Designing fuzzy controller for traffic lights to reduce the length of queues in according to minimize extension of green light time and reduce waiting time

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***Abstract* — This paper presents a fuzzy logic simulation and modeling a controller for an isolated signalized intersection. The idea is used in this system is to minimize the vehicles queue length with minimal waiting time in according to minimize extension of green light time to ensure smooth flow of traffic. A minimum time for the green light has been assumed. The optimum extension of green time is the output of this fuzzy controller. In addition to the existing control system normal conditions, exceptional traffic conditions are also considered. Also we have been reviewed proposed methods in [1]. At the end simulation results are shown .**

Keywords—Fuzzy traffic controller; the fuzzy simulation; traffic flow; equations of state space; reduce waiting time

I. INTRODUCTION

Nowadays there is heavy traffic in large cities due to transportation management is important. Control traffic signals is an important research areas in Intelligent Transportation Systems (ITS) traffic systems. Because it has the direct impact on the improvement of urban transport. Webster gave equations for the optimal cycle length and the green phase time assignment, which are the basis of fixed-time control which has been widely used Akcelik, modified [2] .Webster's theory for the over-saturated scenario in a new signal timing algorithm called ARRB[3,4]. These methods perform well with low calculational costs when traffic conditions are consistent with historical records, but cannot respond to real-time variations. With the development of a variety of inexpensive sensors and computer and communication technologies, many advanced methods have been developed to adjust signal timings according to real-time traffic data. For instance, vehicle actuated control, which extends green signals according to the detected headway in real time, is one such method. A number of adaptive traffic control systems have been deployed all over the world, such as SCOOT, SCATS, OPAC, and RHODES. In recent years, artificial intelligence techniques have been introduced into signal control using fuzzy logic controllers and genetic algorithms (GA) [5].

Such as fuzzy systems based on human knowledge and experience in many applications such as traffic, have good and significant performance .Where there is uncertainty about the performance of a set of data can be extracted from the expert, these systems show a good ability[6]

Reference [1] has a method that is presented for fuzzy control of traffic lights which the state-space equations are presented in [6] is used. There are problems in [1], in addition to resolving them we will present a method better than and more optimal. In summary, these problems show below:

1. The number of fuzzy rules is not considered optimal. (The maximum number of rules is used.)

2.A general format for the rules is considered is not compatible with membership functions for output.(Figure 4 in [1])

3.qi in the text is considered as an input, but it is considered as output in fuzzy rules. (Figure 4 in [1])

In this paper an attempt has been made to extend the period time of green light which is expected to have minimum increasing as the desired goal is to reduce the queue length and waiting time of vehicles. Also state space equations is used to formulate the average waiting time of vehicles in traffic network at a specific time and the goal is to allow optimal control caused in both normal and exceptions of traffic cases by the fuzzy controller. The fuzzy controller has been designed to optimize the timing of green lights at the same time has very good help to reduce the maximum waiting time of crossing vehicles because fuzzy models are less externally complex; they can be understood easily and very much suitable for non-linear processes.

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State-space equations are used in the paper has been presented by Mr. LI Jinyuan in 2007[6].

II. MODELING A INTERSECTION

A. Display System State Space

The two Phases Signalized Intersection shape that utilizes it for mentioning modeling single intersections in this paper was demonstrating in Fig. 1. In this shape, The Leg 1 and Leg 3 are phase 1 and The Leg 2 and Leg 4 are phase 2[1].

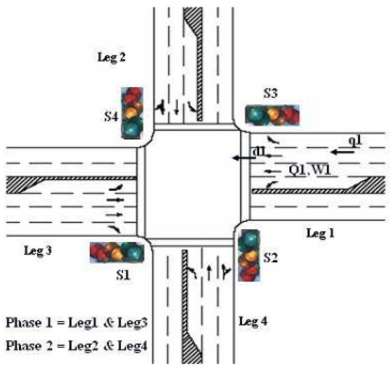

Fig. 1. **two situation in a intersection**

The system state-space equations are presented in[6] as equation (1) and (2) .

$$X(n+1) = AX(n) + B(n)S(n) + C(n) \tag{1}$$

$$y(n) = CX(n) \tag{2}$$

and in (3) the system state vector is shown .

$$X(n) = [Q_1(n)\ Q_2(n)\ \dots\ Q_M(n)\ W_1(n)\ W_2(n)\ \dots\ W_M(n)]^T \tag{3}$$

Queue length is an important variable in describing the traffic at a intersection. Here the queue is defined as in (4).

$$Q_i(n+1) = Q_i(n) + q_i(n) - d_i(n)\ S_i(n) \tag{4}$$

$i = 0,1,2,3...M$ is the index of the traffic streams.

$n = 0,1,2,...N-1$ is the index of the discretized time intervals.

$Q_i(n)$: The number of vehicles in the queue at *n*th time.

$q_i(n)$: The number of vehicles are connected in *i*th queue in the *n*th time.

$d_i(n)$: The number of vehicles are departed in *i*th queue in the *n*th time.

$S_i(n)$: Take 0 for stop and 1 for go; The state 0 as $(S_1,S_2,S_3,S_4) = (0,1,0,1)$ means that the branches 2 and 4 have green light and red light is in branches 1 and 3 therefore the vehicles in branch 2 and 4 will be allowed to pass.

Also the state 1 as $(S_1,S_2,S_3,S_4) = (1,0,1,0)$ means that the branches 1 and 3 have green light and red light is in branches 2 and 4 therefore the vehicles in branch 1 and 3 will be allowed to pass and vehicles in branch 2 and 4 should be stop.

The second input of the system state space is the waiting time of vehicles it is defined as (5).

$$W_i(n+1) = W_i(n) + TQ_i(n) + \frac{1}{2}Tq_i(n) - \frac{1}{2}Td_i(n)S_i \tag{5}$$

$W_i(n)$: Vehicles waiting time in the queue until nth time

T : the length of the discretized time interval

As shows in (5) any interval of time waiting is added whit the previous value so it can be represented as weighted traffic density in each state. To obtain the waiting time in each period of time can to remove the phrase $W_i(n)$ in (5).

Equations (4) and (5) are the state-space equations describing the dynamic evolution of the traffic state at a single intersection.

The waiting time and the number of vehicles are popular performance indicators for traffic control signals. The waiting time is used here as the performance indicators. Therefore, the optimization objective is defined as (6).

$$\min\{W(n) = \sum_{i=1}^{M} W_i(n)\} \tag{6}$$

B. Fuzzy Modeling System

The design of a fuzzy control system, the first step is to select the input /s and output/s of system . We consider $W_i(n)$ and $Q_i(n)$ as the inputs of system. These variables constitute the state vector in the system state space equations (3).The output of system is the extension of green time which will be displayed whit $E_i(n)$.

The second step is to fuzzification the input and output variables. At These stage , the input and output of system are defined as linguistic variables.

C. Membership Functions

Determine the exact membership grades are not so important, because it is show only the degree of inclination (adaptability the elements have to the sets). These degrees are determined subjectively by personal [8].

To design fuzzy controller for this system implication minimum Mamdani is used.

Two membership function for two input ($W_i(n)$ and $Q_i(n)$) this fuzzy system as Fig. 2, 3 show are divided in to 5 categories ,VS(Very short),S(Short),L(Long),VL(Very Long), EL(Extremely long)

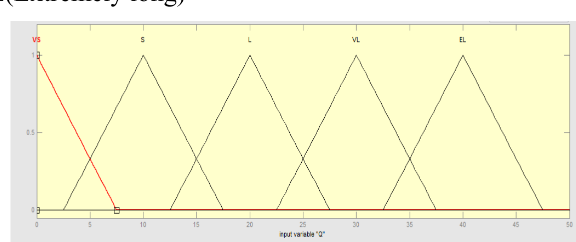

Fig. 2. Membership function for $Q_i(n)$

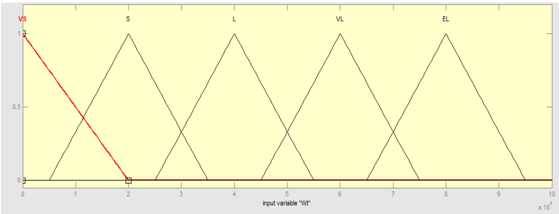

Fig. 3. Membership function for $W_i(n)$

The output of system that is called Extension also as Fig. 4 shows is divided in to 5 categories , Z(Zero), S(Short), L (Long), VL(Very Long), EL(Extremely Long) .

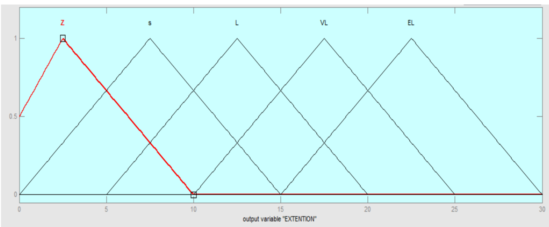

Fig. 4 Membership function for the output Extension

D. Rule Base

A fuzzy rule base be formed a set of fuzzy IF-THEN rules. The fuzzy rule base because other components of the fuzzy system are used for the effective and efficient implementation of these rules, is the heart of a fuzzy system[9].

Rule base in fuzzy control system has been developed based on IF-THEN. All rules are statement based on IF-AND-THEN [7]. The rules base summarizes in Table 1. For example, the first row of the table is:

IF (W1 = Very Short AND Q1 = Very Short) THEN Extension is Zero.

TABLE I. FUZZY RULE BASE

Rules	Input1 W_i	Input2 Q_i	Output E_i
1	VS	VS	Z
2	VS	S	Z
3	VS	L	S
4	VS	VL	S
5	VS	EL	L
6	S	VS	Z
7	S	S	S
8	S	L	S
9	S	VL	L
10	S	EL	L
11	L	VS	S
12	L	S	S
13	L	L	L
14	L	VL	L
15	L	EL	L
16	VL	VS	S
17	VL	S	S
18	VL	L	L
19	VL	VL	VL
20	VL	EL	EL
21	EL	VS	L
22	EL	S	L
23	EL	L	L
24	EL	VL	VL
25	EL	EL	EL

According to fuzzy rules set forth in Table 1 the relationship between inputs and outputs will be in Fig. 5.

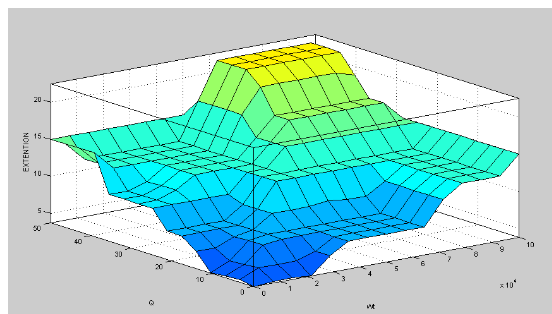

Fig. 4. The relationship between input and output membership functions

III. SIMULATION RESULTS

A. Detailed Modeling

1. Sensors are placed at a certain distant from the intersection, the maximum vehicle that can be detected queuing is 50 vehicles.

2. Maximum green light is assumed for phase 1, 140 seconds and for phase 2, 60 seconds, which this times are also considered is constant for fixed- time control.

3. Minimum green light is assumed for phase 1,110 seconds and for phase 2, 30 seconds and totally fuzzy decision is taken for 30 seconds.

4. The number of vehicles departed from *i*th queue in *n*th time interval is compatible with the following formula:

$$d_i = \min \{ Q_i(n) + q_i(n) , d_{si}(n) \} \quad (7)$$

Thus, the saturation flow rate is defined as:

$$d_{si} = d_{cons}(n) + \beta q_i(n) \quad (8)$$

In this formula d_{cons} is defined as $d_{cons} \geq 30$ and β is the parameter of the variable value is between 0 and 1, as the table below show[1].

TABLE II. THE POSION OF TRAFFIC BY VARIATIONS OF Β

The Position of Traffic	**β**
Non Saturation	$0.7 \leq \beta$
Saturation	$0.4 \leq \beta \leq 0.6$
Super Sturation	$0.1 \leq \beta \leq 0.3$
Instable	β=0

B. *Simulation*

The simulation is done by MATLAB software version 7.4. Over 100 cases have been considered in the simulation. The Fuzzy logic toolbox is useful to build quickly the required rules and changes are easily made.

Function qdrand () is used to generate the random value q_i and d_i (As shown in Fig. 6) and then the Classical_control () is preparing values W_n and Q_n to enter fuzzy controller(As shown in Fig. 7).

```
function [q,d] = qdrand (Qn)
temp = 0;
dcons= 30;
Beta = rand(1,1);
ds = 0;
rg = [3,30];
q = randint(1,1,rg);
ds = dcons + Beta*q;
temp = min( ( Qn + q ),ds);
d = temp;
end
```

Fig. 5. qdrand function code used in the simulation program

```
function [ST,Q,W] = Classical_control(s,d,q,Qn,Wn)

  ST = [0 0];
  T = 5;
  temp = [0 0;0 0];
  Q1 = Qn;
  W1 = Wn;
  if s==0 %0101
 Q1(1,1) = Qn(1,1)+q(1,1);
 W1(1,1) = Wn(1,1)+T*Qn(1,1)+1/2*T*q(1,1);
 Q1(2,1) = Qn(2,1)+q(2,1)-d(2,1);
 W1(2,1)=Wn(2,1)+T*Qn(2,1)+1/2*T*q(2,1)-1/2*T*d(2,1);
  end
  if s==1    %1010

Q1(1,1) = Qn(1,1)+q(1,1)-d(1,1);
W1(1,1)=Wn(1,1)+T*Qn(1,1)+1/2*T*q(1,1)-1/2*T*d(1,1);
Q1(2,1) = Qn(2,1)+q(2,1);
 W1(2,1) = Wn(2,1)+T*Qn(2,1)+1/2*T*q(2,1);
  end
  temp = [W1(1,1) Q1(1,1);W1(2,1) Q1(2,1)];

 if s==1
  ST = [temp(1,1) temp(1,2)];
 end
 if s==0
 ST = [temp(2,1) temp(2,2)];
  end
  Q = Q1;
  W = W1;
  End
```

Fig. 6. Classical_controler function used in the initial simulation program

The simulations were done in MATLAB Simulink which details are shown in Fig. 8.

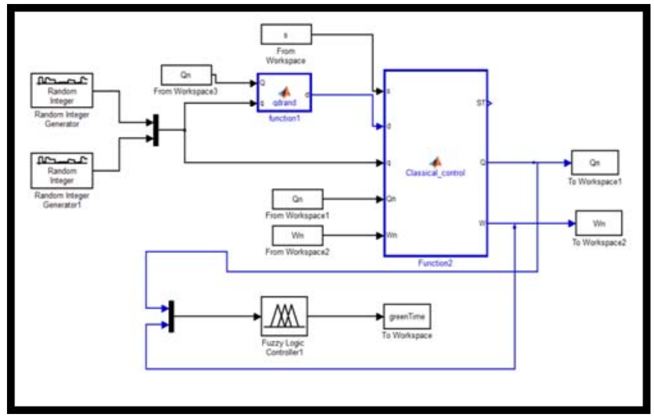

Fig. 7. Simulink block diagram of fuzzy control signal

C. *Result*

In the proposed fuzzy model, the average queue length and waiting time for vehicles was introduced as the system parameters. As shown in Table 3, after simulation and comparison with fixed-time control system, in 100 cases we had 24.69% saving on the amount of time. This value is shown the maximum amount of the green light time at the Fixed- time and this means that the amount of red light has decreased. As result number of cars will be less on the road have red light. This controller has been optimized waiting time in according to have minimum extension of green time with control the vehicle queue length for smoother traffic flow.

TABLE III. COMPARE GREEN LIGHTS IN EACH DIRECTION

Type of controller	**Time Spent green light (minimum extend of green light time)**
Fuzzy	9940 seconds
Fixed-time	7480 seconds
Improvement percentage	24.69%

The amount of green light for each branch of intersection at fuzzy and fixed-time controller in 100 states are shown in Fig. 9 and Fig. 10.

Queue length show in Fig. 11 and 12. As it can be observed in many cases the expected queue length is zero.

For one side of the intersection maximum green time considered 60 seconds and by the other side 140 seconds taken.

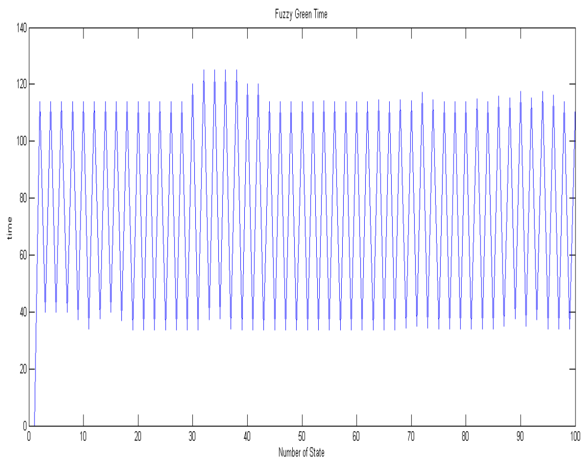

Fig. 8. The amount of green time for traffic light by fuzzy controller

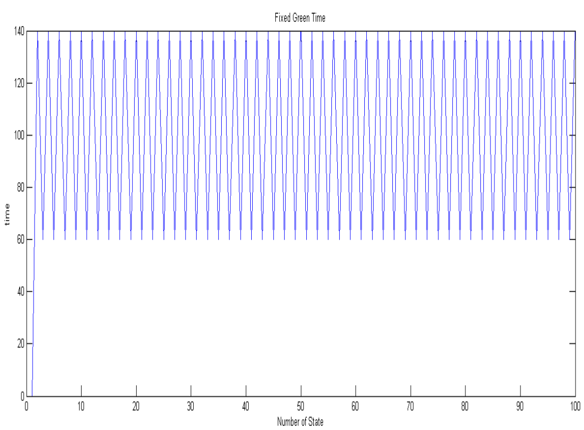

Fig. 9. The amount of green time for traffic light by fixed-time controller

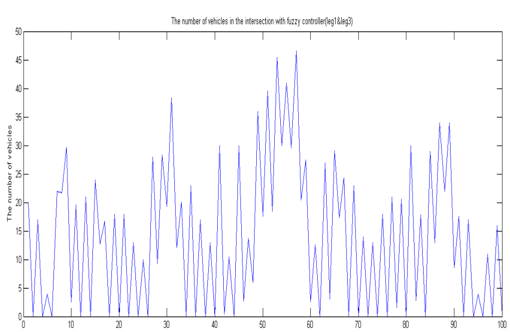

Fig. 10. The queue length In phase1, (number of cars)

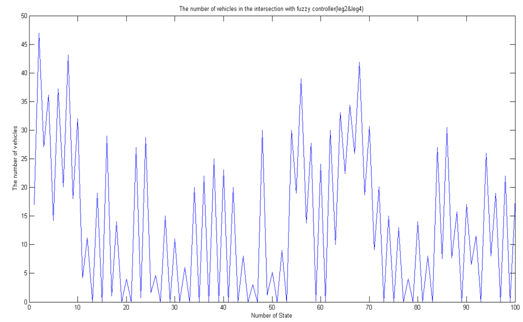

Fig. 11. The queue length In phase2, (number of cars)

As a basic premise of the fuzzy control, 30 and 110 seconds for the minimum time to be considered that this time can be extended up to maximum green time. Maximum green time is considered as the green time is considered for Fixed-time controller. This extension is based on queue length and waiting time of vehicles As result the optimum extension of green time for the output of this fuzzy controller is obtained.

IV. Conclusion

1.After simulation and comparison with fixed time systems, in 100 states we had 24.69% saving on the amount of time. Simulation results and the percentage of improvement show that the Fuzzy intelligent of controller reduces the average waiting time vehicles in any lane of intersection compared to Fixed-time control and this means that the amount of red light is reduced .In other words the number of cars will be reduce on the road it has red.

2. The controller is proposed to avoid the maximum time for the green light.

3. If in the proposed fuzzy controller reduce the minimum green signal time, we will achieve better results.

4. The fuzzy controller has low system complexity and thus its implementation is easier and cheaper. As a result of the reduced system downtime and facilitates error correction.

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