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Improving traffic and emergency vehicle clearance at congested intersections using fuzzy inference engine

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ABSTRACT

Traffic signals play an important role in controlling and coordinating the traffic movement in cities especially in urban areas. As the traffic is exponentially increasing in cities and the pre-timed traffic light control is insufficient in effective timing of the traffic lights, it leads to poor traffic clearance and ultimately to heavy traffic congestion at intersections. Even the Emergency vehicles like Ambulance and Fire brigade are struck at such intersections and experience a prolonged waiting time. An adaptive and intelligent approach in design of traffic light signals is desirable and this paper contributes in applying fuzzy logic to control traffic signal of single four-way intersection giving priority to the Emergency vehicle clearance. The proposed control system is composed of two parallel controllers to select the appropriate lane for green signal and also to decide the appropriate green light time as per the real time traffic condition. Performance of the proposed system is evaluated by using simulations and comparing with pre-timed control system in changing traffic flow condition. Simulation results show significant improvement over the pre-timed control in terms of traffic clearance and lowering of Emergency vehicle wait time at the intersection especially when traffic intensity is high.

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1. INTRODUCTION

As the number of vehicles are continuously increasing on the streets, a serious problem of traffic congestion occurs even if the traffic signals are implemented for controlled flow of traffic. This problem occurs because traffic is characterized by uncertainty and random behaviour whereas the pre-timed conventional green/red traffic signals have constant time phases switched between cycles. Although, the design of pre-timed signal control is simple, generally its performance is poor in heavy traffic clearance in minimizing wait time for emergency transit, so need for an intelligent and adaptive control system arises. The objective of this research is to design an adaptive traffic light control system that aids in heavy traffic clearance at crossroads as well as assisting in emergency vehicle clearance, thus saving both time and lives of commuters.

Fuzzy logic started by Zadeh [1] has been widely used by researchers for solving traffic congestion problem at intersections. Fuzzy logic-based control scheme is very similar to human thinking and can imitate an ideal policeman at the intersection. Fuzzy logic in signal control [2] was firstly presented by illustration of a hypothetical model based on fuzzy logic controllers for confined crossing points. In [3] the development of fuzzy logic in traffic control was extensively discussed. Fuzzy logic traffic system [4] was designed to adjust the phase sequence and duration of traffic lights at isolated intersection. This system was tested by collecting real time data from signalized intersection in Hawalli governorate in the State of Kuwait. Proposed system was tested and compared with the vehicle actuated system and improved performance resulted in case of heavy traffic volumes. A fuzzy based control system for green time extension of traffic lights [5] was compared with fixed time conventional method. The simulation results were better in terms of average delay experienced by the vehicles. Other remarkable works in this area include [6-11] in which the designed fuzzy controllers reduced the average waiting time of vehicles as compared to pre-timed traditional systems. A two -stage fuzzy traffic signal control method [12] was suggested and compared with pre timed control method. The results were analysed in terms of average waiting time of vehicles and reduced waiting time was obtained but as the cascaded controllers required different inputs to take decision of next green phase and its delay time, it added to the cost and complexity. Another work [13] introduced a hybrid system by integrating WSN with fuzzy logic. Total of sixteen sensors were deployed at an intersection to collect data in terms of traffic quantity and wait time for green light by using fuzzy inference and the priority degree for each lane was generated. Reduction in average waiting time and increased traffic flows from all lanes was obtained but the designed system lacked giving priority to emergency transit. Traffic clearance at intersections by giving priority to emergency transit [14-18] extended the green time on detection of emergency vehicle. The recent works in this area include [19] in which a fuzzy inference system uses five input variables to fix the green light interval. Although an 18% improvement in performance was obtained while conducting experiments in simulated environment but due to large scale of inputs the system complexity was high.

The phase sequencing in [4] was fixed and cycle time was adjusted to abridge idle green time but the system lacked giving priority to emergency transit. In our proposed work, the design supports two fuzzy controllers for lane sequencing and adjusting green time as to prioritize emergency transit while considering the traffic density too. Our proposed system is designed such that the emergency transit is given the highest priority and cleared in minimum time. Other designs [5-11] contributed in improving the waiting time of vehicles at isolated intersections yet, a simple design for easy implementation was needed in terms of collecting the input parameters for the system. The system proposed in this paper makes use of two parallel fuzzy controllers designed to work on the same inputs fed to decide for the next green phase and select its green-time. This made the system less complex and ease of physical implementation. The cost and complexity of the systems [12-19] due to large scale of inputs required was taken care in the proposed design as the system requires inputs in terms of the traffic volume sensed at each lane and detection of EMV. The proposed system in this paper is designed in a way to achieve simplicity in collection of inputs and easy implementation for both busy and underutilized intersection.

2. PROPOSED METHOD

2.1. Model of parallel fuzzy control system

Modeling is a vital step to develop an effective control system and for simulation of a physical process. Fuzzy logic is a distinct idea for emergent models of physical processes. Fuzzy models are less intricate; they can be understood straightforwardly and are much appropriate for stochastic processes. The applications of fuzzy logic in designing intelligent control systems are given by [20-22]. Therefore, a fuzzy control model is developed for traffic light control of a typical intersection with four lanes and each lane having two sub-lanes for going forward and turning left respectively as shown in Figure 1. Traffic signal design principles and related terms are explained clearly in [23]. In the perceived model, traffic is considered to enter the lanes in groups and emergency vehicles enter randomly on any lane. The traffic parameters are sensed using roadside sensors and given as input to the fuzzy controller. Various traffic sensing techniques in sensor networks for data collection are discussed in [24-25]. For easy and cost-effective actual implementation of the designed system we have chosen the inputs with a motive that they can be sensed by simple and readily available sensors without much investment needed in providing infrastructure to the designed system. To select the next green light lane and decide the appropriate green time of the selected lane in an isolated four-lane traffic intersection we propose a Mamdani model of parallel fuzzy inference system with five inputs that can be easily sensed by the roadside sensors. The inputs are taken as:

- Traffic at lane i (l_i), where i=1,2,3,4 (number of vehicles in lane i)
- Emergency vehicle (EMV) presence in any lane

Decision making of the fuzzy system is based on the weights $w(l_i)$ of the sensed inputs of each lane where i=1,2,3,4. The designed system takes the total number of vehicles on each lane and emergency vehicle detected on any lane as weights for decision making. The block diagram of the proposed fuzzy inference system is shown in Figure 2. The maximum traffic for which the fuzzy system works efficiently is taken to be 100 vehicles on each lane.

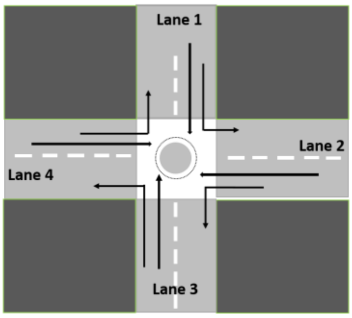


Figure 1. Typical isolated intersection showing traffic movements

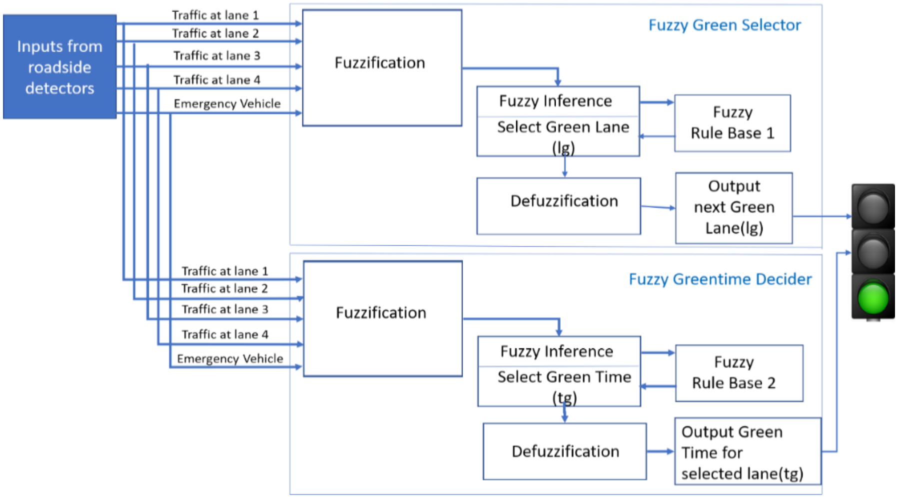


Figure 2. Block diagram of the proposed parallel fuzzy system

The sensed inputs from roadside detectors are fed to both the fuzzy green selector and fuzzy green time decider controllers working in parallel. The membership function of input traffic on lanes (l_i) is shown in Figure 3. Three characteristics are taken for designing the membership function for this input variable and their values are given in Table 1. The membership function for detection of emergency vehicle on lane l_i where i=1,2,3,4 is shown in Figure 4. The membership functions are designed as:

- EmVehicle=1; If Emergency vehicle appears on l_1
- EmVehicle=2; If Emergency vehicle appears on l_2
- EmVehicle=3; If Emergency vehicle appears on l_3
- EmVehicle=4; If Emergency vehicle appears on l_4
- EmVehicle=0; If Emergency vehicle is absent

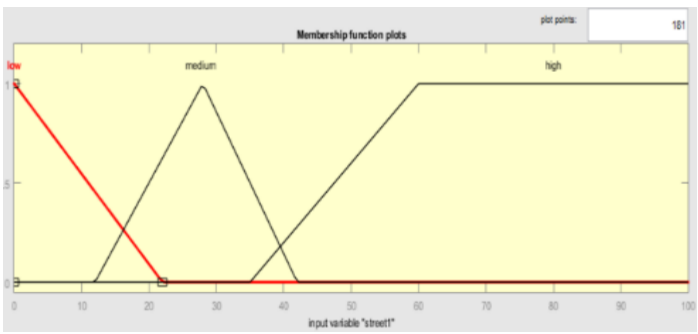


Figure 3. Membership function of input variable Traffic on lanes (li)

Table 1. Values of the membership function of input variable traffic on lanes (li)

Variable	Characteristics	Value (vehicle count)
Traffic on lanes (l_i)	Low	0-23
	Medium	12-42
	High	35-100

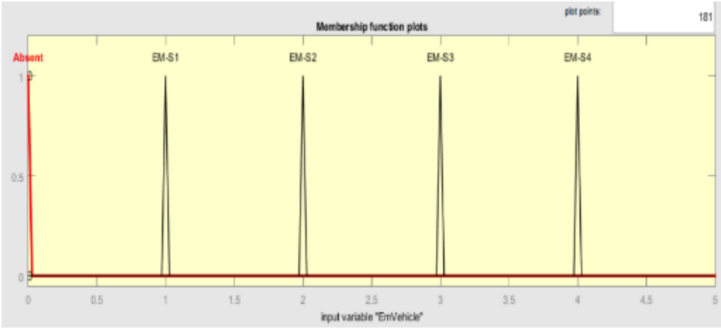


Figure 4. Membership function of EM vehicle

The Rule editor of fuzzy green selector system is given in Figure 5. Total 85 rules are constructed in Rule Base 1 to select the next green lane. For example, the third rule can be expressed as: *IF traffic on Lane 1=low AND traffic on Lane2=low AND traffic on Lane3=low AND traffic on Lane4=high AND EMVehicle = Absent THEN Next Greenlane(l_g)=Lane4.*

A no-differ (random selection of next green-lane) output is used for input values that are similar or with little difference so that output selection can be any lane for nextgreen. Similarly, fuzzy greentime decider works using 93 rules that are formulated in Rule Base 2 to decide the greentime of the selected lane. For example: *IF traffic on Lane 1=low AND traffic on Lane2=low AND traffic on Lane3=low AND traffic on Lane4=high AND EMVehicle=Absent THEN Greentime(t_g)=high.*

Two outputs are obtained from the designed system. The output obtained from fuzzy green selector is next green lane (l_g) and from fuzzy greentime decider is greentime for selected lane (t_g). The membership functions for both the outputs are triangular functions and shown in Figure 6(a) and Figure 6(b) respectively.

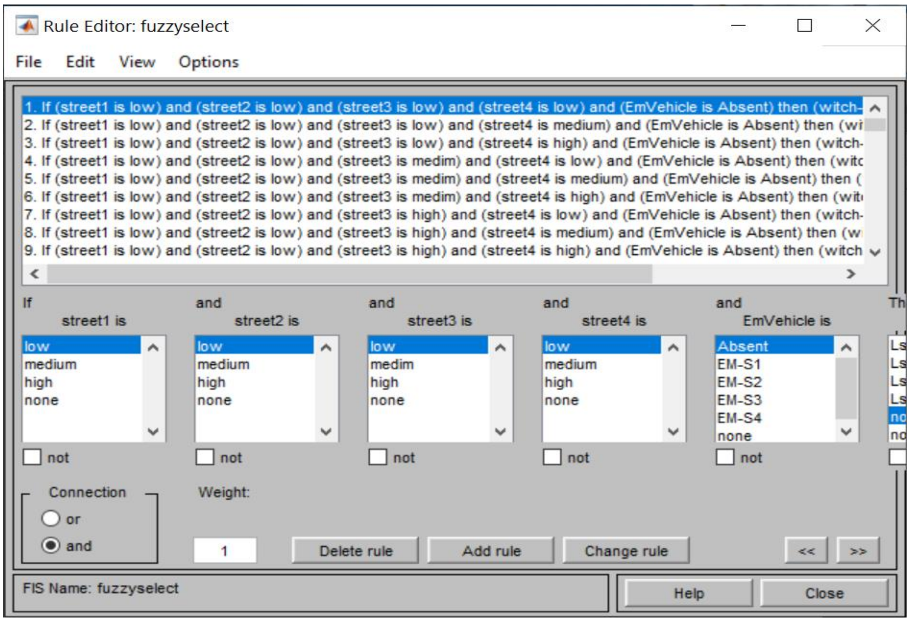
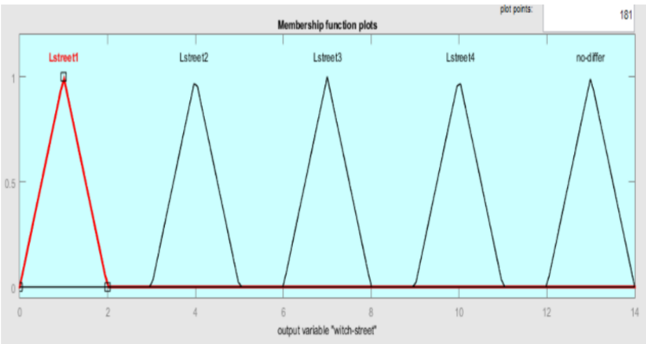
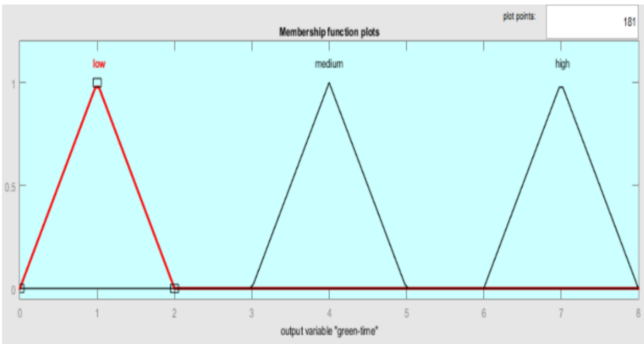


Figure 5. Rule editor of fuzzy green selector



(a)



(b)

Figure 6. Membership functions: (a) Next greenlane (l_g) and (b) Greentime of selected lane (t_g)

2.2. Simulation environment and algorithm to evaluate the proposed system performance

It is necessary to choose a simulation environment like that of a real time traffic intersection and consider all the possible traffic statistics to test the designed system. Performance of the proposed parallel fuzzy logic controller is evaluated by comparing it with the existing fixed-timed control method. In order to make comparisons, identical conditions have been set during the simulations. The initial parameters are set according to the intersection before the actual implementation. The flowchart of the proposed fuzzy traffic light control system is given in Figure 7. The algorithm has been designed by considering and evaluating the following system parameters:

- Traffic is assumed to enter in platoons on each lane and the count is stored in matrix x_i, where i=1,2,3,4. The traffic density on lanes is varied in terms of low, medium and high traffic by taking different values of x_i.
- The cycletime (t_c) is the time for one complete cycle which is divided between lanes as greentime to clear the traffic x_i efficiently. If there are remaining vehicles after completion of cycletime $t_c(k)$ they are added to the vehicles entering in the next platoon and are cleared in the next cycletime $t_c(k+1)$. The matrix totalCars stores the total traffic count on each lane.
- A timeout (t_o) is also considered to take care of the lane which has not received green signal since a long time to avoid extensive wait time at lanes that have very less traffic.
- Simulations are extensively performed for maximum vehicles (C_{max}) ranging from 100 to 1000 moving towards the intersection in all four lanes in all possible traffic scenarios to get a wide range of results for evaluating the performance of designed system.
- The percentage clearance of traffic specially for the high traffic and average emergency vehicle (EMV) wait time are considered as the parameters to evaluate and compare the performance of the proposed system and traditional fixed time system.

The flowchart in Figure 7 clearly demonstrates the steps taken to simulate the designed fuzzy traffic light control system. It is observed that vehicles are entering in platoons on all four lanes and need to be cleared in a particular cycletime while giving priority to emergency transit in such a way that once detected, the EMV is passed through the intersection with minimum waiting time. The vehicles entering on each of the four lanes and presence of emergency transit is detected by roadside sensors and given as input to the designed parallel controllers namely fuzzy next green selector and fuzzy greentime decider. The next lane to have green light is decided with the help of designed fuzzy rules and its greentime is also decided in parallel. The algorithm also checks the condition where a low traffic lane does not get green clearance for a prolonged time and thus avoids the problem of high waiting time for vehicles present in low traffic lanes. This is done by comparing the green-wait-time of lanes with a timeout (t_o). The system is simulated for groups of vehicles entering on the lanes ranging from 100 to 1000 cars/lane and performance is studied in terms of traffic clearance and waiting time of EMV. The next section of the paper discusses the performance of the designed system.

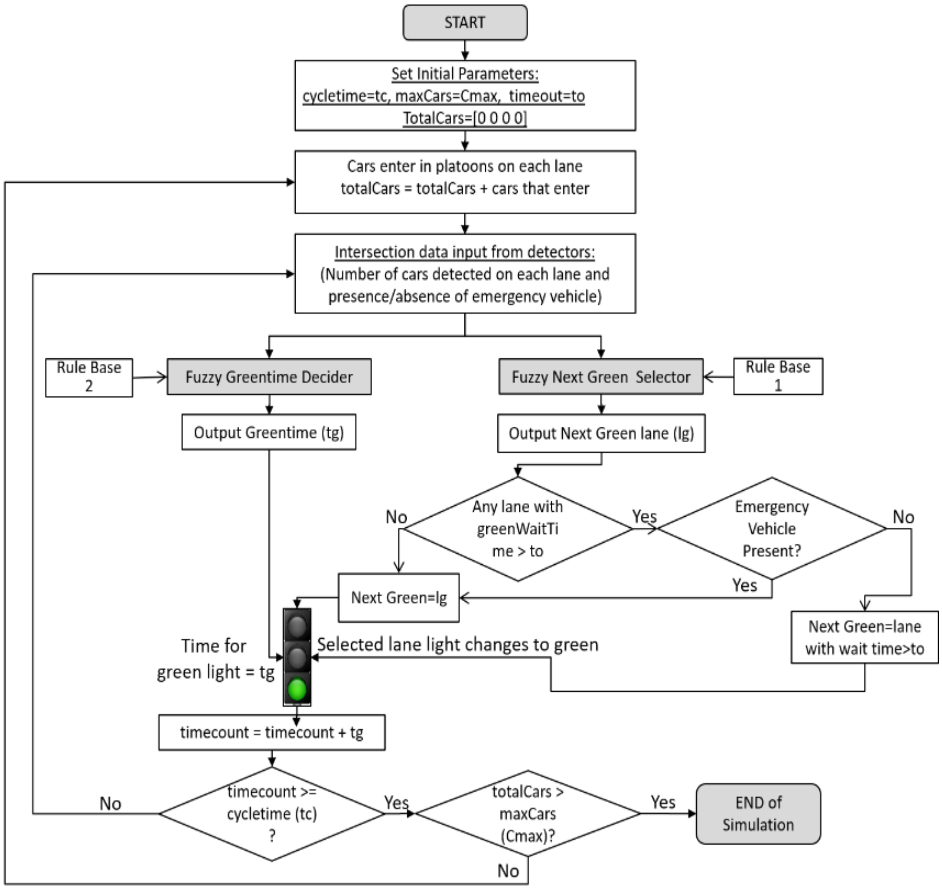


Figure 7. Flowchart of the proposed Fuzzy traffic light control system

3. RESULTS AND DISCUSSION

For extensive evaluation of the designed system, the simulation is performed taking different traffic scenarios including low, medium, high and even mixed traffic conditions on lanes of the intersection and results are compared with the traditional fixed time traffic light control system. The controller was tested using fuzzy logic toolbox in MATLAB. Following assumptions are made before running the simulations.

- Traffic is considered to enter in platoons in each cycle and size of these platoons is varied to obtain different traffic scenarios.
- The system is assumed to start from state 0 i.e there are no vehicles on any lane.
- An optimum cycle time is chosen so that both fuzzy and fixed time systems clear maximum incoming traffic.
- It is assumed that 2% of traffic entering in each lane is emergency vehicle and its clearance in minimum waiting time is a major criterion in deciding the performance of the designed system.
- The fixed time traffic light control system has a fixed green time of 1 minute for each lane with fixed lane sequencing ($l_1 \rightarrow l_2 \rightarrow l_3 \rightarrow l_4$).
- The fuzzy system is designed to work effectively within a range of 0-100 cars waiting/lane as this data is close to the real scenario.

Further, the results are obtained for all the possible traffic scenarios given in Table 2 that can be perceived at an isolated urban intersection.

Table 2. Traffic scenarios and traffic distributions taken to evaluate the designed system

Traffic scenarios		Traffic distribution
Uniform Traffic Distribution on all lanes	Low Traffic	80 vehicles/cycle with 20 vehicles/lane
	Medium Traffic	120 vehicles/cycle with 30vehicles/lane
	High Traffic	160 vehicles/cycle with 40 vehicles/lane
Non-Uniform Traffic Distribution on all lanes	Mixed Traffic Scenario 1	High on one lane, medium on two lanes and low traffic on one lane.
	Mixed Traffic Scenario 2	High on two lanes, medium on one and low on one lane.
	Mixed Traffic Scenario 3	High on three lanes and low traffic on one lane

3.1. Uniform traffic distribution on all lanes

The obtained simulation results for low traffic are shown in Figure 8. It can be perceived that both systems show similar performance with 100% traffic clearance but there is a comparable difference in EMV wait time at intersection. Proposed fuzzy system clears the EMV in minimum time of 30 sec throughout the extend of simulation as it addresses the EMV as soon as it is detected whereas fixed time traditional systems clear the EMV in time ranging between 1.5 to 3.5 minutes which is significantly high specially when traffic is low. For medium traffic distribution on all lanes the difference in traffic clearance is clearly observed in Figure 9. Proposed Fuzzy system shows percentage clearance of 95%-99% whereas the traditional fixed time control system clears 80%-82% traffic. The EMV waiting time for fuzzy system in this case is observed to be a minimum of 30sec whereas it varies between 2 to 3 minutes in fixed time system which is significantly high. For high traffic distribution, difference in traffic clearance is clearly observed in Figure 10. Traffic clearance in fuzzy system range is between 93%-98% whereas in fixed time control system it is observed to be 85%-87% for the same cycle time. The EMV waiting time for fuzzy system even in the case of heavy traffic is observed to be a minimum of 30 sec as seen in results obtained, whereas it varies between 2 to 3 minutes in fixed time system which is significantly high.

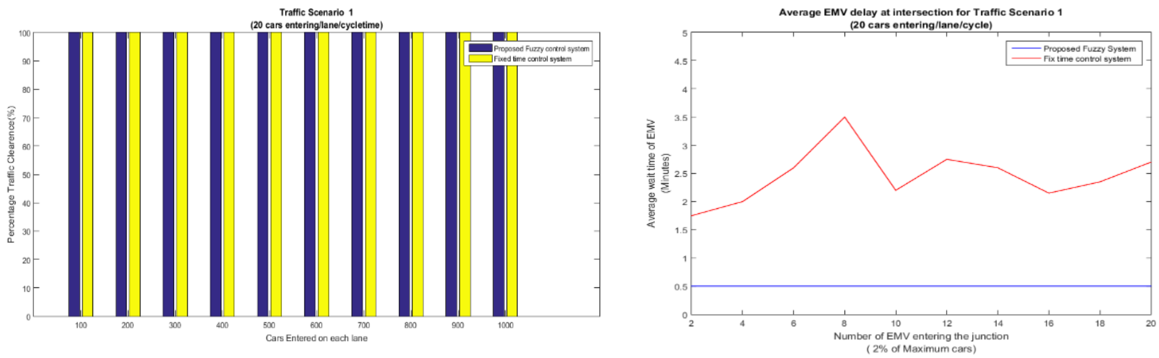


Figure 8. Comparison of traffic clearance and EMV waiting time for low traffic scenario

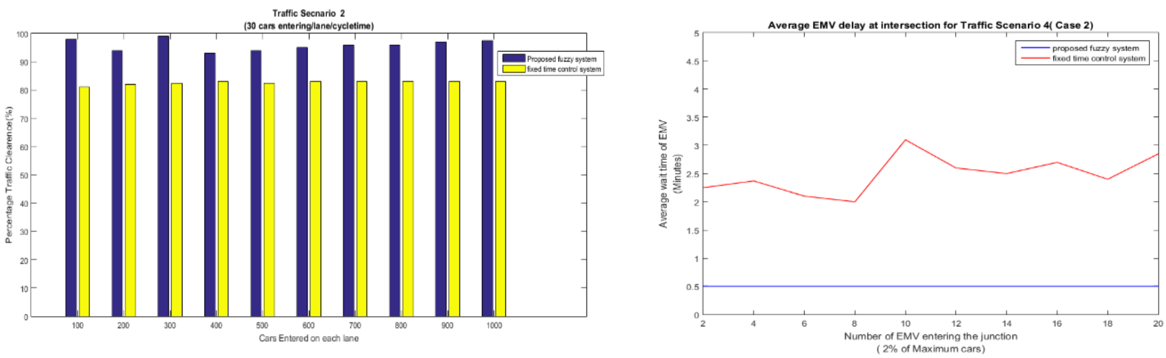


Figure 9. Comparison of traffic clearance and EMV waiting time for medium traffic scenario

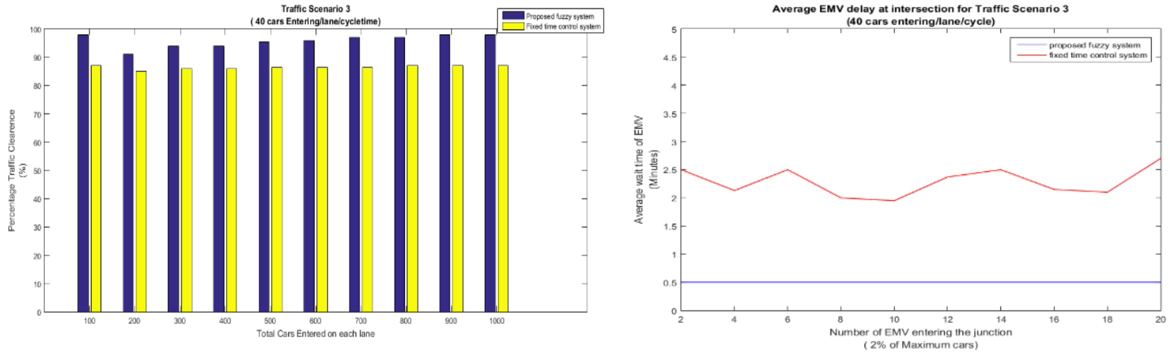


Figure 10. Comparison of traffic clearance and EMV waiting time for high traffic scenario

3.2. Non-uniformly distributed traffic on lanes

This scenario is created with non-uniform traffic entry rate on each lane at the intersection which is close to the real time scenario. We have evaluated the performance of both systems under all possible scenarios.

Mixed traffic scenario 1: The traffic distribution for this scenario is taken as given in Table 2. The percentage traffic clearance of the lane with high traffic intensity in fuzzy system is nearly 100% whereas fixed time system clears only 70-75% of the traffic in high traffic lane as seen in Figure 11. So, there is an improvement of 25-30% in heavy traffic clearance. The average EMV waiting time is minimum (30 sec) for fuzzy system and between 2-3 minutes for fixed time control. The huge difference in both traffic clearance and EMV wait time proves the benefit of fuzzy system over fixed time system.

Mixed traffic scenario 2: The scenario uses traffic distribution as given in Table 2. Improvement of 25-30% in traffic clearance by fuzzy system is clearly obtained in Figure 12 and the average EMV waiting time is minimum (30 sec) for fuzzy system and between 2-3 minutes for fixed time control system. This shows an appreciable improvement in clearance efficiency of the proposed fuzzy controller along with attending and clearing the EMV in minimum time at the intersection.

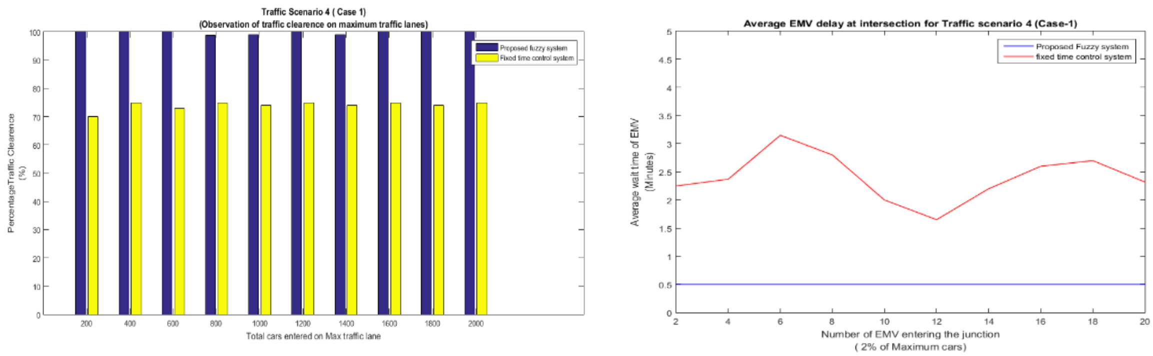


Figure 11. Comparison of traffic clearance and EMV waiting time for mixed traffic scenario 1

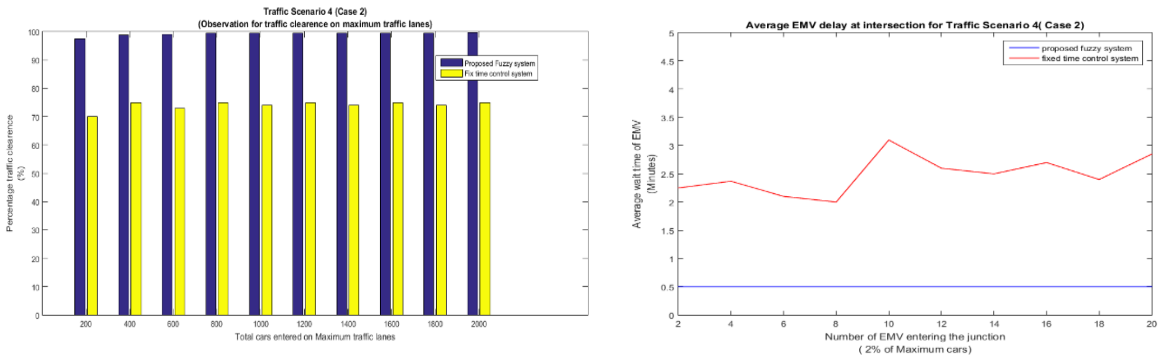


Figure 12. Comparison of traffic clearance and EMV waiting time for mixed traffic scenario 2

Mixed traffic scenario 3: This scenario is created with heavy traffic on three lanes and low on one lane as given in Table 2. Figure 13 shows the simulation results for percentage traffic clearance of high traffic lanes. An average high traffic clearance of 95% is obtained for proposed fuzzy system whereas fixed time system gives only 75% clearance for the heavy traffic lanes. The average EMV waiting time of 3 minutes for fixed time control system as seen from Figure 13 is significantly high as compared to the minimum time of 30 seconds obtained by the fuzzy controller.

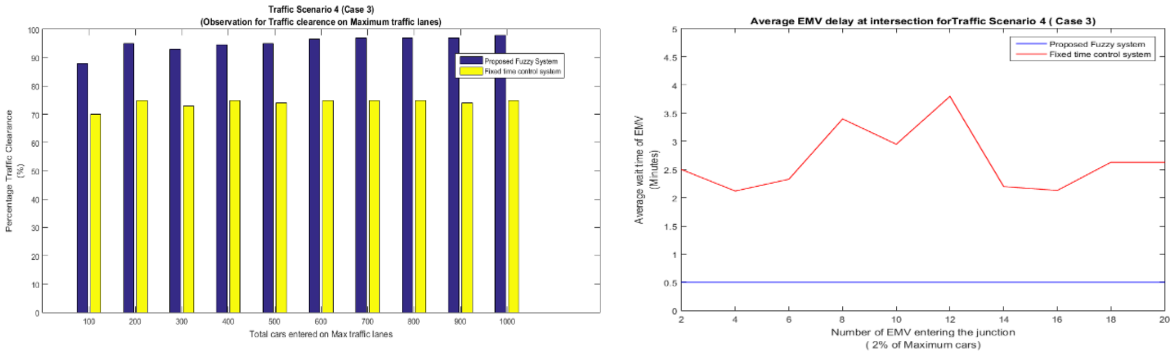


Figure 13. Comparison of traffic clearance and EMV waiting time for mixed traffic scenario 3

4. CONCLUSION

The results are evaluated by considering multiple traffic scenarios at a single intersection. The results clearly portray that the proposed fuzzy traffic light controller gives a better traffic clearance at the intersection in each traffic scenario and that too by addressing the EMV as soon as it arrives and is detected at the intersection hence reducing the EMV waiting time and taking its fast clearance as a priority. The proposed fuzzy system clears the EMV in minimum duration in all the possible traffic scenarios. Results clearly portray that traffic clearance for low traffic scenario is same for fixed and proposed fuzzy system but for medium, high and non-uniform traffic entry rate at intersection the proposed system gives fairly better clearance. The proposed system integrates traffic clearance with fast EMV clearance at intersections and so it can be easily implemented in the present traffic signal infrastructure of cities to provide intelligent traffic signaling. Future work is emphasized on enhancing the system to work for connected intersections for streamlined passage of EMV detected at one intersection through the lane of the next intersection without even stopping. Other enhancements can be done by considering the number of pedestrians waiting to cross the road and minimizing the waiting time of pedestrians.

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