Mean Absolute Percentage Error) calculations. The input in [12] was the time and day and the output was the traffic volume.

Different from the above research, we use time and the number of Motorcycle (MC), Light Vehicle (LV), and Heavy Vehicle (HV) as input variables to be analyzed with Mamdani fuzzy implication. This study examines two problems as follows: the predictions of traffic volumes and green light durations using Mamdani fuzzy implication at Kaligarang and Kariadi intersections; the determination of the accuracy of the predictions based on MAPE (Mean Absolute Percentage Error).

2. Method

This study discusses the problem of predicting traffic volume and green light duration at 2 major intersections in Semarang City, Central Java, namely the Kaligarang intersection and the Kariadi intersection with two time periods in the morning and afternoon. The research was carried out in February – March 2021. If the library sources have been collected, then proceed with the core understanding of the library sources which is used as the basis for analyzing research. The data are the number of vehicles passing through the intersections which are classified into MC (Motorcycle), LV (Light Vehicle), and HV (Heavy Vehicle). According to Marpaung [13], LV (Light Vehicles) have a type of vehicles such as passenger cars, oplets, microbuses, pick-ups and small trucks, HV (Heavy Vehicle) have a type of vehicles such as bus, 2 axle trucks, 3 axles trucks, and mixed trucks according to the Bina Marga classification system, and MC (Motorcycle) have a type of vehicles such as motorcycles and 3-wheeled vehicles according to the Bina Marga classification. The data of the number of vehicles per hour are converted into pcu (passenger car unit), where the pcu of LV is 1.0, the pcu for HV and MC are 1.3 and 0.2, respectively.

Data were collected by observing the Kaligarang and Kariadi intersections in Semarang City, Central Java in 2 time periods, morning, and afternoon at 06.00-08.00 WIB and 16.00-18.00 WIB.
Observations are supported by the process of recording the number of vehicles that pass through these roads and documentation in the form of videos as supporting research data. The next stage is analyzing the data into Mamdani fuzzy implications manually and using Matlab 2017. The steps in the Mamdani method are as follows:
1) Fuzzification: converting the input data into the fuzzy set. The input variables for predicting traffic volume are the number MC, LV, and HV as well as the period (morning and afternoon). While the input variables for predicting the duration of the green lights are motorcycles and cars.
2) Construction of Mamdani function implications (Rules): the implication function used in the Mamdani fuzzy logic is the MIN function by taking the minimum membership level of the input variables.
3) Determination of the composition of rules: the composition of the rules in the Mamdani method is the conclusion of the whole by taking the maximum membership level.
4) Defuzzification: this step will change a fuzzy output into a crisp output, which is the prediction of the number of traffic volumes and duration of green lights. In the defuzzification’s step, we use the COA (Centre of Area) method with the following formula
\[ z = \frac{\int_z z \mu(z) dz}{\int \mu(z) dz} \]  
(1)
5) Accuration: The last step is to calculate the accuracy of the prediction using MAPE (Mean Absolute Percentage Error) with the following formula:
\[ MAPE = \frac{\sum_{i=1}^{n} |x_i - \hat{x}_i| \times 100\%}{n} \]  
(2)
Wardani [14] declared that MAPE is the absolute percentage of the error to the actual result over a certain period. According to Lewis (1982) in Adli[15], the interpretation of MAPE values can be seen in Table 1.

| MAPE  | Interpretation  |
|-------|-----------------|
| < 10  | Forecasting is very accurate |
| 10-20 | Good fortune telling |
| 20 - 50 | Reasonable forecast |
| > 50  | Inaccurate forecast |

3. Results and Discussion
In this study, several data are processed including the calculation of the volume of vehicles at the Kaligarang intersection in the east - the north direction in the morning, the volume of vehicles at the Kariadi Intersection in the south-north in the afternoon, the duration of the green light at the Kaligarang intersection, and the duration of the green light at the Kariadi intersection.

3.1. Prediction of Volume of Vehicles at Kaligarang Intersection

In the prediction of the volume of vehicles at the Kaligarang intersection, four variables are used as inputs from the data at the Kaligarang intersection in the direction of east to north movement in the morning. The data are presented in Table 2.

| Variable | Fuzzy Set Name | Universe Set |
|----------|----------------|--------------|
| MC       | Few            | [5,25]       |
Furthermore, these variables are transformed into fuzzy sets as follows:

a. Time Variable

The fuzzification of the Time variable is shown in Table 3.

| Fuzzy Set Name | The domain of membership Function |
|----------------|-----------------------------------|
| Quiet          | [06.00, 06.35]                    |
| Medium         | [06.30, 07.05]                    |
| Busy           | [07.00, 07.35]                    |
| Very busy      | [07.30, 08.00]                    |

The membership function of time variable is as follows:

\[
\mu_{\text{quiet}}(x) = \begin{cases} 
1, & 6.00 \leq x \leq 6.30 \\
\frac{6.35-x}{6.35-6.30}, & 6.30 \leq x \leq 6.35 \\
0, & x \geq 6.35 
\end{cases}
\]

\[
\mu_{\text{busy}}(x) = \begin{cases} 
0, & x \leq 7.00 \text{ or } x \geq 7.35 \\
\frac{x-7.00}{7.30-7.00}, & 7.00 \leq x \leq 7.30 \\
\frac{8.00-x}{8.00-7.30}, & 7.30 \leq x \leq 8.00 
\end{cases}
\]

\[
\mu_{\text{medium}}(x) = \begin{cases} 
0, & x \leq 6.30 \text{ or } x \geq 7.05 \\
\frac{x-6.30}{7.00-6.30}, & 6.30 \leq x \leq 7.00 \\
\frac{7.05-x}{7.05-7.00}, & 7.00 \leq x \leq 7.05 
\end{cases}
\]

\[
\mu_{\text{very busy}}(x) = \begin{cases} 
0, & x \leq 7.30 \\
\frac{x-7.30}{7.35-7.30}, & 7.30 \leq x \leq 7.35 \\
1, & 7.35 \leq x \leq 8.00 
\end{cases}
\]

Figure 1. Membership function of time-variable on Kaligarang intersection

b. HV Variable

Table 4 shows the fuzzification of the HV variable.
Table 4. Fuzzy set of HV variable on Kaligarang intersection

| Fuzzy Set Name | The domain of membership Function |
|----------------|-----------------------------------|
| Few            | [0, 32]                           |
| Many           | [30, 62]                          |

\[
\mu_{few}(x) = \begin{cases} 
1, & 0 \leq x \leq 30 \\
\frac{32-x}{32-30}, & 30 \leq x \leq 32; \\
0, & x \geq 32 
\end{cases} \\
\mu_{many}(x) = \begin{cases} 
0, & x \leq 30 \\
\frac{x-30}{32-30}, & 30 \leq x \leq 32 \\
1, & 32 \leq x \leq 62 
\end{cases}
\]

![Membership function plots](image)

Figure 2. Membership function of HV variable on Kaligarang intersection

c. LV Variable

Fuzzification of the LV variable is described in Table 5.

Table 5. Fuzzy set of LV variable on Kaligarang intersection

| Fuzzy Set Name | The domain of membership Function |
|----------------|-----------------------------------|
| Few            | [30, 45]                           |
| Many           | [40, 55]                           |

\[
\mu_{few}(x) = \begin{cases} 
1, & 30 \leq x \leq 40 \\
\frac{45-x}{45-40}, & 40 \leq x \leq 45; \\
0, & x \geq 45 
\end{cases} \\
\mu_{many}(x) = \begin{cases} 
0, & x \leq 40 \\
\frac{x-40}{45-40}, & 40 \leq x \leq 45 \\
1, & 45 \leq x \leq 55 
\end{cases}
\]
d. MC Variable
Fuzzification of the MC variable is as follows.

**Table 6.** Fuzzy set of MC variable on Kaligarang intersection

| Fuzzy Set Name | The domain of membership Function |
|----------------|-----------------------------------|
| Few            | [0, 15]                           |
| Many           | [10, 25]                          |

\[
\mu\text{few}(x) = \begin{cases} 
1, & 0 \leq x \leq 10 \\
15 - x, & 10 \leq x \leq 15 \\
0, & x \geq 15 
\end{cases}
\]

\[
\mu\text{many}(x) = \begin{cases} 
0, & 0 \leq x \leq 10 \\
10 - x, & 10 \leq x \leq 15 \\
1, & 15 \leq x \leq 25 
\end{cases}
\]

**Figure 3.** Membership function of LV on Kaligarang intersection

e. Volume of vehicles

**Table 7.** Fuzzy set of vehicle volume variable on Kaligarang intersection

| Fuzzy Set Name | The domain of membership Function |
|----------------|-----------------------------------|
| Few            | [0, 35]                           |
| Medium         | [30, 65]                          |
| Many           | [60, 85]                          |

**Figure 4.** Membership function of MC on Kaligarang intersection
\[ \mu_{few}(x) = \begin{cases} 1, & 0 \leq x \leq 30 \\ \frac{35-x}{35-30}, & 30 \leq x \leq 35 \\ 0, & x \geq 35 \end{cases} \]

\[ \mu_{medium}(x) = \begin{cases} 0, & x \leq 30 \text{ or } x \geq 65 \\ \frac{x-30}{35-30}, & 30 \leq x \leq 35 \\ 1, & 35 \leq x \leq 60 \\ \frac{65-x}{65-60}, & 60 \leq x \leq 65 \\ 0, & x \leq 60 \end{cases} \]

\[ \mu_{many}(x) = \begin{cases} 0, & x \leq 60 \\ \frac{x-60}{65-60}, & 60 \leq x \leq 65 \\ 1, & 65 \leq x \leq 85 \end{cases} \]

**Figure 5.** Membership function of the volume of vehicles on Kaligarang intersection

Mamdani fuzzy implications of fuzzy rules in the form of IF-THEN are presented as follows:

**Table 8.** Fuzzy implication (rule) for predicting the volume of vehicles on Kaligarang intersection

| Fuzzy Implication | Time  | HV    | LV    | MC     | Volume |
|-------------------|-------|-------|-------|--------|--------|
| R1                | Quiet | Few   | Few   | Few    | Few    |
| R2                | Medium| Few   | Few   | Few    | Few    |
| R3                | Busy  | Few   | Few   | Few    | Medium |
| R4                | Very busy | Few   | Few   | Few    | Medium |
| R5                | Quiet | Few   | Few   | Many   | Medium |
| R6                | Medium| Few   | Few   | Many   | Medium |
| R7                | Busy  | Few   | Few   | Many   | Medium |
| R8                | Very busy | Few   | Few   | Many   | Medium |
| R9                | Quiet | Few   | Many  | Few    | Medium |
| R10               | Medium| Few   | Many  | Few    | Medium |
| R11               | Busy  | Few   | Many  | Few    | Medium |
| R12               | Very busy | Few   | Many  | Few    | Medium |
| R13               | Quiet | Few   | Many  | Many   | Many   |
| R14               | Medium| Few   | Many  | Many   | Many   |
| R15               | Busy  | Few   | Many  | Many   | Many   |
| R16               | Very busy | Few   | Many  | Many   | Many   |
| R17               | Quiet | Many  | Few   | Few    | Medium |
| R18               | Medium| Many  | Few   | Few    | Medium |
Calculation of the predicted volume of vehicles at the Kaligarang intersection in the east-north direction using Matlab produces the following output:

Based on Figure 6, the input variables: a time of 06:15 am HV = 0, L = 55, and MC = 23 produces an output of 73.9 (many). Furthermore, prediction using manual calculation is as follows.

a. Fuzzification

Time [06.15] = has a value of 1 with the provisions of the equation:

\[ \mu_{\text{quiet}}(06.15) = \begin{cases} 1, & 6.00 \leq x \leq 6.30 \\ 6.35 - x, & 6.30 \leq x \leq 6.35 \\ 0, & x \geq 6.35 \end{cases} \]

HV [0] = has a value of 1 with the provisions of the equation:

\[ \mu_{\text{few}}(15) = \begin{cases} 1, & 0 \leq x \leq 30 \\ 32 - x, & 30 \leq x \leq 32 \\ 0, & x \geq 32 \end{cases} \]

LV [55] = has a value of 1 with the provisions of the equation:

\[ \mu_{\text{many}}(x) = \begin{cases} 0, & x \leq 40 \\ 45 - x, & 40 \leq x \leq 45 \\ 1, & 45 \leq x \leq 55 \end{cases} \]
MC [23] = has a value of 1 with the provisions of the equation:

\[
\mu_{many}(x) = \begin{cases} 
0, & x \leq 10 \\
\frac{x - 10}{15 - 10}, & 10 \leq x \leq 15 \\
1, & 15 \leq x \leq 25 
\end{cases}
\]

Inference

[R13] IF Quiet time AND HV few AND LV many AND MC many THEN Vehicle’s Volume many

\[
\text{membership degree } R_{13} = \mu_{quiet}(1) \cap \mu_{few}(0) \cap \mu_{many}(55) \cap \mu_{many} = \min(1,1,1,1) = 1.
\]

Then determine the value of the tangent line as follows:

\[
t_1 = \frac{t_1 - 60}{65 - 60} = 1 \iff t_1 - 60 = 1 \times 5 \iff t_1 = 65
\]

Then can be seen the calculation result in Figure 7.

![Figure 7. Rule viewer on Kaligarang intersection](image)

c. Defuzzification

\[
z = \frac{\int \mu(x)z \, dz}{\int \mu(x) \, dx}
\]

Determine the value of Moment (M) in the following way:

\[
M_1 = \int_{65}^{85} z - 60 \, dz = \frac{1}{2} z^2 \Big|_{65}^{85} = \frac{1}{2} (85)^2 - \frac{1}{2} (65)^2 = 3.612,5
\]

\[
M_2 = \int_{65}^{85} \frac{1}{5} z \, dz = \frac{1}{2} \left( \frac{1}{5} z^2 \right) \Big|_{65}^{85} = \frac{1}{2} \left( \frac{1}{5} (85)^2 - \frac{1}{5} (65)^2 \right) = 150.
\]

Determine the value of the Area (A) in the following way:

\[
A_1 = \frac{5 \times 1}{2} = 2.5; \ A_2 = 20 \times 1 = 20; \ A_{total} = 2.5 + 20 = 22.5.
\]

So, the result of \( z = \frac{1.658,333}{22.5} = 73.7 \).

It can be concluded that the output of the Matlab calculation produces a volume of the vehicle of 73,9 (many) and the manual calculation produces a total of 73,7 which has approximately the same result.

The comparison of the actual data of volume of vehicles and the prediction results using MAPE on the East-North direction of Kaligarang Intersection can be seen in Table 9.

| INPUT | OUTPUT |
|-------|--------|
| Time  | HV     | LV    | MC    | Actual data | Prediction result | \(|y - \hat{y}|/y|) |
| 1     | 0      | 55    | 23    | 78         | 73,9               | 0,05 |
| 1     | 0      | 37    | 19    | 56         | 47,5               | 0,15 |
| 3     | 0      | 47    | 17    | 64         | 47,5               | 0,26 |
| 3     | 0      | 35    | 15    | 50         | 47,6               | 0,05 |
Based on Table 9, the MAPE result is 12.67% that is 10-20%. The MAPE evaluation criteria give a good category.

3.2. Prediction of Volume of Vehicle at Kariadi Intersection

We predict the volume of vehicles at the Kariadi intersection in the south-north direction. The input and output variables are transformed into fuzzy sets as follows.

a. Time Variable

Table 10. Fuzzy set of morning time variable on Kariadi intersection

| Fuzzy Set Name     | The domain of membership Function |
|--------------------|-----------------------------------|
| Quiet              | [16.00,16.35]                     |
| Medium             | [16.30,17.05]                     |
| Busy               | [17.00,17.35]                     |
| Very busy          | [17.30,18.00]                     |

b. HV Variable

\[
\mu_{few}(x) = \begin{cases} 
1, & 0 \leq x \leq 5 \\
\frac{5-x}{5-0}, & 5 \leq x \leq 8 \\
0, & x \geq 8 
\end{cases} \]

\[
\mu_{many}(x) = \begin{cases} 
0, & x \leq 5 \\
\frac{x-5}{8-5}, & 5 \leq x \leq 8 \\
1, & 8 \leq x \leq 10 
\end{cases} 
\]

c. LV Variable

\[
\mu_{few}(x) = \begin{cases} 
1, & 10 \leq x \leq 55 \\
\frac{55-x}{60-55}, & 55 \leq x \leq 60 \\
0, & x \geq 60 
\end{cases} \]

\[
\mu_{many}(x) = \begin{cases} 
0, & x \leq 55 \\
\frac{x-55}{60-55}, & 55 \leq x \leq 60 \\
1, & 60 \leq x \leq 100 
\end{cases} \]

d. MC Variable

\[
\mu_{few}(x) = \begin{cases} 
1, & 0 \leq x \leq 40 \\
\frac{40-x}{45-40}, & 40 \leq x \leq 45 \\
0, & x \geq 45 
\end{cases} \]

\[
\mu_{many}(x) = \begin{cases} 
0, & x \leq 40 \\
\frac{x-40}{45-40}, & 40 \leq x \leq 45 \\
1, & 45 \leq x \leq 65 
\end{cases} \]

e. Vehicle Volume Variable

\[
\mu_{few}(x) = \begin{cases} 
1, & 100 \leq x \leq 120 \\
\frac{120-x}{125-120}, & 120 \leq x \leq 125 \\
0, & x \geq 125 
\end{cases} \]

\[
\mu_{medium}(x) = \begin{cases} 
0, & x \leq 120 atau x \geq 145 \\
\frac{x-120}{125-120}, & 120 \leq x \leq 125 \\
\frac{145-x}{145-140}, & 125 \leq x \leq 140 \\
0, & x \leq 140 \\
\frac{x-140}{145-140}, & 140 \leq x \leq 145 \\
1, & 145 \leq x \leq 160 
\end{cases} \]

Mamdani fuzzy implications of fuzzy rules in the form of IF-THEN are presented as follows:

Table 11. Fuzzy implication (rule) of vehicle volume on Kariadi intersection

| Fuzzy Implication | Time | HV  | LV  | MC  | Volume |
|-------------------|------|-----|-----|-----|--------|
| R1                | Quiet| Few | Few | Few | Few    |
| R2                | Medium| Few | Few | Few | Few    |
Calculation of the predicted volume of vehicles at the Kariadi Intersection in the south-north direction using Matlab produces the following output:

Based on Figure 8 with the input time at 4.15 pm and the number of HV, LV, MC is 0, 76, and 33 respectively, the volume of vehicles is 111 (few). Furthermore, the manual calculation gives the result 111, 29 vehicles. It can be concluded that the results of MATLAB and manual calculation do not differ significantly. The MAPE result of vehicle volume on the Kariadi intersection is 8.26% and it is very accurate.
3.3. Calculation of the Duration of The Green Lights at Kaligarang Intersection

Table 12. The number of vehicles on Kaligarang intersection

| Approach | MC (Veh/hour) | Car (Veh/hour) | MC (Veh/cycle) | Car (Veh/cycle) |
|----------|---------------|----------------|----------------|-----------------|
| East     | 688           | 561            | 19             | 16              |
| South    | 590           | 539            | 16             | 15              |
| West     | 952           | 1097           | 26             | 30              |

a. Motorcycle Variable
Fuzzy sets: Few [15, 23], medium [18, 29], many [24, 35].

\[ \mu_{few}(x) = \begin{cases} 1, & 15 \leq x \leq 18 \\ \frac{23 - x}{23 - 18}, & 18 \leq x \leq 23 \\ 0, & x \geq 23 \end{cases} \]

\[ \mu_{medium}(x) = \begin{cases} 0, & x \leq 18 \text{ or } x \geq 29 \\ \frac{x - 18}{24 - 18}, & 18 \leq x \leq 24 \\ \frac{29 - x}{29 - 24}, & 24 \leq x \leq 29 \end{cases} \]

\[ \mu_{many}(x) = \begin{cases} 0, & x \leq 24 \\ \frac{x - 24}{29 - 24}, & 24 \leq x \leq 29 \\ 1, & 29 \leq x \leq 35 \end{cases} \]

b. Car Variable
Fuzzy sets: Few [15, 23], medium [18, 29], many [24, 35].

\[ \mu_{few}(x) = \begin{cases} 1, & 15 \leq x \leq 18 \\ \frac{23 - x}{23 - 18}, & 18 \leq x \leq 23 \\ 0, & x \geq 23 \end{cases} \]

\[ \mu_{medium}(x) = \begin{cases} 0, & x \leq 18 \text{ or } x \geq 29 \\ \frac{x - 18}{24 - 18}, & 18 \leq x \leq 24 \\ \frac{29 - x}{29 - 24}, & 24 \leq x \leq 29 \end{cases} \]

\[ \mu_{many}(x) = \begin{cases} 0, & x \leq 24 \\ \frac{x - 24}{29 - 24}, & 24 \leq x \leq 29 \\ 1, & 29 \leq x \leq 35 \end{cases} \]

c. Green Light Variable
Fuzzy sets: Short [25, 55], medium [50, 75], long [70, 100].

\[ \mu_{short}(x) = \begin{cases} 1, & 25 \leq x \leq 50 \\ \frac{55 - x}{50 - 55}, & 50 \leq x \leq 55 \\ 0, & x \geq 55 \end{cases} \]

\[ \mu_{medium}(x) = \begin{cases} 0, & x \leq 70 \\ \frac{x - 70}{75 - 70}, & 70 \leq x \leq 75 \\ 1, & 75 \leq x \leq 100 \end{cases} \]

Mamdani fuzzy implications or rules-based in the form of IF-THEN are presented below:

Table 13. Fuzzy implication (rule) of green light duration on Kaligarang intersection

| Rules | Motorcycle | Car | Greenlight |
|-------|------------|-----|------------|
| R1    | Few        | Few | Short      |
| R2    | Few        | Medium | Short     |
| R3    | Few        | Many | Medium     |
| R4    | Medium     | Few | Short      |
| R5    | Medium     | Medium | Medium    |
| R6    | Medium     | Many | Long       |
| R7    | Many       | Few | Medium     |
| R8    | Many       | Medium | Long     |
| R9    | Many       | Many | Long       |
Calculation of the duration of the green lights at the Kaligarang Intersection using Matlab is as follows:

![Figure 9](image)

**Figure 9.** The duration of green lights at the Kaligarang intersection on the west approach.

In Figure 9, the input of motorcycles and cars per cycle in the west approach is 26 (medium) and 30 (many), and the output of green light duration is 85.9 seconds (long). The manual calculation gives the duration of the green lights of 85.7 seconds (long). The accuracy of predictions is determined through MAPE which is shown in Table 14.

**Table 14.** MAPE duration of green light Kaligarang intersection

| DIRECTION | INPUT | OUTPUT | \(|(y-\bar{y})/y|\) |
|-----------|-------|--------|------------------|
|           | MOTORCYCLE | CAR | Actual data | Prediction Results |        |
| East      | 19     | 16     | 55             | 38.8               | 0.29    |
| South     | 16     | 15     | 25             | 38.6               | 0.54    |
| West      | 26     | 30     | 75             | 85.9               | 0.15    |

| Quantity | \(|(y-\bar{y})/y|\) |
|-----------|------------------|
| MAPE      | 13.16            |

Based on Table 21 above, the MAPE result is 13.16% which lies in the interval 10-20%. Based on the MAPE evaluation criteria, it is good.

### 3.4. Calculation of Duration of the Green Lights at Kariadi Intersection

**Table 15.** The number of vehicles on Kariadi intersection

| Approach | MC (Veh/hour) | Car (veh/hour) | MC (Veh/cycle) | Car (veh/cycle) |
|----------|---------------|----------------|----------------|-----------------|
| South    | 432           | 1039           | 13             | 31              |
| West     | 356           | 804            | 11             | 24              |
| North    | 435           | 1296           | 13             | 39              |

**a. Motorcycle Variable**

Fuzzy sets: Few [5, 15], Many [10, 20].

\[
\mu_{few}(x) = \begin{cases} 
1, & 5 \leq x \leq 10 \\
15 - x & 10 \leq x \leq 15 \\
0, & x \geq 15 
\end{cases} 
\]

\[
\mu_{many}(x) = \begin{cases} 
0, & x < 10 \\
\frac{x - 10}{15 - 10} & 10 \leq x \leq 15 \\
1, & 15 \leq x \leq 20 
\end{cases} 
\]

**b. Car Variable**

Fuzzy sets: few [20, 28], medium [23, 37], many [32, 40].
\[ \mu_{few}(x) \begin{cases} 1, & 20 \leq x \leq 23 \\ 28 - x, & 23 \leq x \leq 28 \\ 0, & x \geq 28 \end{cases} \]

\[ \mu_{medium}(x) \begin{cases} \frac{x-23}{28-23}, & 23 \leq x \leq 28 \\ 1, & 28 \leq x \leq 32 \\ \frac{37-x}{37-32}, & 32 \leq x \leq 37 \end{cases} \]

\[ \mu_{many}(x) \begin{cases} 0, & 32 \leq x \leq 37 \\ \frac{x-32}{37-32}, & 37 \leq x \leq 40 \end{cases} \]

c. Green Light Variable
Fuzzy sets: Short \([30, 55]\), long \([50, 110]\).

\[ \mu_{short}(x) \begin{cases} 1, & 30 \leq x \leq 50 \\ \frac{55-x}{55-50}, & 50 \leq x \leq 55 \\ 0, & x \geq 55 \end{cases} \]

\[ \mu_{long}(x) \begin{cases} 0, & 50 \leq x \leq 55 \\ \frac{x-50}{55-50}, & 55 \leq x \leq 110 \end{cases} \]

Mamdani fuzzy implications or rule based are presented in Table 16.

**Table 16.** Fuzzy implication (rule) of green light duration on Kariadi intersection

| Rules | Motorcycle | Car | Greenlight |
|-------|------------|-----|------------|
| R1    | Few        | Few | Short      |
| R2    | Few        | Medium | Short     |
| R3    | Few        | Many | Long       |
| R4    | Many       | Few | Short      |
| R5    | Many       | Medium | Short     |
| R6    | Many       | Many | Long       |

Calculation of the duration of the green light at the Kariadi Intersection using Matlab produces the following output.

**Figure 10.** The duration of the green lights at the Kariadi intersection on the north approach

Based on Figure 10, the motor and car inputs on the north approach are 13 (many) and 39 (many), respectively, and the output is 81 seconds (long). The manual calculation with the same input gives a green light duration of 80,7 seconds (long) which is not much different from Matlab calculation.

**Table 17.** MAPE Duration of Green Light Kariadi intersection

| DIRECTION | INPUT MOTORCYCLE | CAR | OUTPUT Actual data | Prediction Results | \(|(y-\hat{y})/y|\) |
|-----------|-----------------|-----|--------------------|--------------------|-------------------|
| South     | 13              | 31  | 35                 | 41,6               | 0,19              |
| West      | 11              | 24  | 35                 | 41,3               | 0,18              |
| North     | 13              | 39  | 110                | 81                 | 0,26              |

| Quantity \(|(y-\hat{y})/y|\) | 0,10 |
|---------------------------|------|
| MAPE                      | 3,5% |

The MAPE result of green light duration on Kariadi Intersection is 3,5% and it is very accurate.
4. Conclusion
In this study, the traffic volume predictions at Kaligarang Intersection were obtained. The traffic volume in the east-north direction is 74 vehicles (many), while the traffic volume at Kariadi Intersection in the south-north direction is 111 vehicles (few). This study also calculates the duration of the green light at the two intersections. The inputs in the east approach of Kaligarang Intersection which consists of 19 vehicles (few) of motorcycles (per cycle) and 16 vehicles (few) of cars (per cycle) gave the duration of the green light of 39 seconds (short). Meanwhile, the inputs in the south approach of Kaligarang Intersection which consists of 16 vehicles (few) of motorcycles and 15 vehicles (few) of cars gave the prediction of duration of the green light of 39 seconds (short). The duration of the green light at the Kaligarang intersection on the west approach with the number of motorcycles 26 (medium) and the number of cars 30 vehicles (many) is 86 seconds (long). Further, the predictions of the duration of green lights at the Kariadi intersection are as follows: the number of motorcycles is 13 vehicles (many) and the number of cars is 31 vehicles (medium) on the south approach got the duration of green light of 42 seconds (short); the number of motorcycles is 11 (few) and the number of cars is 24 (few) on the west approach received the duration 42 seconds (short); the number of motorcycles is 13 vehicles (many) and the number of cars is 39 vehicles (many) on the north approach received the duration of the green light of 81 seconds (long).

The accuracy of traffic volume predictions based on MAPE (Mean Absolute Percentage Error) are as follows: the MAPE of prediction on the direction east-north of Kaligarang Intersection is
12.67% where the category is good and the MAPE of prediction on the south-north direction of Kariadi Intersection is 3.77% which is very accurate. The accuracy of the prediction of green light duration at Kaligarang Intersection is 13.16% so that the MAPE criteria are good, while the accuracy of prediction of the green light duration at Kariadi Intersection is 3.5% which is very accurate.

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