J. of Ramanujan Society of Mathematics and Mathematical Sciences
Vol. 10, No. 2 (2023), pp. 199-212

DOI: 10.56827/JRSMMS.2023.1002.15 **ISSN (Online): 2582-5461**

ISSN (Print): 2319-1023

TRAFFIC LIGHT CONTROLLER FOR SMART CITIES USING FUZZY LOGIC

Dharmendra Kumar and J. P. Tripathi

Department of Mathematics,
R. N. College, Hajipur - 844101, Bihar, INDIA

E-mail : thinking.dmh@gmail.com, jiteshmaths@gmail.com

(**Received:** *May 08, 2023* **Accepted:** *Jun. 25, 2023* **Published:** *Jun. 30, 2023)*

Abstract: Today, smart cities are very much affected due to traffic jam and traffic signals. Traffic light controller is the best solution for solving the traffic jam problems. The existing signal controllers are not sufficient to give the appropriate solutions to these types of traffic problems. Only a very efficient and up to date smart fuzzy light controller (FLC) can cater to this gigantic problem of massive, unruly, uncontrolled traffic.In the proposed paper, we have introduced an FLC which incorporates all the modern manifestations of fuzzy logic, capable of providing a solution to the mind-boggling problem of traffic jams. This controller, consists of four inputs, and two outputs, encompassing several linguistic variables, thus, capable of catering to worst imagined traffic problems.

Keywords and Phrases: Linguistic Variables (LV), Membership Functions (MF), Traffic Light Controller (TLC), Fuzzy Light Controller (FLC).

2020 Mathematics Subject Classification: Primary 03B52, Secondary 93C42, 94D05.

1. Introduction

Traffic snarls and traffic congestion is a gift of modern rapid development, a necessary evil that cannot be avoided. The entire scientific community is racking its head to find a convenient solution to this problem, choking the entire movement in the cities. The challenges and problems created by traffic jams in mega-cities or in densely populated areas, due to a high number of vehicles on the road are very difficult [4]. These problems affect the daily life of the people. It causes delay in the smooth, and efficient movement of services and goods, thus creating a bottle-neck in the economic growth and development. The traffic problem is based on impression and uncertainty which can be explained with the help of the fuzzy theory proposed by Zadeh [11] in 1965. The linguistic variables introduced by Zadeh [12] in 1975 are used to deal with the impression and uncertainty. The fuzzy logic system is a rule-based system in which decisions of human beings to control the traffic system are converted into fuzzy 'If-Then' rules [2]. K. S. Arikumar et al. [1] introduced a fuzzy model using sensors to eliminate traffic congestion. This system is applicable to varying flows of density. S. Mohanaselvi et al. [6] proposed a fuzzy logic controller which is best suited for improving the performance of traffic signal controllers. Lafuente-Arroyo et al. [5] said that road intersections controlled by human beings are more effective than traditional methods. Li- li Zhang et al. [13] proposed UTSC-CPS. This is the urban traffic signal control which is an innovative in extending the capabilities of the system. It also exposes the result of the current traffic signal control. It emphasizes a communication between the real-time control & simulation system. Ecem Acar et al. [3] shows the automation of traffic signalization and suggests its integration wih the philosophy of fuzzy logic. J. P. Tripathi et al. [8, 9] proposed a Fuzzy Lights Controller to management of a road traffic junction. Ugwu et al. [10] proposed a sensors-based fuzzy model. This system is able to eliminate traffic congestion. Raoul De Charette et al [7] introduced a method for recognizing traffic lights in real-time for rural and urban areas. This method is modular and is based onimage processing.

2. Fuzzy Variables

In this communication, we evolved a TLC using fuzzy logic. In this model of TLC, we have taken four input and two output variables. All four input variables are important for a traffic light controller.

2.1. Input Variables

2.1.1. Number of Vehicles

This shows the total number of arriving vehicles in a particular direction.

2.1.2. Speed of Vehicles (in km/h)

This is very important for showing the speed of the vehicles passing in a particular direction.

2.1.3. The Smoothness of the Road (In Percentage)

This indicates the condition of the road i.e., if the road condition is bad then traffic flow is low and waiting time is high in general, and so on.

2.1.4. Range of Visibility (In Meters)

The range of visibility is affected by fog, especially in the winter season.

2.2. Output Variables

The required output variables are given as –

(i)Traffic flow (in percentage) and

(ii) Waiting time (in minutes)

For more accuracy, we have taken five linguistic variables for the 1^{st} input i.e., Number of Vehicles, five linguistic variables for the 2^{nd} input i.e., Speed of Vehicles, three linguistic variables for the 3^{rd} input i.e., Smoothness of Road and three linguistic variables for the 4^{th} input i.e., Range of Visibility.

In a similar way, we have taken five linguistic variables for the 1^{st} output (Traffic Flow) and three linguistic variables for the 2^{nd} output (Waiting Time).

The ranges of input variables, output variables, and their linguistic variables are provided in the Table given below;

Inputs								Outputs			
No. of Vehicles		Speed of Vehicles (In km/h)		The Smoothness of the Road (In percentage)		Range of visibility (In meters)		Traffic Flow (in percentage)		Waiting Time (In minutes)	
Range	LV	Range	LV	Range	LV	Range	LV	Range	LV	Range	LV
0 – 30	Very Less	0 – 15	Very Low	0 – 40	Bad	0 – 200	Low	0 – 20	Very Low	0 – 3	Less
20 – 70	Less	10 – 30	Low	30 – 70	Average	150 – 600	Medium	15 – 40	Low	2 – 7	Medium
60 – 110	Medium	20 – 50	Medium	60 – 100	Good	500 – 1000	High	30 – 70	Medium	5 – 10	High
100 – 160	Large	35 – 60	High					50 – 90	High		
150 – 200	Very Large	50 – 80	Very High					75 – 100	Very High		

3. The Membership Functions of Fuzzy Input and Output

The five linguistic variables for the first input i.e., Number of Vehicles are very-less(VL), less(L), medium(M), large(L), and very-large(VL).

Similarly, for the second input (Speed of Vehicles), there are five linguistic variables named very-low(VL), low(L), medium(M), high(H), and very-high(VH). The linguistic variable for the third input (Smoothness of Road) are bad (B), average (A), and good (G). The linguistic variables for the fourth input (Range of visibility) are low (L), medium (M), and high (H).

In a similar way, the linguistic variables for the first output i.e., Traffic Flow are, very low(VL), low(L), medium(M), high(H) & very-high(VH), and the linguistic variables for the second output i.e., Waiting Time are less(L), medium(M), and high(H).

Now, we define a triangular membership function of each linguistic variable of input and output which are given below

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

$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{15} & , \quad 0 \le x \le 15 \\ \frac{30-x}{15} & , \quad 15 \le x \le 30 \\ 0 & , \quad x > 30 \end{cases} \quad \mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 20 \\ \frac{x-20}{25} & , \quad 20 \le x \le 45 \\ \frac{70-x}{25} & , \quad 45 \le x \le 70 \\ 0 & , \quad x > 70 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 60 \\ \frac{x-60}{25} & , \quad 60 \le x \le 85 \\ \frac{110-x}{25} & , \quad 85 \le x \le 110 \\ 0 & , \quad x > 110 \end{cases}$$

$$\mu_{\widetilde{LA}}(x) = \begin{cases} 0 & , \quad x < 100 \\ \frac{x-100}{30} & , \quad 100 \le x \le 130 \\ \frac{160-x}{30} & , \quad 130 \le x \le 160 \\ 0 & , \quad x > 160 \end{cases}$$

$$\mu_{\widetilde{VLA}}(x) = \begin{cases} 0 & , \quad x < 150 \\ \frac{x-150}{25} & , \quad 150 \le x \le 175 \\ \frac{200-x}{25} & , \quad 175 \le x \le 200 \\ 0 & , \quad x > 200 \end{cases}$$

The membership functions for the second input "Speed of Vehicles in particular directions" are defined as

$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{7.5} & , \quad 0 \le x \le 7.5 \\ \frac{15-x}{7.5} & , \quad 7.5 \le x \le 15 \\ 0 & , \quad x > 15 \end{cases} \quad \mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 10 \\ \frac{x-10}{10} & , \quad 10 \le x \le 20 \\ \frac{30-x}{10} & , \quad 20 \le x \le 30 \\ 0 & , \quad x > 30 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 20 \\ \frac{x-20}{15} & , \quad 20 \le x \le 35 \\ \frac{50-x}{15} & , \quad 35 \le x \le 50 \\ 0 & , \quad x > 50 \end{cases} \quad \mu_{\tilde{H}}(x) = \begin{cases} 0 & , \quad x < 35 \\ \frac{x-35}{12.5} & , \quad 35 \le x \le 47.5 \\ \frac{60-x}{12.5} & , \quad 47.5 \le x \le 60 \\ 0 & , \quad x > 60 \end{cases}$$

$$\mu_{\widetilde{VH}}(x) = \begin{cases} 0 & , \quad x < 50 \\ \frac{x-50}{15} & , \quad 50 \le x \le 65 \\ \frac{80-x}{15} & , \quad 65 \le x \le 80 \\ 0 & , \quad x > 80 \end{cases}$$

The membership functions for the third input "Smoothness of Road" are defined as

$$\mu_{\tilde{B}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{20} & , \quad 0 \le x \le 20 \\ \frac{40-x}{20} & , \quad 20 \le x \le 40 \\ 0 & , \quad x > 40 \end{cases} \quad \mu_{\tilde{A}}(x) = \begin{cases} 0 & , \quad x < 30 \\ \frac{x-30}{20} & , \quad 30 \le x \le 50 \\ \frac{70-x}{20} & , \quad 50 \le x \le 70 \\ 0 & , \quad x > 70 \end{cases}$$

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

The membership functions for the fourth input "Range of visibility" are defined as

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{100} & , \quad 0 \le x \le 100 \\ \frac{200-x}{100} & , \quad 100 \le x \le 200 \\ 0 & , \quad x > 200 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 150 \\ \frac{x-150}{225} & , \quad 150 \le x \le 375 \\ \frac{600-x}{225} & , \quad 375 \le x \le 600 \\ 0 & , \quad x > 600 \end{cases}$$

$$\mu_{\tilde{H}}(x) = \begin{cases} 0 & , \quad x < 500 \\ \frac{x-500}{250} & , \quad 500 \le x \le 750 \\ \frac{1000-x}{250} & , \quad 750 \le x \le 1000 \\ 0 & , \quad x > 1000 \end{cases}$$

The membership functions for the first output "Traffic Flow" are defined as

$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{10} & , \quad 0 \leq x \leq 10 \\ \frac{20-x}{10} & , \quad 10 \leq x \leq 20 \\ 0 & , \quad x > 20 \end{cases} \quad \mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 15 \\ \frac{x-15}{12.5} & , \quad 15 \leq x \leq 27.5 \\ \frac{40-x}{12.5} & , \quad 27.5 \leq x \leq 40 \\ 0 & , \quad x > 40 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 30 \\ \frac{x-30}{20} & , \quad 30 \leq x \leq 50 \\ \frac{70-x}{20} & , \quad 50 \leq x \leq 70 \\ 0 & , \quad x > 70 \end{cases} \quad \mu_{\tilde{H}}(x) = \begin{cases} 0 & , \quad x < 50 \\ \frac{x-50}{20} & , \quad 50 \leq x \leq 70 \\ \frac{90-x}{20} & , \quad 70 \leq x \leq 90 \\ 0 & , \quad x > 90 \end{cases}$$

$$\mu_{\widetilde{VH}}(x) = \begin{cases} 0 & , \quad x < 75 \\ \frac{x-75}{12.5} & , \quad 75 \leq x \leq 87.5 \\ \frac{100-x}{12.5} & , \quad 87.5 \leq x \leq 100 \\ 0 & , \quad x > 100 \end{cases}$$

The membership functions for the second output "Waiting Time" are defined as

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{1.5} & , \quad 0 \leq x \leq 1.5 \\ \frac{3-x}{1.5} & , \quad 1.5 \leq x \leq 3 \\ 0 & , \quad x > 3 \end{cases} \quad \mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 2 \\ \frac{x-2}{2.5} & , \quad 2 \leq x \leq 4.5 \\ \frac{7-x}{2.5} & , \quad 4.5 \leq x \leq 7 \\ 0 & , \quad x > 7 \end{cases}$$

$$\mu_{\tilde{H}}(x) = \begin{cases} 0 & , \quad x < 5 \\ \frac{x-5}{2.5} & , \quad 5 \leq x \leq 7.5 \\ \frac{10-x}{2.5} & , \quad 7.5 \leq x \leq 10 \\ 0 & , \quad x > 10 \end{cases}$$

4. Fuzzy If -Then Rules

Human beings on the basis of their intelligence, have made certain rules for vehicular movement on roads, which is working for them quite efficiently. The thinking process of human beings has similarities with the fuzzy inference system. We, in the paper, have devised 225 fuzzy 'If-Then' rules. Here on the basis of four input we have achieved two outputs. Some of them are given below

Rules No.	Input				Output	
	No. of Vehicles	Speed of Vehicles	Smoothness of Road	Range of visibility	Traffic Fluency	Waiting Time
1.	VL	VL	B	L	M	L
2.	VL	M	B	H	H	L
3.	VL	M	G	H	VH	L
4.	VL	H	B	L	M	L
5.	VL	H	G	H	VH	L
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
218.	LA	M	G	M	L	H
219.	VLA	VH	B	H	L	H
220.	VLA	VH	A	L	VL	H
221.	VLA	VH	A	M	L	H
222.	VLA	VH	A	H	L	H
223.	VLA	VH	G	L	VL	H
224.	VLA	VH	G	M	L	H
225.	VLA	VH	G	H	L	H

5. Fuzzy Logic Controller

Here we use FIS tool in MATLAB to implement the proposed traffic light controller. The input and output are designed in the following Fig. 1

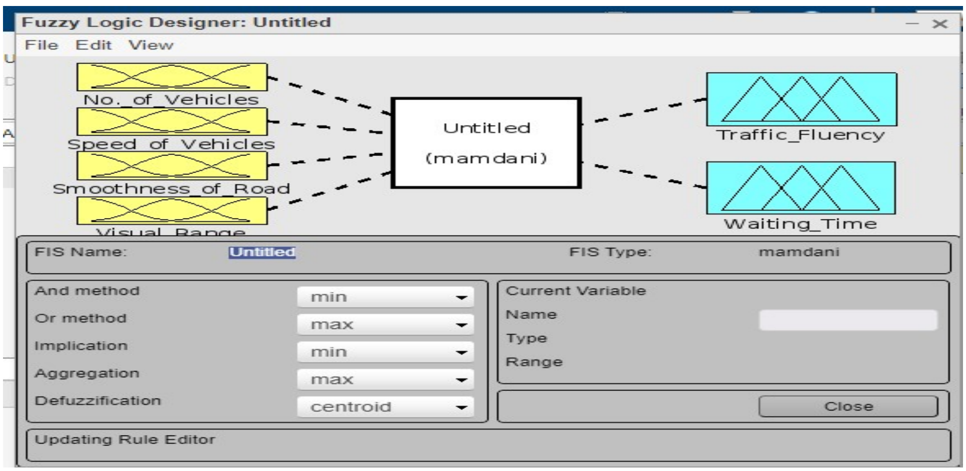

Figure 1: Mamdani FIS

5.0.1. First Input (Number of Vehicles)

The membership functions for the first input (Number of Vehicles) are very-less(0 – 30), less (20 – 70), medium (60 – 110), large (100 – 160), and very-large (150 – 200) which are given in Fig. 2.

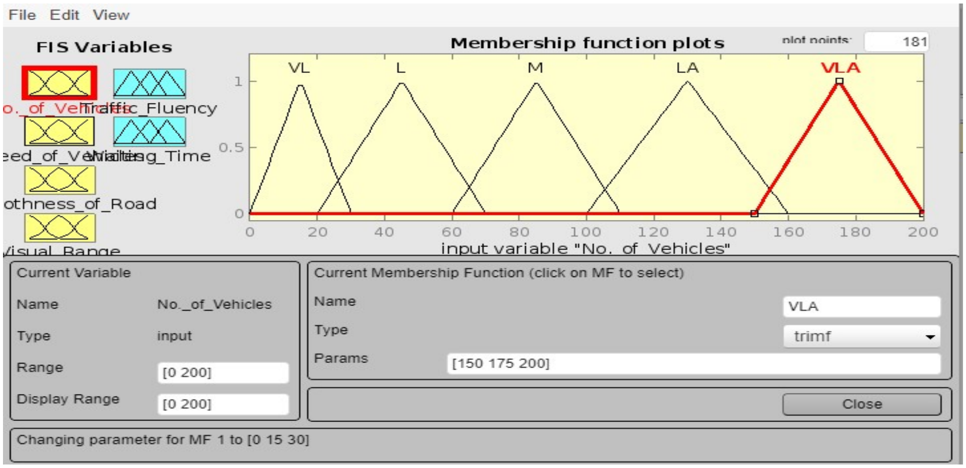

Figure 2: MF (No. of Vehicles)

5.0.2. Second Input (Speed of Vehicles)

The membership functions for the second input (Speed of Vehicles in a particular direction) are very-low(0 – 15), low(10 – 30), medium(20 – 50), high(35 – 60), and very-high (50 – 80) which are given in Fig. 3.

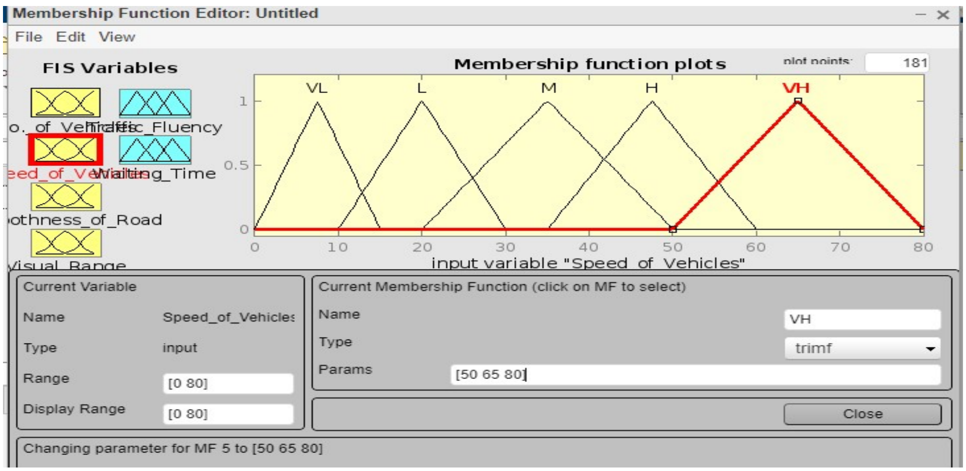

Figure 3: MF (Speed of Vehicles)

5.0.3. Third Input (The Smoothness of the Road)

The membership functions for the third input (Smoothness of Road in percentage) are bad (0 – 40), average (30 – 70), and good (60 – 100) which are given in Fig. 4.

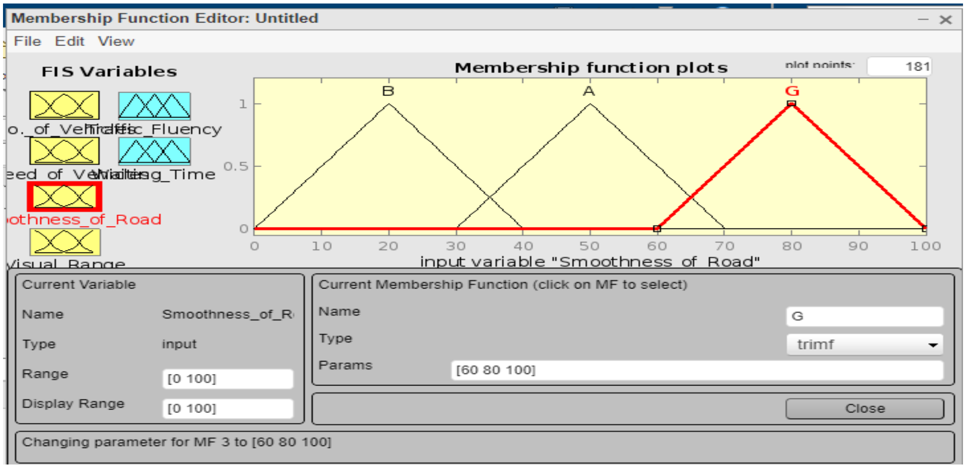

Figure 4: MF (The Smoothness of the Road)

5.0.4. Fourth Input (Range of Visibility)

The membership functions for the fourth input (range of visibility in meters) are low (0 – 200), medium (150 – 600), and high (500 – 1000) which are plotted in Fig. 5.

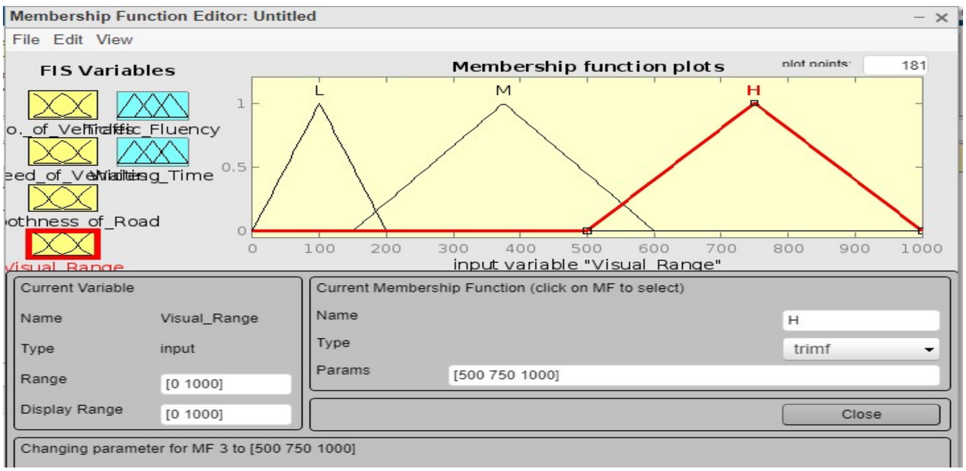

Figure 5: MF (Range of visibility)

5.1. Output

5.1.1. First Output (Traffic Flow)

The membership Functions for the first output (Traffic Flow in percentage) are very-low(0 – 20), low(15 – 40), medium(30 – 70), high(50 – 90), and very-high(75 – 100) which are plotted in Fig. 6.

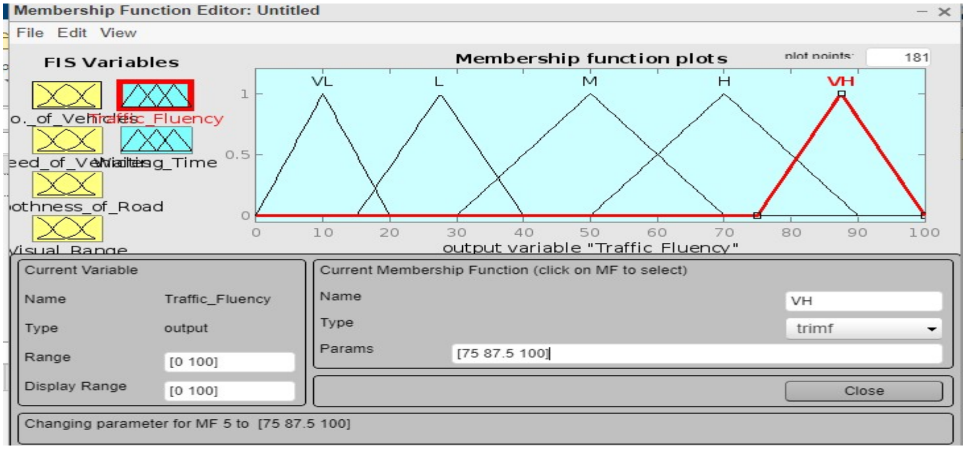

Figure 6: MF (Traffic Flow)

5.1.2. Second Output (Waiting Time)

The membership functions for the second output (Waiting Time in minutes) are less (0 – 3), medium (2 – 7), and high (5 – 10) which are plotted as shown in Fig. 7.

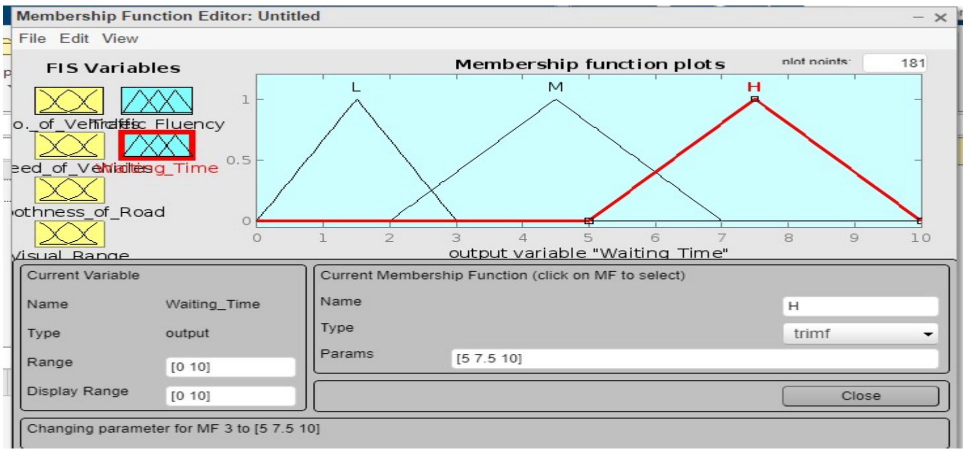

Figure 7: Membership Function (Waiting Time)

5.2. Fuzzy Rule

The fuzzy 'If–Then' rules made by us are inserted using Rule Editor of Mamdani FIS in MATLAB which are shown in Fig. 8.

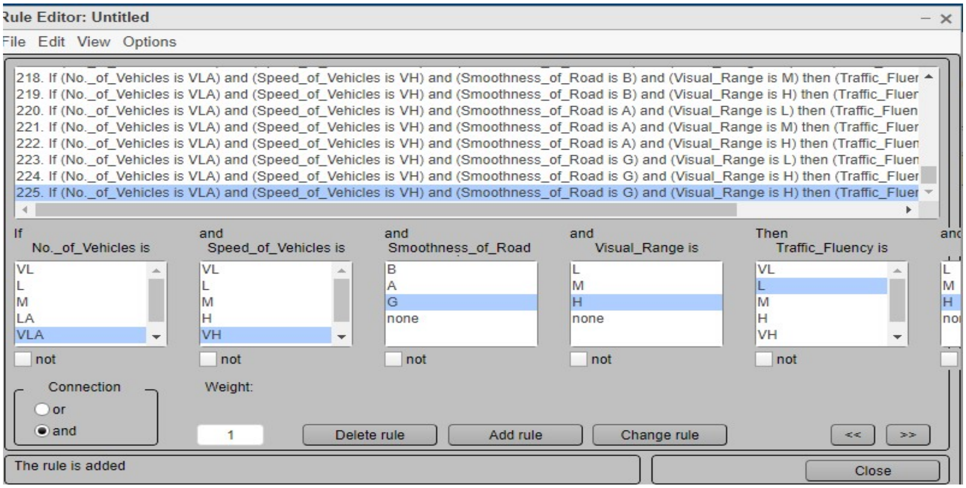

Figure 8: Rule Editor

5.2.1. The fuzzy If-Then rules can be viewed graphically with the help of Rule Viewer of FIS in MATLAB which is shown in Fig. 9.

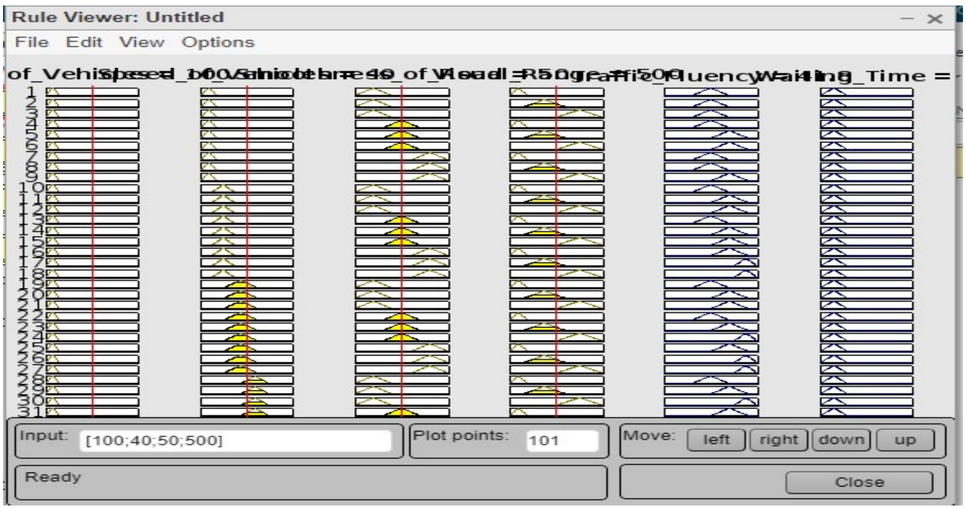

Figure 9: Rule Viewer

5.3. Surface Viewer

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

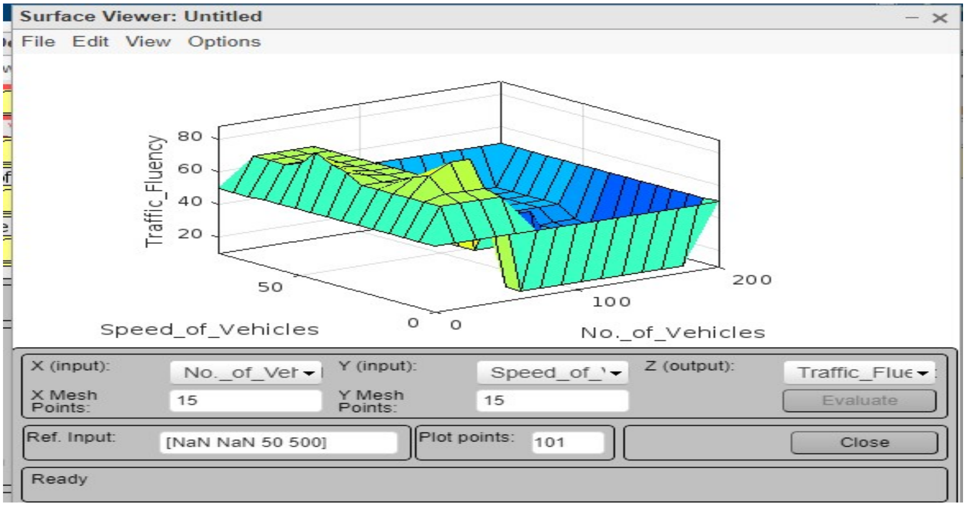

Figure 10: Surface Viewer

6. Conclusion

In this paper, an FLC is introduced to enhance the efficiency of the TLC. The proposed FLC shows a better performance than the all-erstwhile developed FLC's on account of its more flexible nature with reference to its input. This controller consists of four input variables such as No. of Vehicles, Speed of Vehicles, Smoothness of Road, and Range of visibility, to improve traffic flow and reduce waiting time. Thus, using this traffic light controller, traffic congestion can be easily managed in any weather and road condition. This is self-explanatory and a perusal of the paper can establish it.

References

[1] Arikumar K. S., Swetha R., Swathy D., Cognitive Road Traffic Controller using Fuzzy Logic in IoT, International Journal of Computer & Organization Trends (IJCOT), Vol. 7, Issue 2(2017), 1-5.

[2] Askerzade, I. N., Mustafa S. Mahmood, Design and Implementation of Intelligent Traffic Control by using Fuzzy Logic, Talk in 1st International Fuzzy Systems Symposium October 1-2, Ankara (2009), 52-59.

[3] Ecem Acar, Sevilay K. S., Fuzzy Logic Control Automation for Traffic Signalization system" European Journal of Science and Technology, Special Issue 28(2021), 1044-1047.

[4] Jensen M. B., Philipsen M. P., Møgelmose A., Moeslund T. B. and Trivedi M. M., Vision for Looking at Traffic Lights, IEEE Transactions on Intelligent Transportation Systems, (2016), 1800-1815.

[5] Lafuente-Arroyo, Sergio, et al., A Decision Support System for the Automatic Management of Keep-Clear Signs based on Support Vector Machines and Geographic Information Systems, Expert Systems with Applications, 37.1 (2010), 767-773.

[6] Mohanaselvi S. and Shanpriya B., Application of Fuzzy Logic to Control Traffic Signals, The 11^{th} National Conference on Mathematical Techniques and Applications, AIP Conference Proceedings, 2112 (2019), 020045(1-9).

[7] Raoul De Charette, Fawzi Nashashibi, Traffic light recognition using image processing compared to learning processes, IEEE, IROS, (2009), 333-338.

[8] Shukla H. S., Jitesh Pati Tripathi, Traffic Management System Using Fuzzy Logic, Journal of International Academy of Physical Sciences, Vol. 15 No. 2 (2011), 189-196.

[9] Tripathi Jitesh P., Shukla H. S., Management of a Road Traffic Junction Using Fuzzy Lights Controller, Journal of Rajasthan Academy of Physical Sciences (JRAOPS), Vol. 11 No. 3(2012), 209-222.

[10] Ugwu C., Bale, Dennis, An Application of fuzzy Logic Model in Solving Road Traffic Congestion, International Journal of Engineering Research & Technology (IJERT), Vol. 3, Issue 2 (2014), 2960-2969.

[11] Zadeh, Lotfi A., Fuzzy Sets, Information and Control 8.3 (1965), 338-353.

[12] Zadeh, Lotfi A., The Concept of a Linguistic Variable and its Application to Approximate Reasoning - 1, Information Sciences, 8.3 (1975), 199-249.

[13] Zhang Li-li, Zhao Qi, Wang Li and Zhang Ling-yu, Research on Urban Traffic Signal Control System Based on Cyber Physical Systems, Hindawi Journal of Advanced Transportation, (2020), 1-6.

This page intentionally left blank.