Effective Lane Management for Emergency Vehicles and Adaptive Signaling For Dynamic Traffic Congestion Using Fuzzy Logic

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Abstract: Proliferation of vehicles, ineffective traffic management and insufficient road infrastructure increase traffic congestion in urban areas. In traditional traffic control system, round robin algorithm is used for scheduling traffic controller in which equal priority is assigned for all the lanes in the intersection. It is failed to measure the traffic density. It leads to ineffective lane utilization. The main objective of this paper is to i) reduce the average waiting time of a vehicle at an intersection using effective lane management based on fuzzy logic and heuristic value ii) to reduce the average waiting time of emergency vehicles by applying prioritization and iii) adaptive signaling for dynamic traffic behavior. From the simulation results, it shows that the proposed system is effective during traffic congestion in the real time environment.

***Index Terms:* fuzzy logic, heuristic value, average waiting time, adaptive signaling.**

I. INTRODUCTION

Traffic congestion in metropolitan cities around the world is increasing every day. Distance travelled by people in the world is increasing and the driving distance of a vehicle is also increasing. In India, for the financial year 2018, the sales growth of the automobiles sector is 9.2% and the number of vehicles sold is 4.2 million capturing 4th largest place in the automobile market in the world. India has a large road network of about 55,00,000 km claiming the second largest road network in the world. During the financial year 2018, approximately 10000 km of road was constructed. The growth rate of the road is about 0.18% which is less when compared to the growth rate of vehicles. It is clear from the above data that the traffic on roads is increasing every day. The traffic congestion in India has a high impact on the economy. According to a study, the traffic congestion accumulates a loss of 1.47 lakh crore rupee annually in the cities Delhi, Mumbai, Bangalore, and Kolkata. Traffic congestion leads to losses in productivity, fuel wastage, environment degradation, reducing the usage of roads and related crashes. Increase in the usage of private vehicles, ineffective traffic management and insufficient roads increase traffic congestion exponentially in urban areas. Out of the above major three factors, efficient, effective traffic management can be improved by using the advancement of technology. Traffic management in road intersections where the traffic signals are installed is crucial. Traffic congestion in these area can be reduced by effectively utilizing the same resource. Traffic signal in India is managed by automatic signals or by traffic inspectors. In automatic traffic signaling cycles are repeated based on the fixed time for each path. In the fixed cycle method, equal timing is followed for all the lanes irrespective of the lane traffic density (Tang et al). With the advent of technology such as sensor devices, machine learning algorithms congestion in traffic signals can be managed effectively. Wireless sensor networks have attracted many researchers due to its low cost, remote data collection and scalability(Nellore K et al). In which, a dynamic traffic signaling based on the queue length is adapted. The queue length of each of the road is sensed by placing sensors in the appropriate places in the road. The algorithm uses the artificial intelligence algorithm to predict the cycle of the traffic signal and the predicted cycle is adjusted by considering the actual queue length of the traffic in the road. From the literature survey, it explicitly shows that the current traffic management system is not adequate to deal the present traffic density. In order to improve the current traffic management system, we proposed effective lane management system to

i) Reduce the average waiting time of a vehicle using effective lane management

ii) Reduce the average waiting time of a emergency vehicle using prioritization

iii) Provide adaptive signaling for dynamic traffic congestion The rest of the paper is organized as follows i) Section 2 describes the related work ii) Section 3 defines the problem statement and network model iii) Section 4 discusses about the proposed system iv) Section 5 deals with the experimental results and v) Section 6 gives the conclusion.

II. RELATED WORK

Traffic modeling requires to measure traffic parameters with high accuracy. Many models have been developed to measure traffic flow (Kwong, Smith et al and Innamaa S.) which uses the present traffic along with historical data for controlling traffic flows.

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Instead of considering the traffic at the intersection, considering the actual traffic in the entire network may give a performance improvement. A Multi-regression Dynamic Model (MDM) is proposed to forecast the traffic in the intersection. Intervention in the MDM is used to predict the traffic flow. (Queen CM et al.) For predicting the short term traffic, Support Vector regression Models have been proposed by Lippi M et al. in which the similarity index is used and it is measured between the time series data. Castillo et al and Zhu et al. used Gaussian method to predict the short term traffic flow. Castillo et al used generalized beta variables in Gaussian network. The generalized beta variables are used to give traffic parameters and it is used for prediction. It also uses the current as well as historical data. Zhu et al. used the linear conditional Gaussian Bayesian network to predict the short term traffic congestion. Comret el al. proposed a traffic prediction model based on a hidden Markov model and the expectation-maximization algorithm.

Chen et al. proposed the Wireless sensor network for Intelligent Transport System (WITS). It has three subsystems. Vehicle sensor node and the roadside sensor measures the vehicle parameters and sends to the strategy subsystem. The strategy subsystem uses Artificial Intelligence to optimize traffic congestion. Based on the decision given by the strategy subsystem, the execution subsystem controls the traffic signal in the intersection. The drawback of this model is the centralized control which is not effective for controlling the entire network. Hence a decentralized model is proposed by Tubaishat et al. An intersection unit is introduced in this model and it coordinates with the neighboring signals. It improves the localization flow in the traffic signal. An intelligent traffic system using time division multiple access is proposed by Yousef et al. It contains the minimum of two wireless sensor node in each road to calculate the queue length, the arrival and departure of the vehicle. The base station collects the information from all WSN and sends to the traffic signals time manipulation algorithm (TSTMA). Based on the data, TSTMA algorithm dynamically calculates the queue length on each road and controls the traffic signal. TSTMA works better for both single and multiple intersections. Instead of individual sensors, an array of sensors in the road is proposed by Hussain et al. To ease the communication Zigbee protocol is used. The signaling algorithm is implemented in a microcontroller. An adaptive traffic signal controlling algorithm is proposed by Faye et al. The sensor nodes are spatially distributed over the nodes. Four level hierarchy is used in this architecture. The use of centralized approach using base station is to overcome by using a distributed approach. A deadline based traffic signaling is proposed by Ahmad et al. The traffic signals work based on the type of vehicle present in the road. The vehicles are categorized into priorities. WSN senses the priority of the vehicle crossing and the decision is based on the number of high priority, medium priority, and low priority vehicles in the road. Srivastava et al proposed a method for traffic signal management in a simulated environment known as Green Light District simulator (GLD). GLD is based on the number of cycles a vehicle has to wait to get a green signal. It tries to reduce the average waiting cycle. It addresses the problem of the green signal for an empty lane and reducing the number of average waiting cycle. A microscopic traffic congestion control model using a wireless sensor network is given by Pascale et al. in which a simulation tool is proposed to control the traffic when the sensor node fails. Mathematical modeling of data is used along with the actual data for traffic analysis to overcome the effect of sensor node failures. 4423 million Intelligent Transport System (ITS) is developed in Hong Kong using cameras and wireless sensor networks to measure the traffic in the city. The government of Hong Kong uses this ITS to manage, control and monitor the traffic. All the major highways, tunnels, roads and part of the trunk roads are covered in this project. Traffic signaling using fuzzy logic is proposed by Wei et al. The parameters for the fuzzy logic are found using the multi-objective genetic algorithm. The traffic is tested only for a single intersection and is failed to consider multi intersection. An optimized Particle Swarm Optimization (PSO) algorithm used to control the traffic congestion is proposed by Juan Chen et al. PSO with isolation niches is given by Peng et al. It uses the microscopic traffic flow analysis to control the traffic signal. Multi-objective PSO is proposed by S. Kachroudi and N. Bhouri, it considers the private and public mode of transports for traffic congestion control. All these algorithms is suitable for a smaller network of traffic signals. Hence it is required to design a traffic signal system for a large network with a huge number of vehicles.

III. PROBLEM STATEMENT AND NETWORK MODEL

A. Problem Statement

In traditional traffic control system, round robin algorithm is used for scheduling traffic controller in which equal priority is assigned for all the lanes in the intersection. It is failed to measure the traffic density. It leads to ineffective lane utilization as some of the lanes may not have the vehicle during green light. Green light detector, is used to identify whether the lane is having traffic or not during green signal. In case of the lane is not having the vehicles then the green signal is provided to some other lane having the traffic. However, it is failed to locate any emergency vehicle in adjacent lanes. In order address the issues involved in traditional system, effective lane management using fuzzy logic and emergency based traffic control system is designed. The main objective of this paper is i) to reduce average waiting time in the traffic signal by effective scheduling using fuzzy logic and heuristic value and ii) to reduce the average waiting time of the emergency vehicle in the intersection by effective prioritization.

B. Network Model

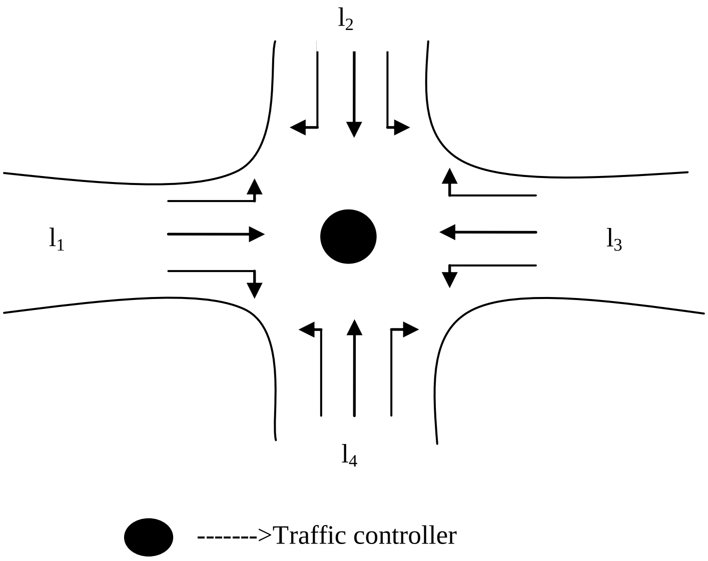
Consider experimental environment (road intersection) consists of four lanes namely l_1,l_2,l_3 and l_4 as shown in fig(1). Traffic controller is placed in the middle of the junction. Each lane equipped with IR sensors. Sensors are distributed using Gaussian distribution model.

$$f(x) = \frac{1}{2\pi\sigma^2} . e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad (1)$$

Where x is the mean of distribution of sensors in the lane l_i. σ is standard deviation and σ^2 is variance. Vehicle distribution is done based on the Poisson distribution model $p(v)$.

$$p(v) = \frac{\lambda t^v . e^{-\lambda t}}{v!} \qquad v = \{1,2,3, \dots , n\} \quad (2)$$

Where $p(v)$ is the probability of the vehicles (v) in the lane l_i during the time interval t. λ is average vehicle arrival rate with respect to time t.



Fig(1) Experimental Environment of the proposed system

Traffic controller has three phases namely, alert short form 'O', stop short form 'R' and move short form 'G'. Initially all the phases are set as R. Directional antenna is fixed in all the sides of the traffic controller to find the occurrence of the emergency vehicle. Emergency vehicle also equipped with antenna for sending the signal to the traffic controller. 13.56 MHz license free frequency is used for communication. Heuristic value (h_v) derived from the past experience of the traffic control system. h_v is used for controlling the signaling timing of the traffic controller. IR sensors are used for finding the occurrence of the vehicles in the lane l_i. Fuzzy logic is implemented for controlling the phase of the traffic controller based on the fuzzy linguistic variable (T_{di}). Priority queue is used as the data structure for processing emergency vehicle. Emergency vehicle is treated as interrupt. Traditional system using round robin algorithm is implemented for evaluating the proposed system. Average waiting time is taken as the performance metrics.

IV. PROPOSED SYSTEM

Proposed system focuses on i) Effective lane management using fuzzy logic and heuristic value and ii) lane management for emergency vehicle .

A. Effective lane management using fuzzy logic and heuristic value

In general, IR sensors are used for counting the objects. In this paper, instead of counting the objects precisely, average value of the counting is taken to find the density of the traffic. For easier maintenance, entire lane $L = \{l_1, l_2, l_3, l_4\}$ is divided into equal sized local sensing region q_1, q_2, q_3. The size of the local sensing region is calculated by using

$$A_{qj} = \frac{A_{li}}{3} \quad (3)$$

Where A_{qj} is area of the local sensing region j, A_{li} is the total area of the lane i. For counting the objects in the lane, IR sensors are fixed in both sides of the lane. It continuously communicates with each other by sending and receiving the signal. If the IR sensor is not able to receive the signal due to the vehicle presence, then the count is increased. From the count, density of the traffic (T_{di}) is computed. It is calculated by using

$$T_{di} = \frac{\sum_{i=1}^{n} S_{qi}}{n} \quad (4)$$

Where T_{di} is the traffic density in the i^{th} sensing region of the j^{th} lane. S_{qi} is average sensing value of IR sensors in the i^{th} region. n is the total number of sensor nodes in the local sensing region i. Expert system using fuzzy logic comprises of fuzzification, inference, knowledge base and de-fuzzification. Fuzzification is the process of finding suitable input variables. Inference system consists of fuzzy rules that are formulated based on the knowledge base through system input-output learning. Assigning the values for input and linguistic variables is referred as universe of disclose. Fuzzy rule consists of eighty-one IF –THEN rules, AND operator is used for applying more than one rules. De-fuzzification focuses on linguistic variables. In this paper, fuzzy system is designed to take intelligent decision for traffic control management. It is mainly used to i) find the traffic density of the lane ii) selection of the lane and iii) processing the lane. Input variables are q_{d1}, q_{d2}, q_{d3}. q_{di} is the vehicle density in the local sensing region i. Linguistic variables are VERY LOW, LOW, MEDIUM and HIGH. Input variables, linguistic variable and fuzzy rule for the lane i are discussed in the table(1). For simulation, maximum capacity of each local sensing region i is set to be 40. Input variable and range for linguistic variable is discussed in the table(2). Fuzzy rule for processing the lane based on the lane traffic density is discussed in the table (3).

B. Proposed algorithm for Effective lane management

Variable used in the algorithm are discussed in table (4)

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q_{d1}	q_{d1}	q_{d1}	T_d	Fuzzy Rules
L	L	L	VERY LOW	
L	L	H	LOW	If $(q_{d1} == L\ AND\ q_{d2} == L\ AND\ q_{d3} == L)\ THEN\ T_d\ is\ VERY\ LOW$
L	H	L	LOW	If($q_{d1}! = L\ AND\ q_{d2} == L\ AND\ q_{d3} == L)AND\ (q_{d1} == L\ AND\ q_{d2}! = L\ AND\ q_{d3} == L)AND(q_{d1} == L\ AND\ q_{d2} == L\ AND\ q_{d3}! = L)THEN\ T_d\ is\ LOW$
L	H	H	MEDIUM	
H	L	L	LOW	If($q_{d1} == H\ AND\ q_{d2}! = H\ AND\ q_{d3} == H)AND\ (q_{d1}! = H\ AND\ q_{d2} == H\ AND\ q_{d3} == H)AND(q_{d1} == H\ AND\ q_{d2} == H\ AND\ q_{d3}! = H)THEN\ T_d\ is\ MEDIUM$
H	L	H	MEDIUM	If$(q_{d1} == H\ AND\ q_{d2} == H\ AND\ q_{d3} == H)\ THEN\ T_d\ is\ HIGH$
H	H	L	MEDIUM	
H	H	H	HIGH	

Table 1. Input variable, linguistic variable and fuzzy rule for finding density of the lane i.

Input variable	Linguistic variable	Range
q_{di}	VERY LOW	<10
	LOW	10-20
	MEDIUM	20-30
	HIGH	30-40

Table 2. Input variable and range for linguistic variable of the proposed system

L_{d1}	L_{d2}	L_{d3}	L_{d4}	Decision of the proposed fuzzy system
L	L	L	L	As all lanes traffic density are low, regular scheduling is done using heuristic value ie., all the lanes are processed based on the estimated servicing time
L	L	L	H	L_{d4} is processed first, rest of the lanes are having equal priority, hence regular scheduling is done for L_{d1}, L_{d2}, L_{d3}.
L	L	H	L	L_{d3} is processed first, rest of the lanes are having equal priority, hence regular scheduling is done for L_{d1}, L_{d2}, L_{d4}.
L	L	H	H	L_{d3}, L_{d4} are having highest priority, hence recently processed lane processed last. Once highest priority lane processed then control goes to lowest priority lane
L	H	L	L	L_{d2} is processed first, rest of the lanes are having equal priority, hence regular scheduling is done for L_{d1}, L_{d3}, L_{d4}.
L	H	L	H	L_{d3}, L_{d4} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
L	H	H	L	L_{d2}, L_{d3} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
L	H	H	H	L_{d2}, L_{d3}, L_{d4} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	L	L	L	L_{d1} is processed first, rest of the lanes are having equal priority, hence regular scheduling is done for L_{d2}, L_{d3}, L_{d4}.
H	L	L	H	L_{d1}, L_{d4} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	L	H	L	L_{d1}, L_{d3} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane

H	L	H	H	L_{d1}, L_{d3}, L_{d4} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	H	L	L	L_{d1}, L_{d2} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	H	L	H	L_{d1}, L_{d2}, L_{d4} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	H	H	L	L_{d1}, L_{d2}, L_{d3} are having highest priority, hence recently used lane processed last. Once highest priority lane processed then control goes to lowest priority lane
H	H	H	H	As all lanes traffic density are high, regular scheduling is done using heuristic value ie., all the lanes are processed based on the estimated servicing time

Table (3) Fuzzy rule for processing the lane based on the lane traffic density

Variable used	Purpose
LRL	Returns least recently used lane
Stack	Data structure, last entered element processed first
Max	Returns maximum value in the set
Min	Returns minimum value in the set
S_{qi}	Sensing value of the local sensing region i
A_{qj}	Area of the local sensing region j
A_{li}	Area of the lane i
N	Total number of sensor nodes in the local sensing region
q_{d1}	Traffic density in the local sensing region i
l_{d1}	Traffic density in the lane
c,c1	Counting variable
l_{lp}	Lane having lowest priority
l_{hp}	Lane having highest priority
Lane having highest traffic density is getting highest priority.	

Table.4 variable used in the algorithm for effective lane management

Algorithm:

Step1: For easier maintenance, partition each lane (l_i) into equal sized local sensing region (q_i) using

$$A_{qj} = \frac{A_{li}}{3}$$

Step 2: For each sensing region i, count the vehicles and take average vehicle count in the region i using

$$T_{di} = \frac{\sum_{i=1}^{n} S_{qi}}{n} \quad where\ 1 > i < 4$$

Step 3: Apply fuzzy logic to find the density of the lane

Fuzzy(q_{d1}, q_{d2}, q_{d3})

return linguistic variable

Step 4: prioritize the lane , highest priority is processed first then the lowest priority lane is processed.

Step 4.1: Max{}= {l_{d1}, l_{d2}, l_{d3}, l_{d4}}

return a set consists of lanes having high traffic density (l_{hp})

```
c= count(l_hp)
do
{
if(c>1)
stack=LRL(l_hp)
c- -
} until c==0
do
{
process stack
} until stack==empty
```

Step 4.2 Min{}= {l_{d1}, l_{d2}, l_{d3}, l_{d4}}

return a set consists of l_{lp}

```
c1= count(l_lp )
do
{
 if(c1>1)
stack=LRL(l_lp )
c1- -
} until c1==0
do{
process stack
}until stack==empty
```

C. Lane management for emergency vehicle

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Vehicles which needs immediate requirement of the lane is named as emergency vehicles (E_i) like ambulance, fire tender, VIP vehicles etc., For finding the presence of emergency vehicle in the traffic signal, emergency vehicle transmit the signal with frequency 13.56MHz using directional antenna. For receiving the signal one more directional antenna is fixed in the traffic control system. As intersection of the traffic control system has four lanes , all the sides of the traffic control system equipped with directional antenna to find exact lane of the emergency vehicle. If the traffic control system finds the occurrence of the emergency vehicle in the signal, it locates the exact lane of the emergency vehicle. Possible lanes of the vehicle are discussed as follows

Case 1: Emergency vehicle is in the same lane which is currently being processed, processing time(P_{tE}) is updated using

$P_{tE} = h_t + \Delta_t$ Where $\Delta_t = 0 \; if \; S_s = 0 \; \& \; A_{pti} < h_t$ and $\Delta_t = k \; if \; S_s > 0 \; \& \; A_{pti} = h_t$ (5)

Where P_{tE} denotes processing time for the lane having emergency vehicle. h_t heuristic value gives the estimated time allocated for the lane i. Δ_t is additional time required to process the emergency vehicle. k is the constant. The value of k depends on the signal strength. A_{pti} denotes actual processing time of the lane i. If the strength of the signal is less than zero and actual processing time is less than the heuristic (h_t) value then it does not require any additional time to process emergency vehicle. if the actual time spent on the lane exceeds the heuristic value of the lane and emergency vehicle is waiting to process, then the processing time is increased based on the signal strength.

Case 2: Emergency vehicle lane and servicing lane are different If the lane having emergency vehicle and the lane that is currently being processed are different, emergency vehicle is processed like interrupt. Before processing emergency lane, currently processing lane details such as lane number and actual time (A_t) spent on the lane is stored in the buffer. Once emergency vehicle is processed , control restores the previously processed lane. Processing duration of the lane having emergency vehicle is

$$P_{tE} = \Delta_t \tag{6}$$

Where Δ_t is time needed to process the emergency vehicle. Once the emergency vehicle is processed, control is transferred to the previously pooled lane. Time needed to process the pooled lane (P_{tp}) is computed by using

$$P_{tp} = h(t) - A_t \tag{7}$$

Where S_{tp} is the time required to process the polled lane in the buffer. $h(t)$ is estimated time allocated for the lane. A_t is actual time spent on the lane.

D. Proposed algorithm for emergency vehicle lane management

Variable used in the algorithm are discussed is as follows.

Variable used	Purpose
l_E	Lane having emergency vehicle
l_s	Lane is being currently processed
P_{tE}	Time required to process emergency vehicle
h_t	Estimated time to process the lane I (heuristic value)
Δ_t	Additional time required to process the lane having emergency vehicle
S_s	Strength of the signal received by the directional antenna
A_{sti}	Actual spent time for the lane i
K	Constant
Temp	Variable for storing lane details and actual spent time on the lane for restoring
l_{sc}	Phase color of the lane that is currently being processed
l_{Ec}	Phase color of the lane having emergency vehicle
O	Orange
G	Green
P_{tp}	processing time for the pooled lane

Algorithm:

do
Case 1:
if $(l_E == l_s)$
{
$P_{tE} = h_t + \Delta_t$ where $\Delta_t = 0 \; if \; S_s = 0 \; \& \; A_{pti} < h_t$
$\Delta_t = k \; if \; S_s > 0 \; \& \; A_{pti} = h_t$
}
do
{
Increase k
} Until $S_s = 0$
(P_{tE})

Case 2:
If $(l_E != l_s)$
{
temp=l_s
}
do
{
set $l_{sc} = O$
set $l_{Ec} = G$
} until $S_s < 0$
goto temp
continue until $(P_{tp} = h_t - \Delta_t) > 0$
repeat

Once controller receives the signal from the emergency vehicle, it gives green light to the particular lane immediately. It is implemented using priority queue. As directional antenna is used, it does not require any additional intelligence to find the exact lane of the emergency vehicle.

V. EXPERIMENTAL RESULTS

Average waiting time is taken as the performance metric to evaluate the proposed system. Average waiting time is the average number of cycles a vehicle has to wait at the intersection during one round trip.

Algorithm	Time (Cycles)	Delay (Cycles)
Traditional system using round robin	4000	26.7
	8000	26.7
Green Light Detector	4000	22.6
	8000	22.6
Proposed System	4000	20.5
	8000	18.6

Table 5: Results of simulations of normal vehicle

Table 6: Results of simulations of emergency vehicle

Algorithm	**Time (Cycles)**	**Delay (Cycles)**
Traditional system using round robin	4000	20.6
	8000	20.6
Green Light Detector	4000	18.5
	8000	17.5
Proposed System	4000	7.9
	8000	6.5

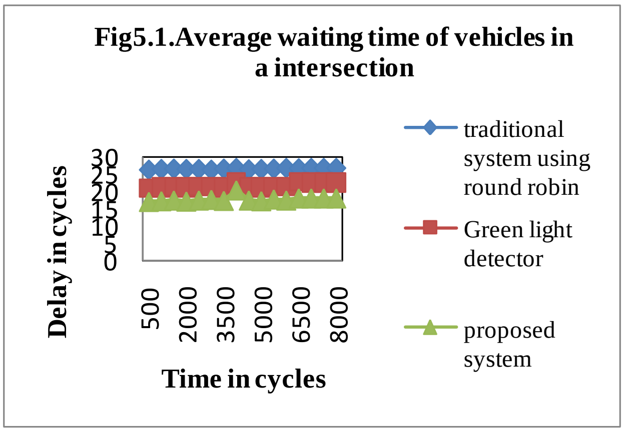

Fig. 5.1 and Fig. 5.2 shows the performance of the proposed system as a function of time in terms of average waiting delay.

From the results, it shows that the proposed system outperforms the existing system with reduced average waiting time.

VI. CONCLUSION AND FUTURE WORK

The proposed idea is designed for effective lane management system using fuzzy logic and heuristic value. Furthermore, emergency vehicle is managed effectively based on prioritization. The simulation result shows that the proposed system significantly reduces the average waiting time of the emergency vehicles. It increases the chance of emergency vehicle reaching destination on time by effective prioritization. In future, it will be implemented in the real time environment.

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