International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Traffic Light Controller for Urban Cities Using Fuzzy Approach

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Submitted: 20/07/2023 **Revised**: 10/09/2023 **Accepted**: 22/09/2023

Abstract: Traffic Congestion affects the urban cities very much. The daily life of the people is affected due to this traffic congestion. This affects the economy of the country directly or indirectly. Therefore, there is a need of an automated traffic light controller to reduce the traffic congestion so that the people have to wait less. In this paper, we introduce a traffic light controller for urban cities using fuzzy approach.

Keywords: *Linguistic Variables, Membership Functions, Triangular Membership Functions (TMF), Fuzzification, Defuzzification, Fuzzy Logic Controller (FLC), Traffic Light Controller (TLC).*

1. Introduction

Traffic Congestion is one of the real-life problems which is based on the uncertainty and imprecision. A fuzzy set theory is applicable to solve the problem based on uncertainty and imprecision. The concept of fuzzy set theory is introduced by Zadeh, Lotfi A. [1], [2]. In 1990, the concept of fuzzy logic is introduced by Zadeh, Lotfi A. [3] and the application of fuzzy logic [4], [5] is introduced as a traffic signal controller. Jensen et al [6] provide the dataset with traffic lights and stereo vision to improve traffic light recognition.

Dharmendra Kumar and J.P. Tripathi [7] introduced a paper in which the importance of fuzzification and defuzzification in Traffic Light Controller (TLC) has been explained. They have also studied the different Traffic Signal Controllers (TSLs) and found the comparison between two recent TSLs [8]. They have developed a TLC using Fuzzy Logic in 2023 [9].

2. Fuzzy Inputs and Output

The traffic light controller proposed in this paper is a fuzzy logic controller based on three inputs and one output. The inputs and output are given as follows

2.1. Inputs:

- **Number of Vehicles**: This indicates the number of vehicles present in a particular lane of the intersection.
- **Speed of Vehicles (in km/h)**: This indicates the speed of vehicles passing at the intersection.
- **Weather Condition (in percentage):** This indicates that how is the visibility at the intersection, where traffic is congested. The visibility is affected by fog, generally in winter season.

2.2. Outputs: The output is Traffic Flow Time. This indicates the time it takes for traffic to flow.

3. Linguistic Variables (LVs) of Input and Output

Here we have selected four linguistic variables for each input and output. The ranges of each linguistic variable of inputs and outputs are given in the Table – 1 given below;

Input						***Output***	
No. of Vehicles		***Speed of Vehicles (in km/h)***		***Weather Condition (in percentage)***		***Traffic Flow Time***	
Range	**LV**	**Range**	**LV**	**Range**	**LV**	**Range**	**LV**
0-20	Very Less	0-20	Very Low	0-20	Very Bad	0-2	Very Less
15-60	Less	15-40	Low	15-50	Bad	01-Mar	Less
50-110	Medium	30-70	Medium	45-75	Average	02-Apr	Medium
90-150	High	60-100	High	70-100	Good	03-May	High

Table 1. The ranges of each linguistic variable of inputs and outputs

4. The Triangular Membership Functions

The membership functions for the first input "Number of Vehicles" are defined as –

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$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{10} & , \ 0 \le x \le 10 \\ \frac{20 - x}{10} & , \ 10 \le x \le 20 \\ 0 & , \quad x > 20 \end{cases} \quad \ldots\ldots\ldots (1)$$

$$\mu_{\widetilde{L}}(x) = \begin{cases} 0 & , \quad x < 15 \\ \frac{x - 15}{22.5} & , \ 15 \le x \le 37.5 \\ \frac{60 - x}{22.5} & , \ 37.5 \le x \le 60 \\ 0 & , \quad x > 60 \end{cases} \quad \ldots\ldots\ldots (2)$$

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0 & , \quad x < 50 \\ \frac{x - 50}{30} & , \ 50 \le x \le 80 \\ \frac{110 - x}{30} & , \ 80 \le x \le 110 \\ 0 & , \quad x > 110 \end{cases} \quad \ldots\ldots\ldots (3)$$

$$\mu_{\widetilde{H}}(x) = \begin{cases} 0 & , \quad x < 90 \\ \frac{x - 90}{30} & , \ 90 \le x \le 120 \\ \frac{150 - x}{30} & , \ 120 \le x \le 150 \\ 0 & , \quad x > 150 \end{cases} \quad \ldots\ldots\ldots (4)$$

The membership functions for the second input "Speed of Vehicles" are defined as –

$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{10} & , \ 0 \le x \le 10 \\ \frac{20 - x}{10} & , \ 10 \le x \le 20 \\ 0 & , \quad x > 20 \end{cases} \quad \ldots\ldots\ldots (5)$$

$$\mu_{\widetilde{L}}(x) = \begin{cases} 0 & , \quad x < 15 \\ \frac{x - 15}{12.5} & , \ 15 \le x \le 27.5 \\ \frac{40 - x}{12.5} & , \ 27.5 \le x \le 40 \\ 0 & , \quad x > 40 \end{cases} \quad \ldots\ldots\ldots (6)$$

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0 & , \quad x < 30 \\ \frac{x - 30}{20} & , \ 30 \le x \le 50 \\ \frac{70 - x}{20} & , \ 50 \le x \le 70 \\ 0 & , \quad x > 70 \end{cases} \quad \ldots\ldots\ldots (7)$$

$$\mu_{\widetilde{H}}(x) = \begin{cases} 0 & , \quad x < 60 \\ \frac{x-60}{20} & , \ 60 \le x \le 80 \\ \frac{100-x}{20} & , \ 80 \le x \le 100 \\ 0 & , \quad x > 100 \end{cases} \quad \ldots\ldots\ldots (8)$$

5. Fuzzy If – Then Rules:

The thinking process of traffic police to handle traffic congestion can be converted into fuzzy If-Then rules. Here

The membership functions for the third input "Weather Condition" are defined as –

$$\mu_{\widetilde{VB}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{10} & , \ 0 \le x \le 10 \\ \frac{20 - x}{10} & , \ 10 \le x \le 20 \\ 0 & , \quad x > 20 \end{cases} \quad \ldots\ldots\ldots (9)$$

$$\mu_{\widetilde{B}}(x) = \begin{cases} 0 & , \quad x < 15 \\ \frac{x - 15}{17.5} & , \ 15 \le x \le 32.5 \\ \frac{50 - x}{17.5} & , \ 32.5 \le x \le 50 \\ 0 & , \quad x > 50 \end{cases} \quad \ldots\ldots\ldots (10)$$

$$\mu_{\widetilde{A}}(x) = \begin{cases} 0 & , \quad x < 45 \\ \frac{x - 45}{15} & , \ 45 \le x \le 60 \\ \frac{75 - x}{15} & , \ 60 \le x \le 75 \\ 0 & , \quad x > 75 \end{cases} \quad \ldots\ldots\ldots (11)$$

The membership functions (MF) for the output "Traffic Flow Time" are defined as –

$$\mu_{V\widetilde{L}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{1} & , \ 0 \le x \le 1 \\ \frac{2 - x}{1} & , \ 1 \le x \le 2 \\ 0 & , \quad x > 2 \end{cases} \quad \ldots\ldots\ldots (13)$$

$$\mu_{\widetilde{L}}(x) = \begin{cases} 0 & , \quad x < 1 \\ \frac{x-1}{1} & , \ 1 \le x \le 2 \\ \frac{3-x}{1} & , \ 2 \le x \le 3 \\ 0 & , \quad x > 3 \end{cases} \quad \ldots\ldots\ldots (14)$$

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0 & , \quad x < 2 \\ \frac{x - 2}{1} & , \ 2 \le x \le 3 \\ \frac{4 - x}{1} & , \ 3 \le x \le 4 \\ 0 & , \quad x > 4 \end{cases} \quad \ldots\ldots\ldots (15)$$

$$\mu_{\widetilde{H}}(x) = \begin{cases} 0 & , \quad x < 3 \\ \frac{x - 3}{1} & , \ 3 \le x \le 4 \\ \frac{5 - x}{1} & , \ 4 \le x \le 5 \\ 0 & , \quad x > 5 \end{cases} \quad \ldots\ldots\ldots (16)$$

we have constructed 64 fuzzy if-then rules on the basis of three inputs to get the appropriate traffic flow time as output, which are given below –

Fuzzy Rule

Rules No.	Input			Outputs
	No. of Vehicles	Speed of Vehicles	Weather Condition	Traffic Flow Time
1.	VL	VL	VB	L
2.	VL	VL	B	L
3.	VL	VL	A	VL
4.	VL	VL	G	VL
5.	VL	L	VB	L
6.	VL	L	B	L
7.	VL	L	A	VL
8.	VL	L	G	VL
9.	VL	M	VB	VL
10.	VL	M	B	VL
11.	VL	M	A	VL
12.	VL	M	G	VL
13.	VL	H	VB	VL
14.	VL	H	B	VL
15.	VL	H	A	VL
16.	VL	H	G	VL
17.	L	VL	VB	L
18.	L	VL	B	L
19.	L	VL	A	L
20.	L	VL	G	L
21.	L	L	VB	L
22.	L	L	B	L
23.	L	L	A	L
24.	L	L	G	VL
25.	L	M	VB	L
26.	L	M	B	L
27.	L	M	A	VL
28.	L	M	G	VL
29.	L	H	VB	L
30.	L	H	B	L
31.	L	H	A	L
32.	L	H	G	VL
33.	M	VL	VB	H
34.	M	VL	B	H
35.	M	VL	A	H
36.	M	VL	G	H
37.	M	L	VB	H
38.	M	L	B	M
39.	M	L	A	M
40.	M	L	G	M
41.	M	M	VB	L
42.	M	M	B	M
43.	M	M	A	H
44.	M	M	G	H
45.	M	H	VB	M
46.	M	H	B	M
47.	M	H	A	L
48.	M	H	G	L
49.	H	VL	VB	H
50.	H	VL	B	H
51.	H	VL	A	H

52.	H	VL	G	M
53.	H	L	VB	H
54.	H	L	B	H
55.	H	L	A	H
56.	H	L	G	H
57.	H	M	VB	H
58.	H	M	B	H
59.	H	M	A	H
60.	H	M	G	H
61.	H	H	VB	H
62.	H	H	B	H
63.	H	H	A	M
64.	H	H	G	M

6. Fuzzy Logic Controller:

The proposed Traffic Light Controller (TLC) has been developed by using mamdani FIS tool in MATLAB and designed as given in Fig.1 –

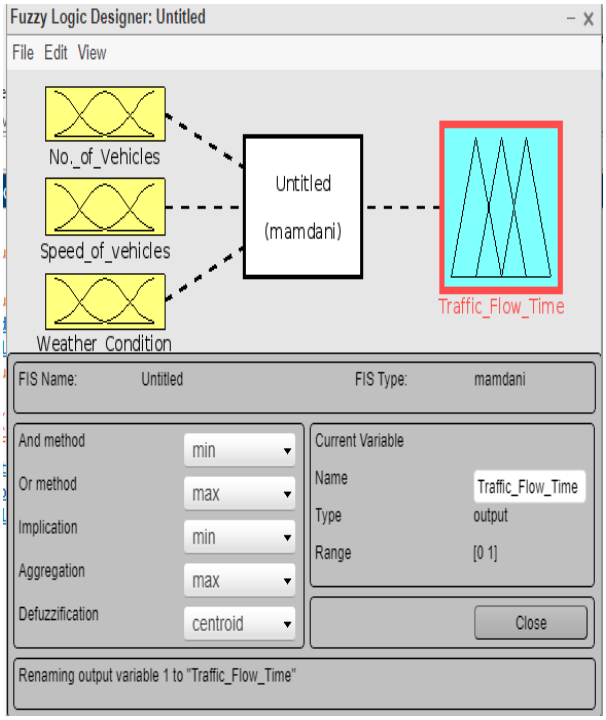

Fig. 1. Mamdani FIS

6.1. (i) First Input (Number of Vehicles):

The membership Functions defined in the equations (1) to (4) are plotted by using Membership Function Editor, which is shown in Fig. 2.

6.1. (ii) Second Input (Speed of Vehicles):

The membership Functions defined in the equations (5) to (8) are plotted by using Membership Function Editor, which is shown in Fig. 3.

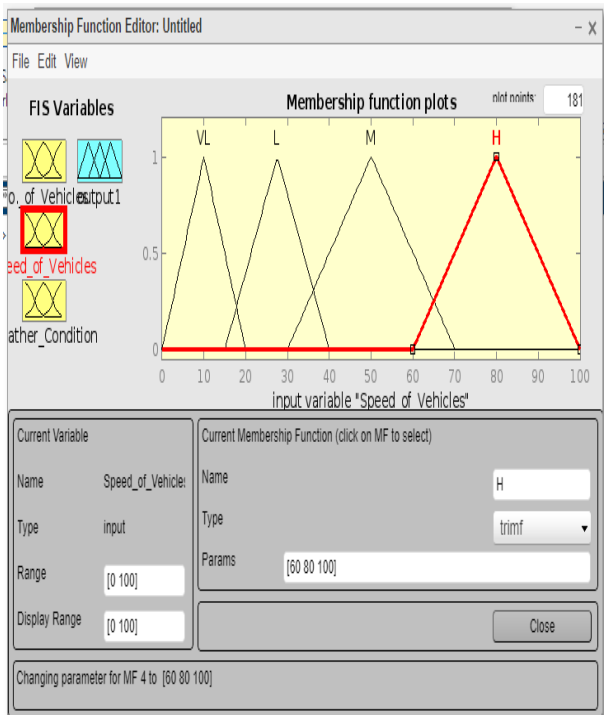

Fig. 2. Membership Function (Speed of Vehicles)

6.1. (iii) Third Input (Weather Condition):

The membership Functions defined in the equations (9) to (12) are plotted by using Membership Function Editor, which is shown in Fig. 4.

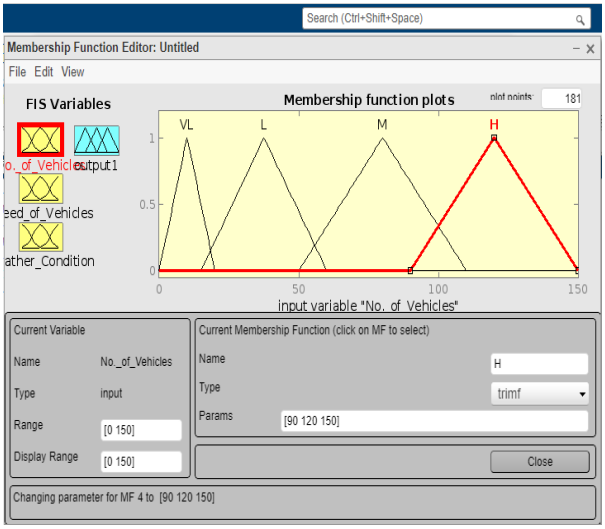

Fig. 3. Membership Function (No. of Vehicles)

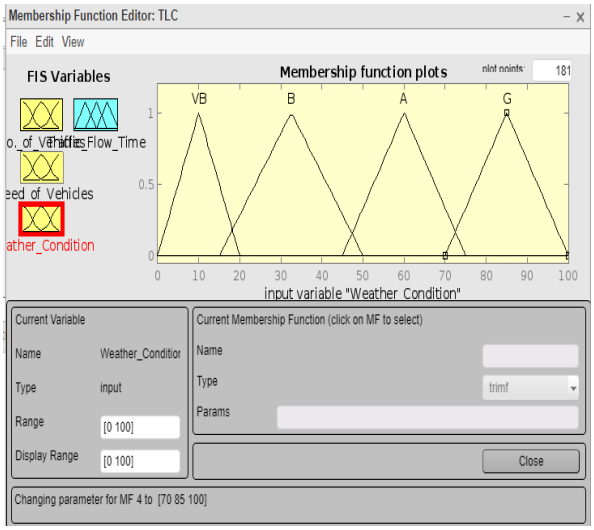

Fig. 4. Membership Function (Weather Condition)

6.2. Output (Traffic Flow Time):

The membership Functions defined in the equations (13) to (16) are plotted by using Membership Function Editor, which is shown in Fig. 5.

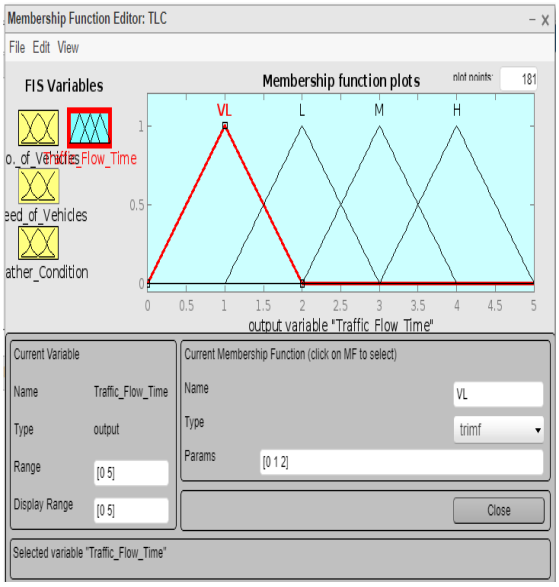

Fig. 5. Membership Function (Traffic Flow Time)

6.3. Fuzzy Rule:

We inserted all the 64 fuzzy If – Then rules by going to the Rule Editor section of Mamdani FIS which are shown in Fig. 6.

Similarly; we can view the inserted rules graphically by going to the Rule Viewer section of FIS which are shown in Fig. 7.

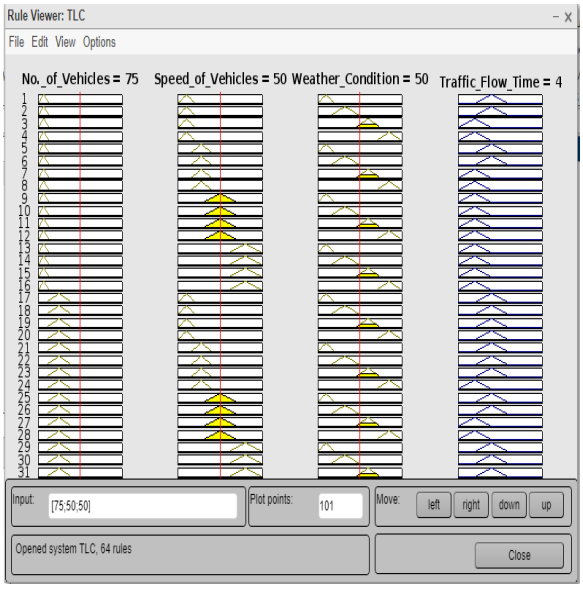

Fig. 7. Rule Viewer

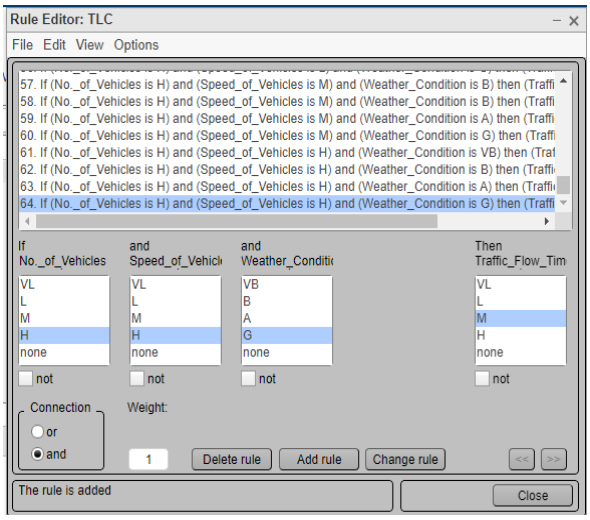

Fig. 6. Rule Editor

6.4. Surface Viewer:

The three-dimensional output surface of the proposed fuzzy logic control system is shown in Fig. 10. This can be viewed by Surface Viewer.

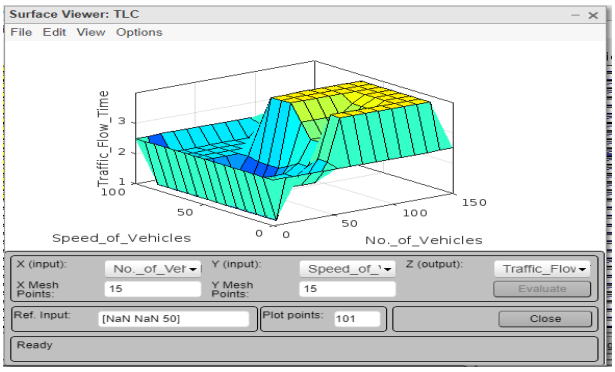

Fig 8. Surface Viewer

7. Results and Discussion:

After inserting the three inputs, we get the required output according to the given fuzzy rules. Some examples are given as;

- If No. of Vehicles =75, Speed of Vehicles=50, Weather Condition=50, then the Traffic Flow Time=4 min.
- If No. of Vehicles =7, Speed of Vehicles=70, Weather Condition=55, then the Traffic Flow Time=1 min.
- If No. of Vehicles =100, Speed of Vehicles=30, Weather Condition=20, then the Traffic Flow Time=3.5 min.
- If No. of Vehicles =120, Speed of Vehicles=50, Weather Condition=90, then the Traffic Flow Time=4 min.
- If No. of Vehicles =125, Speed of Vehicles=60, Weather Condition=60, then the Traffic Flow Time=4.5 min and so on.

8. Conclusion:

The proposed traffic light controller is more flexible and give the better performance than all erstwhile controllers. This TLC consists of three inputs to perform traffic flow. This controller is applicable to provide the appropriate traffic flow time so that traffic congestion can be reduced with less waiting time. Thus; traffic congestion can be handled by using this TLC in any case of visibility.

9. References:

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