REVIEW ARTICLE

SAMRIDDHI Volume 15, Issue 1, 2023 Print ISSN: 2229-7111 Online ISSN: 2454-5767

A Review of Different Fuzzy Models to Evaluate Vehicular Traffic System

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Abstract

These days, the number of vehicles is increasing due to population growth. Consequently, the traffic delay and congestion are growing fast and being a major problem in the world. Due to this traffic problem, our daily life is affected and we have to face many problems such as pollution, accidents, delay in services, wastage of time & money, etc. The improvement of traffic system performance by the traditional control system is difficult. So, this paper includes a review of different methods which are used to develop a Fuzzy-logic controller (FLC) to solve road traffic problems. In this paper, the comparison of various methods is given with the advantages and disadvantages of each method.

Keywords: Fuzzy, Fuzzy-logic controller, Signal Control, Fuzzy Signal Control System (FSCS), Membership Function (MF).

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology (2023); DOI: 10.18090/samriddhi.v15i01.26

Introduction

Today, road traffic jam is a huge problem in the world. Although, the road traffic jam is existing everywhere. Yet, metropolitan cities are most affected by it. The main reason for the traffic congestion is to rise in the population and the vehicles. There are different traffic congestion factors such as incomplete traffic information, insufficient road capacity, poor traffic management, large red-light delays, road accidents, etc. Since traffic problems are characterized by parameters like uncertainty, imprecision, and ambiguity, so, due to these parameters, fuzzy logic methods are very useful to control traffic signals. Zadeh[1] proposed the fuzzy logic concept in 1965, which described uncertainty and imprecision. The problems based on uncertainty and imprecision are characterized by natural languages which are called linguistic variables and the conception of the linguistic variable was given by Zadeh[2] in 1975. Since the real world is based on uncertainty and imprecise, so fuzzy set theory is the best approach for solving real-world problems. Since traffic is a real-world problem, traffic signal control is the best solution to solve traffic problems. So, fuzzy logic is very useful to solve traffic problems. Most researchers use the fuzzy inference system tool in MATLAB to solve the traffic problem.

Fuzzy Traffic Signal Control

At present, traffic signals are widely used to manage traffic jams, but it is not sufficient to get an effective solution for the varying condition of traffic. Generally, there are three lights used in traffic signals. First, the red light is used for stopping the arriving vehicles. Second, the green light is used for allowing the arriving vehicles, and third, the yellow light is used for two purposes; one to indicate that we should slow our vehicle and prepare to stop for the red light, and second to indicate that if we have already crossed the intersection, then we should continue driving. A fuzzy-logic controller (FLC) is used to get the most effective solution for the varying traffic system. Using fuzzy technology in controlling the traffic flow, we can convert the thinking of human beings into an algorithm by applying mathematical models. The thinking process of traffic policemen to run traffic signals is done by 'if – then' fuzzy rules.

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How to cite this article: Tripathi JP, Kumar D, Singh UP. (2023). A Review of Different Fuzzy Models to Evaluate Vehicular Traffic System. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology,* 15(1), 49-54.

Source of support: Nil

Conflict of interest: None

Related Work

Since fuzzy logic is used to manipulate the idea of partial truth lying between '0' and '1', where 0 denotes totally false and 1 denotes totally true. So, this technique is used in information processing applications and industrial control.

The implementation of a traffic monitoring system by density and flow control using IoT is proposed by Shah K. et al[3] in 2015. This system is based on a fuzzy control system applicable to change phase time and reduce waiting time for the 4-phases intersection. Whereas to expand traffic movement by creating elastic phase structures and creation of smart timing resolutions for a four phases intersection, an intelligent traffic lights control system is developed by Jin *et al.*[4] in 2016.

K. Tan *et al.*[5] represented an intelligent traffic light controller built on fuzzy rules. Software has been developed on the basis of this technology and using this software, they simulated the given condition of an isolated traffic junction, at last, they observe that a fuzzy logic controller is the best approach against the conventional fixed-time controller.

U. C. Osigwe *et al.*[6] represented a traffic system design that is an intelligent system used to monitor and control the road traffic. Abdelkader *et al.*[7] introduced a fuzzy logic signal control system in 2021. In this system, cameras are fixed at each road and the images taken from these cameras are given to the fuzzy logic controller as inputs. After the simulation, this controller gives the appropriate results. Since this system is very flexible and provides suitable flexible green timing depending on the total number of vehicles on each road. So, it reduces the waiting time for vehicles on the road.

M. Jha *et al.*[8] presented a traffic controller and introduced a traffic model using MATLAB. This system is mainly based on queuing theory model in which multiple inputs are given to the controller and single output is observed. The fuzzy logic traffic controller is intended by using the Mamdani FIS of MATLAB. This design consists of 3-stages, named the green phase stage, the next phase stage, and the switching stage. This system also works for an emergency vehicle case in traffic movement.

Comparative Study

K S Arikumar *et al.*[9] proposed a FSCS in which they used the sensors. For each signal, they used two sensors. The first sensor was instilled back side of the light and the second was installed at some distance from the first sensor. In the given system, vehicles passing through the traffic signal light were counted by the first sensor, and the vehicles coming to the intersection point were counted by the second sensor.

They took the number of arriving vehicles & the number of vehicles in the queue as inputs and selected three linguistic variables for each input. They construct nine if-then fuzzy rules. They select five linguistic variables for the output. The 5-linguistic variables are very-small(VS), small(S), medium(M), large(L), and very-large(VL). Using the Mamdani FIS of MATLAB, they simulated and get the output for the predicted traffic.

The MF for the first input "arrival of cars" are given –

$$\mu_{\tilde{S}}(x) = \begin{cases} 0 & , \ x < 0 \\ \dfrac{x}{7.5} & , 0 \le x \le 7.5 \\ \dfrac{15 - x}{7.5} & , 7.5 \le x \le 15 \\ 0 & , \ x > 15 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \ x < 16 \\ \frac{x-16}{7} & , 16 \le x \le 23 \\ \frac{30-x}{7} & , \ 23 \le x \le 30 \\ 0 & , \ x > 30 \end{cases}$$

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \ x < 31 \\ \frac{x-31}{7} & , \ 31 \le x \le 38 \\ \frac{45-x}{7} & , \ 38 \le x \le 45 \\ 0 & , \ x > 45 \end{cases}$$

The MF for the second input "Number of cars in queue" are given as –

$$\mu_{\tilde{S}}(x) = \begin{cases} 0 & , \ x < 0 \\ \dfrac{x}{7.5} & , \ 0 \le x \le 7.5 \\ \dfrac{15 - x}{7.5} & , \ 7.5 \le x \le 15 \\ 0 & , \ x > 15 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \ x < 16 \\ \dfrac{x - 16}{7} & , \ 16 \le x \le 23 \\ \dfrac{30 - x}{7} & , \ 23 \le x \le 30 \\ 0 & , \ x > 30 \end{cases}$$

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \ x < 31 \\ \dfrac{x - 31}{7} & , \ 31 \le x \le 38 \\ \dfrac{45 - x}{7} & , \ 38 \le x \le 45 \\ 0 & , \ x > 45 \end{cases}$$

The MF for the output "predicted traffic" are given as –

$$\mu_{\widetilde{VS}}(x) = \begin{cases} 0 & , \ x < 0 \\ \dfrac{x}{4.5} & , \ 0 \le x \le 4.5 \\ \dfrac{9 - x}{4.5} & , \ 4.5 \le x \le 9 \\ 0 & , \ x > 9 \end{cases}$$

$$\mu_{\tilde{S}}(x) = \begin{cases} 0 & , \ x < 10 \\ \dfrac{x - 10}{4} & , \ 10 \le x \le 14 \\ \dfrac{18 - x}{4} & , \ 14 \le x \le 18 \\ 0 & , \ x > 18 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \ x < 19 \\ \dfrac{x - 19}{4} & , \ 19 \le x \le 23 \\ \dfrac{27 - x}{4} & , \ 23 \le x \le 27 \\ 0 & , \ x > 27 \end{cases}$$

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \ x < 28 \\ \dfrac{x - 28}{4} & , \ 28 \le x \le 32 \\ \dfrac{36 - x}{4} & , \ 32 \le x \le 36 \\ 0 & , \ x > 36 \end{cases}$$

$$\mu_{\widetilde{VL}}(x) = \begin{cases} 0 & , \ x < 37 \\ \dfrac{x - 37}{4} & , \ 37 \le x \le 41 \\ \dfrac{45 - x}{4} & , \ 41 \le x \le 45 \\ 0 & , \ x > 45 \end{cases}$$

While S. Mohanaselvi *et al.*[10] proposed a FSCS for a junction of 4-lanes of traffic. At first, they allowed the traffic to move from the north direction and then allowed to move the traffic from the east, south and west directions in progress. In the given design, if the traffic from the north-south is allowed to run, then the traffic from east-west is stopped, and the converse. Here left and right turns are not mentioned. They use the FLSC to maintain the traffic from the north-south direction on one side and the east-west direction on another side. The north-south direction is taken as the main lane. The time of the green light signal is taken from 2 to 60 seconds.

They took 3-fuzzy input variables, named no. of arriving vehicles, no. of queuing vehicles, and weather variation (fog) in the FSCS, and selected 3-linguistic variables Less (L), Medium (M), and High (H) for each input variable. They also selected three linguistic variables Short (S), Medium (M), and Long (L) for the output green light duration and constructed 27 if-then fuzzy rules. After making fuzzy rules, they simulated using Mamdani FIS in MATLAB and got the output for predicted traffic.

The MF for the first input (arriving vehicles) are given as –

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{5} & , \quad 0 \le x \le 5 \\ \frac{10-x}{5} & , \quad 5 \le x \le 10 \\ 0 & , \quad x > 10 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 7 \\ \frac{x-7}{9} & , \quad 7 \le x \le 16 \\ \frac{25-x}{9} & , \quad 16 \le x \le 25 \\ 0 & , \quad x > 25 \end{cases}$$

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

The MF for the second input (queuing vehicles) are given as –

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \frac{x}{5} & , \quad 0 \le x \le 5 \\ \frac{10-x}{5} & , \quad 5 \le x \le 10 \\ 0 & , \quad x > 10 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 7 \\ \frac{x-7}{9} & , \quad 7 \le x \le 16 \\ \frac{25-x}{9} & , \quad 16 \le x \le 25 \\ 0 & , \quad x > 25 \end{cases}$$

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

The MF for the third input (fog) are given as –

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 1000 \\ \frac{x-1000}{250} & , \quad 1000 \le x \le 1250 \\ \frac{1500-x}{250} & , \quad 1250 \le x \le 1500 \\ 0 & , \quad x > 1500 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 400 \\ \frac{x-400}{400} & , \quad 400 \le x \le 800 \\ \frac{1200-x}{400} & , \quad 800 \le x \le 1200 \\ 0 & , \quad x > 1200 \end{cases}$$

$$\mu_{\tilde{H}}(x) = \begin{cases} 0 & , \quad x < 50 \\ \frac{x-50}{225} & , \quad 50 \le x \le 275 \\ \frac{500-x}{225} & , \quad 275 \le x \le 500 \\ 0 & , \quad x > 500 \end{cases}$$

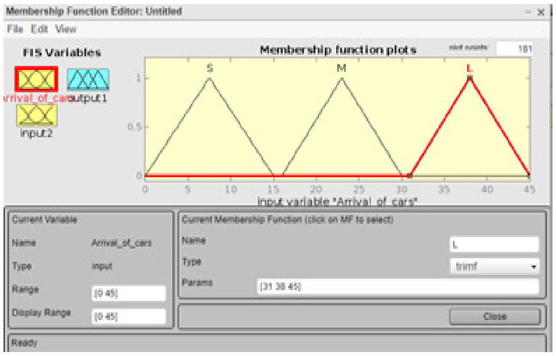
Comparative table

Arikumar, K. S., Swetha, R., & Swathy D. [9]						*Mohanaselvi, S., & Shanpriya, B.* [10]							
Inputs				*Output*		*Inputs*						*Output*	
Arrival of cars		*No. of cars in queue*		*Predicted Traffic*		*Arriving Vehicles*		*Queuing Vehicles*		*Fog*		*Green Light Duration*	
Range	*Linguistic Variable*	*Range*	*Linguistic Variable*	*Range*	*Linguistic Variable*	*Range*	*Linguistic Variable*	*Range*	*Linguistic Variable*	*Visual Range (in meters)*	*Linguistic Variable*	*Time (in sec.)*	*Linguistic Variable*
0–15	Small	0–15	Small	0–9	Very Small	0–10	Less	0–10	Less	1000 – 1500	Low	0–10	Short
16–30	Medium	16–30	Medium	10–18	Small	7–25	Medium	7–25	Medium	400 – 1200	Medium	8–30	Medium
31–45	Large	31–45	Large	19–27	Medium	20–50	High	20–50	High	50 – 500	High	25–60	Long
				28–36	Large								
				37–45	Very Large								

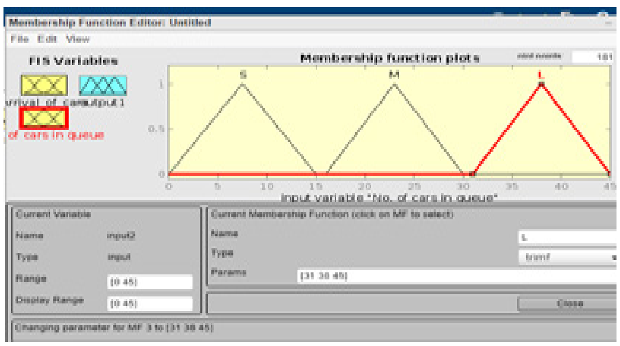
Membership function for Input

Arikumar, K. S., Swetha, R., & Swathy D.[9]

1st Input

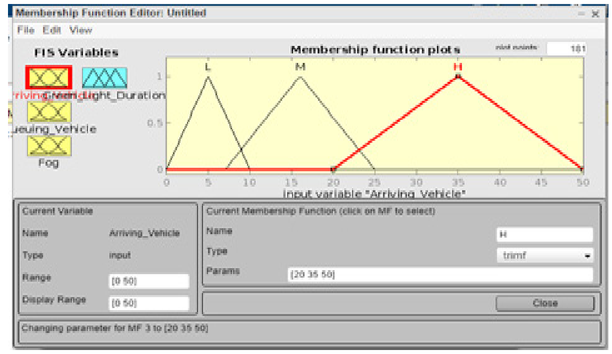


2nd Input

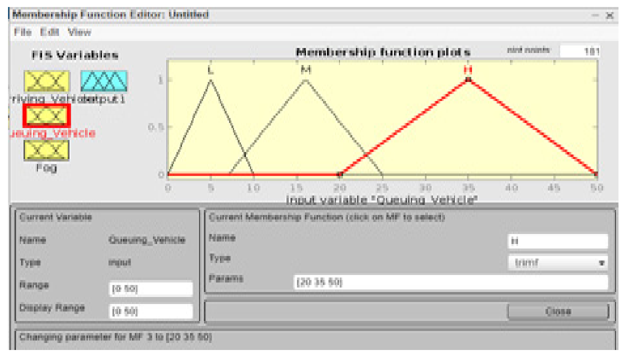


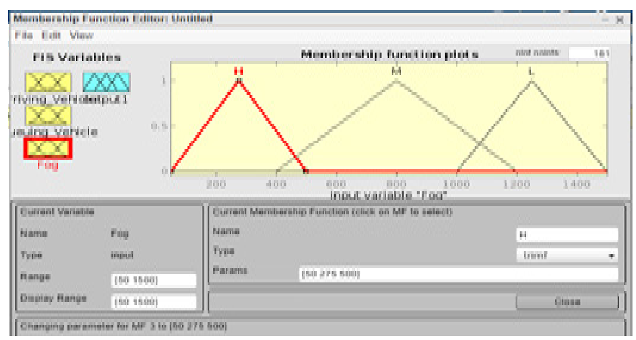
Mohanaselvi, S., & Shanpriya, B.[10]

1st Input



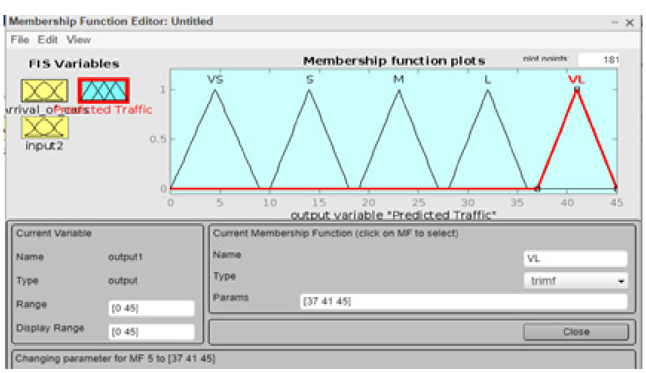
2nd Input



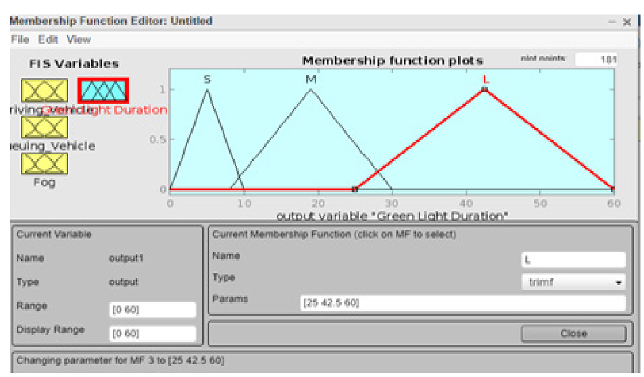


Membership function for output

Mohanaselvi, S., & Shanpriya, B.[10]



Mohanaselvi, S., & Shanpriya, B.[10]



Fuzzy Rules

Mohanaselvi, S., & Shanpriya, B.[10]

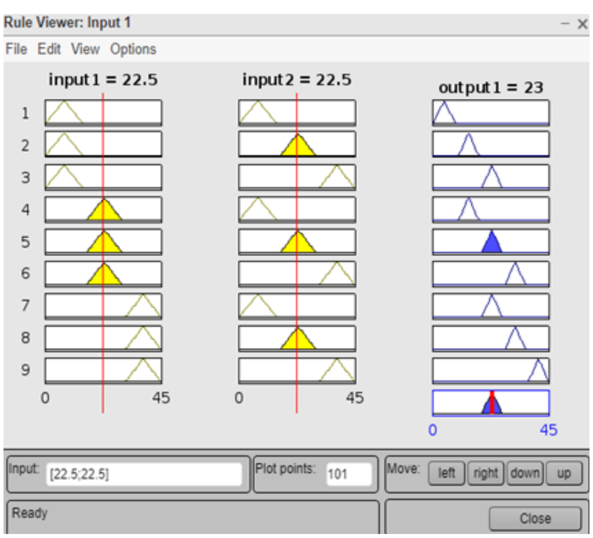
No.	*Arrival*	*Queue*	*Predicted Traffic*
1	S	S	VS
2	S	M	S
3	S	L	M
4	M	S	S
5	M	M	M
6	M	L	L
7	L	S	M
8	L	M	L
9	L	L	VL

Mohanaselvi, S., & Shanpriya, B.[10]

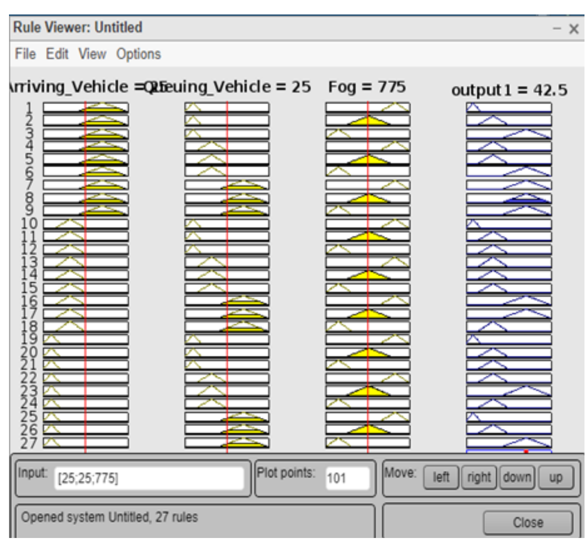
No.	*Arriving Vehicle*	*Queuing Vehicle*	*Fog*	*Green Time Duration*
1	H	L	L	S
2	H	L	M	M
3	H	L	H	L
4	H	M	L	M
5	H	M	M	M
6	H	M	H	L
7	H	H	L	L
8	H	H	M	L
9	H	H	H	L
10	M	L	L	S
11	M	L	M	M
12	M	L	H	M
13	M	M	L	M
14	M	M	M	M
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
22	L	M	L	M
23	L	M	M	L
24	L	M	H	M
25	L	H	L	S
26	L	H	M	M
27	L	H	H	L

Mamdani input - output rule viewer

Mohanaselvi, S., & Shanpriya, B.[10]

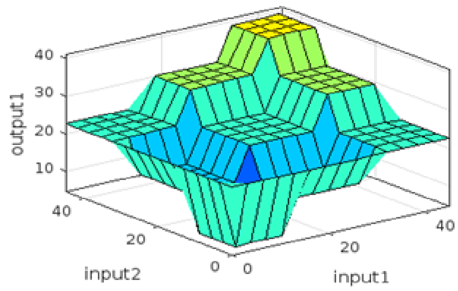


Mohanaselvi, S., & Shanpriya, B.[10]

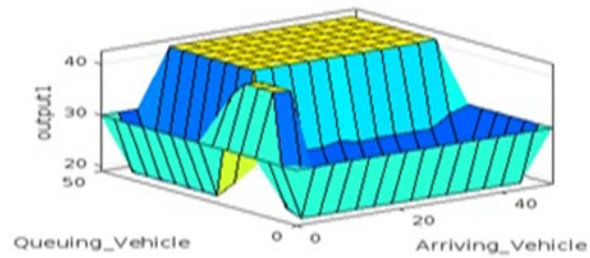


Mamdani Surface Viewer

Mohanaselvi, S., & Shanpriya, B.[10]



Mohanaselvi, S., & Shanpriya, B.[10]



The MF for the output (green light duration) are given as –

$$\mu_{\tilde{S}}(x) = \begin{cases} 0 & , \quad x < 0 \\ \dfrac{x}{5} & , \quad 0 \leq x \leq 5 \\ \dfrac{10 - x}{5} & , \quad 5 \leq x \leq 10 \\ 0 & , \quad x > 10 \end{cases}$$

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & , \quad x < 8 \\ \dfrac{x - 8}{11} & , \quad 8 \leq x \leq 19 \\ \dfrac{30 - x}{11} & , \quad 19 \leq x \leq 30 \\ 0 & , \quad x > 30 \end{cases}$$

$$\mu_{\tilde{L}}(x) = \begin{cases} 0 & , \quad x < 25 \\ \dfrac{x - 25}{17.5} & , \quad 25 \leq x \leq 42.5 \\ \dfrac{60 - x}{17.5} & , \quad 42.5 \leq x \leq 60 \\ 0 & , \quad x > 60 \end{cases}$$

Advantages and Disadvantages

This review paper includes the different approaches for controlling traffic signals, which securely help traffic movement without collision. This also reduces the number of road accidents and helps with safe driving. Since traffic signals are visible easily in foggy weather, at night, or on a rainy day, it is very helpful in traffic movement at the crossing. It also reduces air pollution by reducing the number of vehicles, as proposed in.[11] It is more flexible and gives the most appropriate results.

Now; we discuss the disadvantages of the FLC. The FLC system with sensors is very costly due to the high-cost maintenance of sensors. Sometimes, video cameras are used in the traffic control system, which fails to handle occlusion and shadow overlapping cases, proposed in.[12] The traffic signals also delay the traffic by stopping vehicles at the crossing during the busiest hours.

Conclusion

This paper represents a review of different approaches to the traffic control system, especially the traffic signal control system. In it, we have discussed a FLSC system with sensor nodes. This paper includes a comparative study between two types of traffic signal control systems. Membership functions have been defined mathematically and plotted using the Mamdani Fuzzy Inference System of MATLAB. So, this paper helps to control the traffic signal in mega cities which are the most affected by traffic problems, but this system is very costly due to the high cost of maintenance for sensors.

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