Current Applied Science and Technology Vol. 24 No. 2

Research article

An Efficient Road Traffic Modeling through a Novel Real Time Traffic Simulator

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Curr. Appl. Sci. Technol. 2024, Vol. 24 (No. 2), e0253801; https://doi.org/10.55003/cast.2023.253801

Received: 26 April 2022, Revised: 9 February 2023, Accepted: 17 August 2023, Published: 3 November 2023

Abstract

Dynamic traffic control is a challenging task that involves meeting rising traffic demands and cutting down on intersection delays. The existing yellow/red/green light fixed transition periods used by traffic controllers make it impossible for them to adapt to changing real-time traffic conditions at intersections. Furthermore, it would be impractical to hire traffic officers for every intersection throughout the day due to a lack of personnel, and even if sufficient personnel are available, it would be a very expensive set up. A fuzzy based traffic model was designed and simulated in real time conditions using the developed traffic simulator algorithm to control the traffic jamming at road intersections. The developed fuzzy model was based on three fuzzy inputs and its performance was measured for 13 cases of varying road width. The developed model outperformed the traditional fixed-time delay model in all the cases and the level of improvement was further increased when the congestion was high. Narrower roads were more congested and the improvement with fuzzy systems as compared to its fixed time delay counterparts was as high as 26%. This research findings clearly support the use of fuzzy logic for handling the most challenging problem of traffic congestion in densely populated regions.

Keywords

fuzzy;
traffic simulator;
road width;
environment;
traffic actuated;
sampling interval;
cycle count

1. Introduction

The population of world has increased by 25.3% [1], with an average increase of 9.82% [2] in the number of vehicles in countries like India over last 20 years. The availability of convenient loan facilities and easy-to-pay monthly installment plans in country like India are the root cause leading

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to this growth in the numbers of vehicles on the roads. In urban areas, the problem of traffic congestion causes catastrophic effects on the environment. It has caused unnecessary fuel burning and excessive discharge of greenhouse gases. Traffic light management in the forms of pre-timed controlling, traffic actuated, and adaptive controlling have seemed to be optimum solutions for controlling the traffic at intersections. Pre-timed traffic controlling systems handle low/high volume traffic using a fixed time approach but result in excess waiting time. Traffic actuated control systems reduce waiting time (delay) in comparison to pre-timed systems as they can respond to real time traffic flow. However, they face limitations in the case of heavy traffic flow conditions. Adaptive control systems offer the best solution as green time in adaptive systems can be adjusted according to the demands of traffic volume, i.e., under dynamic traffic conditions. Such systems are ideal because the main goal of traffic control systems is the reduction of overall average delay or an increase in the mean speed of the vehicles, which necessitates an ideal green time at each junction.

The calculation of ideal green time is not solely based on the volume of traffic in the present, but the future predicted value for each intersection is also considered. Moreover, the arrival of vehicles at an intersection is variable that changes with time of the day and with the pseudo random factors associated with the status of the neighboring traffic signals. This variability makes it difficult to model traffic systems with a mathematical approach. In other words, the mathematical modeling of traffic control problems is not appropriate as these problematic factors are totally ill-defined and full of uncertainty. Moreover, traffic congestion is a never-ending problem, so we still face many challenges in developing intelligent transportation system (ITS) that can improve traffic flow at intersections whilst decreasing the uncertainty in traffic flow control. The theory of fuzzy logic was found to be suitable solution for dealing with traffic control problems involving uncertainty and can be used to optimize signalized traffic intersection systems. Fuzzy logic-based systems not only utilize human expert knowledge, but they also allow us to model a traffic scenario by utilizing that knowledge based on if-then rule base structures. They can be used to solve problems of traffic congestion by extending or reducing green time when lanes have either a little or a lot of traffic.

Sadoun [3] simulated a 4-way intersection in order to optimize the timings of traffic signals by comparing three and four phase systems. It was shown that the 3-phase system had an upper edge over the 4-phase system in terms of improvement in queue length, mean utilization and waiting time. Sadoun [4] also recognized the undesirable consequences of delays for both the environment and drivers. Various probability distributions such as Poisson, Exponential and Uniform were considered and then the optimum red-green timings required for flow of traffic were computed. Adewoye *et al.* [5] regulated the phase-splits of traffic lights at road crossings. The researchers constructed and simulated a fuzzy traffic light control system. The usefulness of the fuzzy logic controller in regulating traffic situations at crossings was simulated using MATLAB (fuzzy tool) software. The fuzzy traffic controller makes a judgement on whether to continue the current green phase or end it, based on a set of fuzzy rules that include the IF-THEN rules. Alam and Pandey [6] reduced the average vehicle delay in diverse traffic flow rates, and a two-stage traffic light system for real-time traffic monitoring was developed. The system dynamically regulates the phase and green time of traffic lights at an isolated signalized intersection. The Traffic Urgency Decision Module (TUDM) and the Extension Time Decision Module (ETDM) are two distinct modules utilized. Homaei *et al.* [7] considered a significant intelligent control strategy for traffic operation that involved fuzzy reasoning. The important point of this study was the presentation of a novel fuzzy signal control scheme for full single junction control with emergency vehicle pre-emption. Lai *et al.* [8] created an ANFIS traffic signal controller for four-approach intersections with multilane isolation in order to reduce traffic congestion at intersections. With its fuzzy rule foundation and capacity to learn from a collection of sample data, the ANFIS traffic signal controller outperformed the current system for managing traffic signals and easing congestion at many congested junctions in cities like Malaysia's Kuala Lumpur.

Cao and Wang [9] proposed an enhanced adaptive genetic fuzzy control method for intersection traffic signal control. The system was designed to deal with complicated traffic and reduce delays caused by simple traffic models. They suggested that the population size could be changed, and the Gaussian membership function should be applied to increase computing efficiency. Yusupbekov *et al.* [10] addressed the challenges of developing adaptive fuzzy-logic traffic control systems (AFLTCS) that could handle information fuzziness and uncertainty in the situation of high traffic streams. Based on fuzzy sets and fuzzy logic, methods for the formal description of traffic control at intersections were proposed. Jovanović and Kukić [11] looked at the issue of real-time regulation of an overpopulated crossroad. A fuzzy logic-based mathematical model to address the issue was created. The model was applicable at crossings with overloaded traffic flows. Thereafter, the fuzzy model was contrasted with the fixed-time delay model for overcrowded traffic intersections. Cheng *et al.* [12] organized vehicles in the same lane into smaller groups and scheduled vehicle groups via wireless communication rather than with traffic lights, a concept that is now utilized to schedule waiting vehicles at each lane. When traffic volumes in separate lanes are uneven, a direct scheduling of vehicles can shorten wait times and increase fairness.

Jin *et al.* [13] introduced Fuzzy Intelligent Traffic Signal (FITS) control, an intelligent control system for traffic signal applications. It offered a practical and affordable method for enhancing traffic signal systems used at the time. The control system was set up on a piece of intermediary hardware that could receive messages from the hardware of the signal controller. Zaid *et al.* [14] proposed an automatic algorithm in a transportation system that could control traffic flow and cut down on wasted travel and waiting time. The program was then tested by comparing its outcomes to those obtained manually. Zachariah *et al.* [15] analyzed a static road traffic control intersection automation system to mitigate the effects of traffic jams and the associated repercussions, such as lengthy waiting times, the emission of harmful hydrocarbons from moving vehicles, etc.

Dereli *et al.* [16] considered one intersection and designed a fuzzy-based controller with two inputs: "queue length during a red light" and "remaining vehicles in line after a green light". In this multidimensional problem, the output variables "phase selection" and "extent of green light duration" are combined into one system, and the consistency of this model is evaluated using ANN (Artificial Neural Network) and ANFIS (Adaptive Neuro-Fuzzy Inference system). It is found that fuzzy controllers effectively reduce the delay. Rocha *et al.* [17] customized a fuzzy inference system that could determine when the semaphore should set the green light interval in accordance with particular road needs. Zuraime *et al.* [18] determined the most efficient and ideal timing for traffic signals to accommodate various traffic densities. The study took a four-way intersection into account. According to the findings, different road crossings need varied amounts of effective and ideal green time to ease traffic. Nie *et al.* [19] predicted traffic conditions using the Intelligent Internet of Things (IIoTs). To effectively estimate short-term traffic, Monte Carlo simulations were used in their study. Theoretical analysis of a multitasking learning algorithm across a real-world scenario was proposed and carried out by Nie *et al.* [20], and a deep learning-based architecture with long-short term memory was also constructed. Moreover, the researchers showed that their proposed system could be applied in real world networks.

The basic purpose of a traffic controller is strictly adhered to the improvement of traffic congestion and a controller must alleviate the above-said problems. Therefore, various fuzzy models for signalized traffic intersections were proposed and the ones that can mimic human intelligence are of interest.

2. Materials and Methods

At any time of day, the real-time incoming traffic at a signalized junction is unpredictable. As a result of this, a unique simulator for the simulation of traffic was offered in this study. In our simulator, the quantity of vehicular traffic on each side of the road was generated based on the userrecommended traffic density. A pseudo-random number integer in the interval from 0 to the number of cars that could accommodate into the crossroads at the chosen density was generated by the traffic generation model, which was focused on uniform discrete distribution (traffic). The traffic density in the four lanes can be adjusted independently of each other. It is possible to set a fixed or adjustable amount of time for the traffic to pass. The green period for passing is given to either side of the road according to the congestion control model. Generally, the width of opposite roads is the same, i.e., the width of the north and south lanes is equal, and the east and west roads have the same width, as shown in Figure 1. Hence, an array of two elements is used to represent the width of four roads. The first element of the array represents the width of the north-south road, and the second element represents the width of the east-west road.

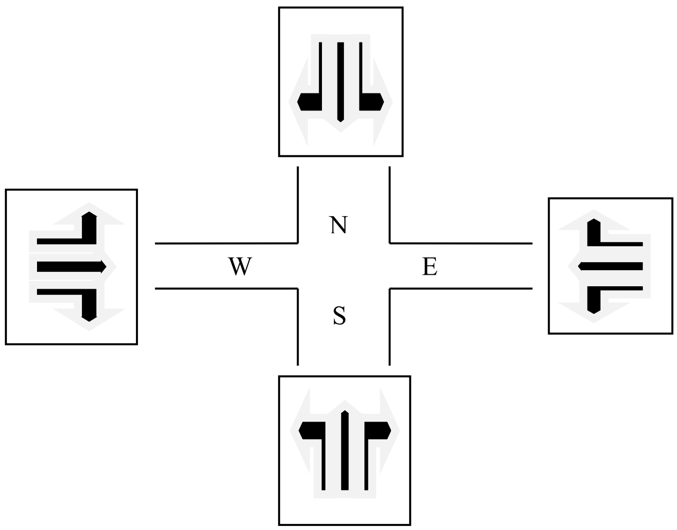

Figure 1. Direction of traffic for each lane at 4-way intersection

2.1 Traffic simulator: Pseudocode

The pseudocodes of the traffic simulator and the variables used are shown in Table 1.

Table 1. Variables used in pseudocodes

TD = Traffic Density	FIX_GT = Fixed Green Time
RW = Road Width	CC = Cycle Count
ST = Simulation Time	SI = Sampling Interval
QL = Queue Length	DIRECT = Direction
WT = Waiting Time	REM_GT = Remaining Green Time
GT = Green Time	N = Time, FLAG
WV = Waiting Vehicles	AD_SEC = Adaptive Second
MT = Model Type	VEH = No. of Vehicles

Pseudocode:

```
Procedure Traffic_Simulator(TD,ST,RW)
    Initialize QL = 100 (For Each Lane), FIX_GT = 60, CC = 0, SI = 5;
    While ST<Simulation_Time
        For DIRECT= 1:4 [East/West/North/South]
            Initialize WT = 0
        REM_GT = GT
            For N = 1:GT
                Rem_GT = Rem_GT-1
                Generate_Random_Traffic();
                Pass_Traffic();
                If (TRAFFIC=0)
                Set FLAG = "EMPTY ROAD"
                End if
                If REM_GT <= 10
                    If (MT= "Fuzzy")
                        AD_SEC=
                    EVALFIS((AR,WV,WT),FIS File)
                    Else
                        AD_SEC = 0
                    End if
                End if
            Update WT, VEH, GT = FIX_GT + AD_SEC
        End for
        End for
    End While
```

2.2 Fuzzy based traffic controller

Using MATLAB, we created a fuzzy-based traffic controller for this project. The proposed fuzzy system's performance was compared to that of a fixed-time traffic light system. A fixed-time traffic system was put in place to measure performance. Fixed time systems always give the traffic in all directions a fixed green time, regardless of dynamic traffic conditions like traffic density and queue length at intersections. In our proposal, we created a fuzzy system in which the lengthening or shortening of green time was managed based on three variables: Rate at which vehicles are arriving (AR), the length of the queue (QL) and the waiting time (WT). The implemented system calculated the queue length by calculating the total number of vehicles in each of the three waiting lanes. It also calculated the arrival rates by sampling the queue length every 'n' second and then by dividing the increased traffic by the sampling interval to find the vehicles arriving at the junction per unit time. A schematic diagram of fuzzy traffic controller is exhibited in Figure 2.

Three input variables with their respective specifications of membership functions are listed in Table 2, and the membership functions of each input and output are as shown in Figure 3 to Figure 6. Using these membership functions, a total number of 27 rules (3x3x3) were formulated and can be seen in Figure 7.

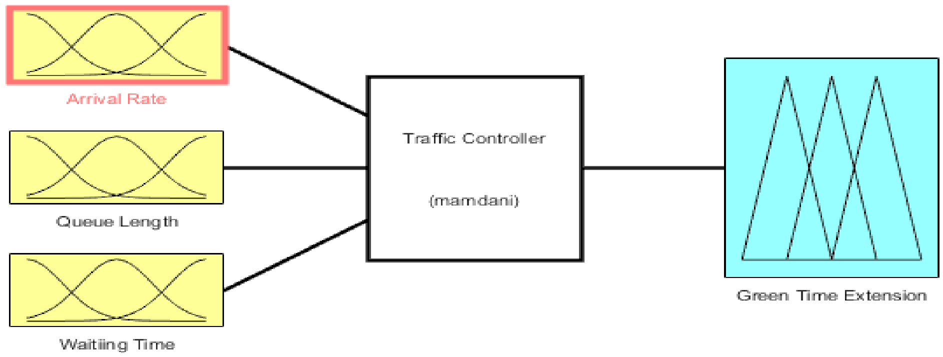

Figure 2. Schematic diagram of fuzzy traffic controller

Table 2. Input/output range specifications

Parameter	Input / Output	Type	Specifications
Arrival Rate	Input	Fuzzy	Three membership functions: 'AR Low':'trapmf',[0 0 0.5 1] 'AR Med':'trimf',[0.5 1 1.5] 'AR High':'trapmf',[1 1.5 5 5]
Queue Length	Input	Fuzzy	Three membership functions: 'QL low':'trapmf',[0 0 100 200] 'QL med':'trimf',[100 200 300] 'QL high':'trapmf',[200 300 1000 1000]
Waiting Time	Input	Fuzzy	Three membership functions: 'WT low':'trapmf',[0 0 125 250] 'WT med':'trimf',[125 250 375] 'WT high':'trapmf',[250 375 500 500]
Green Time	Output	Fuzzy	Three membership functions: 'Reduction':'trapmf',[-40 -40 -20 0] 'Normal':'trimf',[-20 0 20] 'Extension':'trapmf',[0 20 40 40]
Road Width	Input	Non-Fuzzy	------

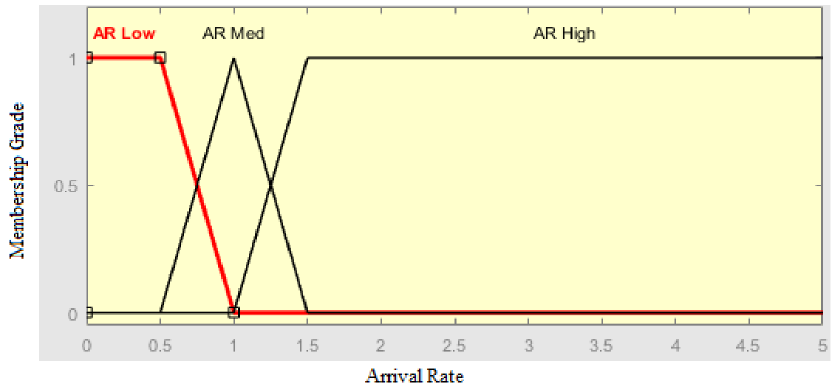

Figure 3. Input1: Arrival rate

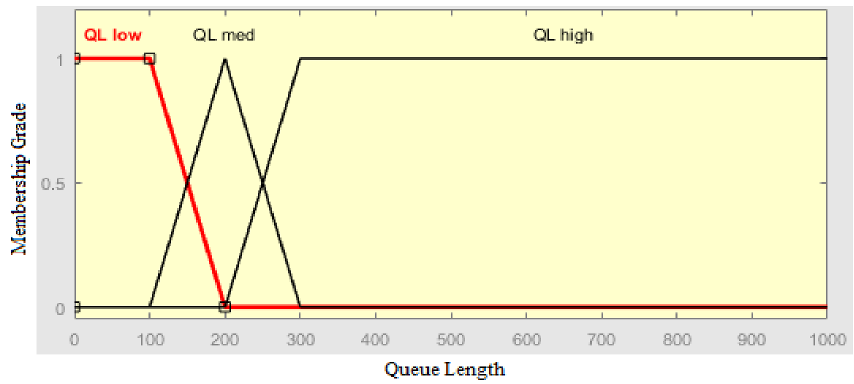

Figure 4. Input2: Queue length

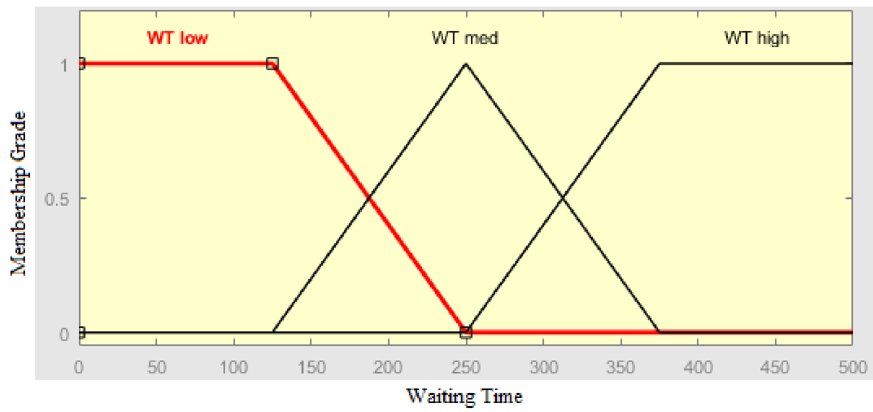

Figure 5. Input3: Waiting time

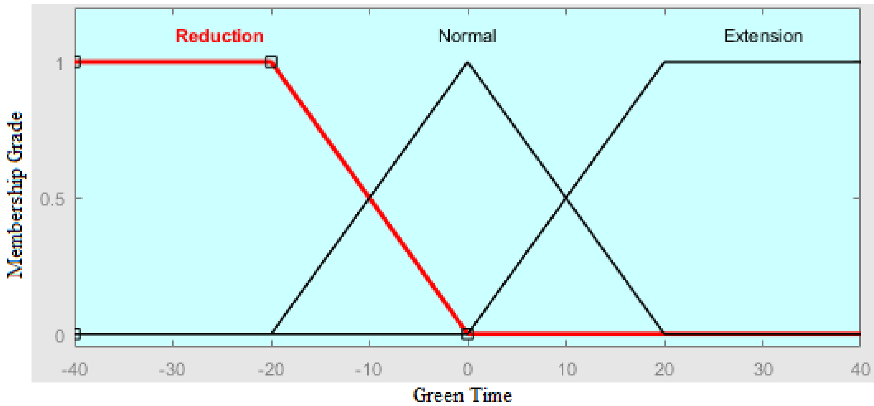

Figure 6. Output: Green time

11. If (Arrival Rate is AR Med) and (Queue Length is QL low) and (Waitiing Time is WT med) then (Green Time Extension is Normal) (1)
12. If (Arrival Rate is AR Med) and (Queue Length is QL low) and (Waitiing Time is WT high) then (Green Time Extension is Reduction) (1)
13. If (Arrival Rate is AR Med) and (Queue Length is QL med) and (Waitiing Time is WT low) then (Green Time Extension is Extension) (1)
14. If (Arrival Rate is AR Med) and (Queue Length is QL med) and (Waitiing Time is WT med) then (Green Time Extension is Normal) (1)
15. If (Arrival Rate is AR Med) and (Queue Length is QL med) and (Waitiing Time is WT high) then (Green Time Extension is Reduction) (1)
16. If (Arrival Rate is AR Med) and (Queue Length is QL high) and (Waitiing Time is WT low) then (Green Time Extension is Extension) (1)
17. If (Arrival Rate is AR Med) and (Queue Length is QL high) and (Waitiing Time is WT med) then (Green Time Extension is Extension) (1)
18. If (Arrival Rate is AR Med) and (Queue Length is QL high) and (Waitiing Time is WT high) then (Green Time Extension is Extension) (1)
19. If (Arrival Rate is AR High) and (Queue Length is QL low) and (Waitiing Time is WT low) then (Green Time Extension is Extension) (1)
20. If (Arrival Rate is AR High) and (Queue Length is QL low) and (Waitiing Time is WT med) then (Green Time Extension is Extension) (1)
21. If (Arrival Rate is AR High) and (Queue Length is QL low) and (Waitiing Time is WT high) then (Green Time Extension is Normal) (1)
22. If (Arrival Rate is AR High) and (Queue Length is QL med) and (Waitiing Time is WT low) then (Green Time Extension is Extension) (1)
23. If (Arrival Rate is AR High) and (Queue Length is QL med) and (Waitiing Time is WT med) then (Green Time Extension is Extension) (1)
24. If (Arrival Rate is AR High) and (Queue Length is QL med) and (Waitiing Time is WT high) then (Green Time Extension is Normal) (1)
25. If (Arrival Rate is AR High) and (Queue Length is QL high) and (Waitiing Time is WT low) then (Green Time Extension is Extension) (1)
26. If (Arrival Rate is AR High) and (Queue Length is QL high) and (Waitiing Time is WT med) then (Green Time Extension is Extension) (1)
27. If (Arrival Rate is AR High) and (Queue Length is QL high) and (Waitiing Time is WT high) then (Green Time Extension is Extension) (1)

Figure 7. Rulebases (Antecedents: queue length, arrival rate, waiting time, and consequent: green time)

2.3 Cases of TD (density of traffic)

For these implementations, we took 81 traffic density cases [21] with 3 traffic stages, i.e. high, medium and low for all the directions, i.e. north, south, east and west. These different combinations are shown in Table 3.

Table 3. TD (81 cases)

Case No.	Traffic Density			
	Lane: North	Lane: East	Lane: West	Lane: South
1	1	1	1	1
2	1	1	1	2
3	1	1	1	3
4	1	1	2	1
5	1	1	2	2
6	1	1	2	3
7	1	1	3	1
-	-	-	-	-
-	-	-	-	-
77	3	3	2	2
78	3	3	2	3
79	3	3	3	1
80	3	3	3	2
81	3	3	3	3

2.4 Delay experienced

To modify the count of automobiles waiting on the north, east, west, and south of the intersection, respectively, four up-down counters were used: Q_n, Q_e, Q_w, and Q_s. Only from the side of the intersection experiencing the green light, traffic was allowed to increase and decrease simultaneously at any given time; on the other three sides, traffic increased as a result of automobiles turning up there but being unable to pass through. The count of waiting cars is the sum of the number of cars on the three sides of the intersection that have a yellow or red light.

Delay experienced by waiting vehicles (D) was then calculated by following formula:

$D = (\sum \text{Sampling interval (in seconds)} * \sum Q_i * A_i \text{ (seconds)})$ [22]

Where, Q_i = queue of waiting vehicles waiting at i^{th} side, here i = [0: North, 1: East, 2: West, 3: South] direction

A_i =0 or 1 {Direction indicating the traffic either passing (0: the side confronting green light) or blockage (1: sides confronting red or yellow light) condition}.

3. Results and Discussion

In this work, the newly identified input parameter 'road width' was considered. This was done with the awareness that road width does not change frequently and remains almost constant until the road is constructed again or is blocked for some unavoidable reason. Hence, road width need not be considered as one of the fuzzy inputs upon which the green time depends and is thus considered as a fixed, non-fuzzy input. The designed fuzzy traffic controller with three inputs was simulated for a period of 2 h for all 81 instances of high traffic density as mentioned in Table 3. We conducted 15 trails for each traffic density case and for each of these, 20 iterations were carried out. Thirteen cases of road width were considered for evaluation of performance and observation of effects and delay improvement in each case, as tabulated in Table 3. In fact, the width of the road affects the number of vehicles that can cross the intersection in parallel (simultaneously). Road width was a constant parameter in the traffic simulator in our recent publications [20, 21], where the width of the road in the north-south direction was 10 m and the width of the road in the east-west direction was 15 m. The work was extended by considering 13 cases of road width values and extensive simulations were conducted in order to study its effect on system performance.

The experimental results are listed in Table 4. Generally, the width of roads on all the four sides in an intersection is same but sometimes it is found that one of the sets of opposite roads are same and the intersecting roads are of different width. To incorporate such cases, we took road width input as vector of two elements, representing width of North-South Road and East-West Road, respectively. For instance, the road width of the North-South Road was 8 m wide, and the East-West Road was 12 m wide [8, 12]. The final improvement in delay observed by the waiting vehicles in all the cases is shown in the third column of Table 4. Percentage delay improvement was found by comparing the waiting delay seen for fuzzy and non-fuzzy systems. Reduction in delay in the fuzzy systems compared to the non-fuzzy delayed systems was expressed as percentage and is listed under delay improvement in Table 4. It was found that the reduction in delay observed by waiting vehicles is large for narrow roads (around 26%), and a smaller improvement is obtained for wide roads (around 4%). This clearly indicates the effectiveness of fuzzy traffic controllers in handling congestion. The bar graph of percentage delay improvement for 13 cases of road width is shown in Figure 8.

Table 4. Different road width cases

Case No. #	**Road Width (meter)**	**Delay Improvement**
Case 1	[8, 8]	26.02%
Case 2	[8, 10]	26.04%
Case 3	[8, 12]	26.07%
Case 4	[10, 10]	26.07%
Case 5	[10, 12]	25.95%
Case 6	[10, 15]	21.30%
Case 7	[12, 12]	26.05%
Case 8	[12, 15]	21.26%
Case 9	[12, 20]	21.34%
Case 10	[15, 15]	4.14%
Case 11	[15, 20]	4.15%
Case 12	[15, 25]	4.15%
Case 13	[20, 20]	4.13%

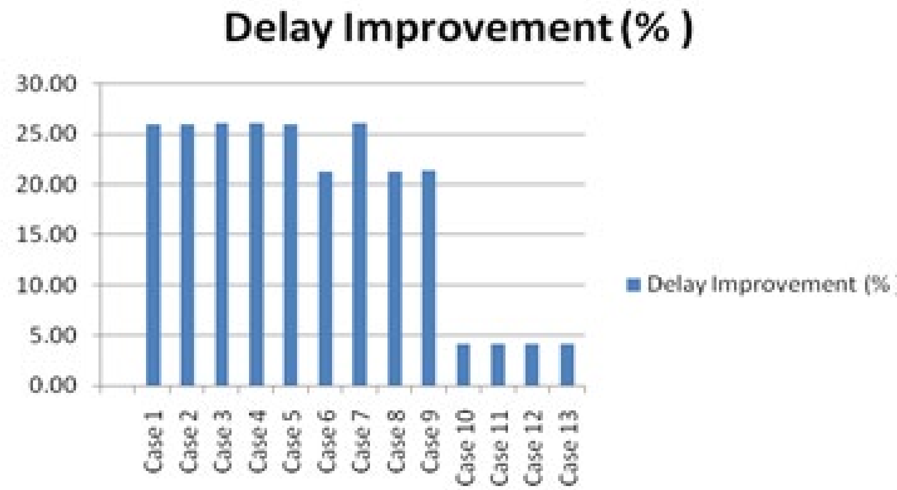

Figure 8. Delay improvement (fuzzy vs fixed time systems)

4. Conclusions

In this study, a novel simulator was used to compare the performance of a proposed fuzzy logic-based traffic control model with a fixed time model for managing traffic at crossroads junctions. The comparison was made in terms of the average delays observed by the vehicles in queues waiting for green signals. An extensive simulation was carried out for each case of the 13 cases of road width. For narrower roads the percentage improvement was approximately 26% which indicated that a fuzzy controller was a good alternative for managing the congestion at intersections. However, for wide roads, the percentage improvement in delay is reduced to about 4%. This is due to the fact that congestion does not occur on wider roads, and the construction of wide roads is one way to handle congestion. To conclude, it can be assumed that intelligent traffic systems are effective and improved systems for managing traffic in highly congested intersections. For wide roads, there is less congestion, only a small improvement in performance can be seen. Hence, it is recommended to use fuzzy based traffic controllers to reduce problems like excessive delays and emission of carbon gases due to automobiles stopped at intersections.

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