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RED approach for traffic lights management based on fuzzy logic "FL-RED"

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***Abstract*: Road's traffic management is an important topic which is more and more covered by various actors in the Intelligent Transportation Systems field via many proposed solutions. Thus, in order to achieve the dream of a smart city, special attention was given to the treatment of cities' traffic management problem; especially in junctions which constitute bottlenecks for traffic flow leading to a poor quality of urban mobility. The aim of this study is to examine further the RED approach for traffic lights management recently proposed for the design of an adaptive signal control system In the context of ITL (Intelligent Traffic Lights) systems, based generally on sensors, and communication technologies. Traffic management is a well known problematic in data networks. Thus, several researchers have studied methods for providing congestion avoidance at the gateway called also router. Inspired by advanced technologies in Internet traffic management, we propose a system based on the RED (Random Early Detection) mechanism widely used by routers to avoid congestion. Our contribution consists of the adaptation of this mechanism to the ITS context by applying it for traffic lights management. Our system will certainly contribute to decrease waiting times, fuel consumption and pollution. This paper will present the complete adaptation of the RED algorithm to the context of the intelligent transport systems. In addition, the RED-based design performance is compared with that of the pre-timed model to gain insights between the two systems.**

Keywords: RED, ITL, ITS, Road Traffic, Performance

I. Introduction

Road's traffic management is an important topic which is more and more covered by various actors in the Intelligent Transportation Systems field via many proposed solutions. Thus, in order to achieve the dream of smart city, a special attention was given to the treatment of cities' traffic management problem; especially in junctions which constitute bottlenecks for traffic flow leading to a poor quality of urban mobility. In this context, so-called ITL (Intelligent Traffic Lights) systems, based generally on sensors, are proposed to address this situation. Therefore, with increasingly high-speed networks, it is increasingly important to have mechanisms that keep throughput high.

Our proposal is an important part of traffic management application; especially in intersections or crossroads, which is the management of traffic lights. It's based on vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) communications and sensors to collect and transmit data, and on the 'RED' (random early detection) mechanism at the traffic lights controller to adapt dynamically the traffic lights system to road traffic load.

Traffic management is a well known problematic in data networks. Thus, several researchers have studied methods for providing congestion avoidance at the gateway called also router. Inspired by advanced technologies in Internet traffic management, we propose a system based on the RED (Random Early Detection) mechanism widely used by routers to avoid congestion. Our contribution consists of the adaptation of this mechanism to the ITS context by applying it for traffic lights management. We propose to control congestion as active queue management (AQM) mechanism witch identify congestion before the queue become enormous. In other words, AQM mechanism discovers congestion at an early stage. Our system is a proactive system, but the majority of the proposed systems in the literature are reactive systems.

The remainder of this paper is organized as follows: Section II presents an overview of the state of the art of ITL management at intersections. Section III presents the RED mechanism. In section IV, our proposal system will be detailed. In section V we present the RED application. Section VI presents results of our simulations.

II. The state of the art of ITL management

Traffic signaling systems, are one of the major components in traffic management strategies [3]. They aim to regulate traffic flows at intersections and managing vehicular movements, by assigning a time slot, in turn, for each direction. This provides the safety to different stakeholders (drivers, pedestrians, etc...). If these systems are not managed correctly it may have a catastrophic effect on environment, health, energy and economy. (Annually, in the USA, congestion causes “3.7 billion hours of delays” and “8.7 billion liters of ‘wasted’ fuel” with a cost of “US$ 63.1 billion” [4]. In Europe it costs nearly 1% of the EU’s GDP [5]).

Before any classification of these systems we will first, define some concepts involved in these systems [20]:

Cycle: defined as being one complete sequence of the operation of traffic signals. The cycle is divided into "phases", time during which, one or more flows are admitted to the crossroads.

In theory, the optimum cycle length can be approximated with the well-known Webster’s equation (1), as a function of lost times and critical flow ratios:

$$c_0 = \frac{1.5*L+5}{1-\frac{1}{X_c}*\sum_1^n \frac{v_i}{s_i}} \quad (1)$$

C_0 : optimum cycle length.

L : sum of yellow and all red times.

$1/X_c$: degree of intersection utilization (usually 0.95)

V_i/S_i : max flow ratio for critical lane group i.

Phase: is an interval during which a combination of green lights authorized by the management unit will be activated. The phases are determined from movements each direction can perform. A typical signal cycle with four phases is shown in Figure1.

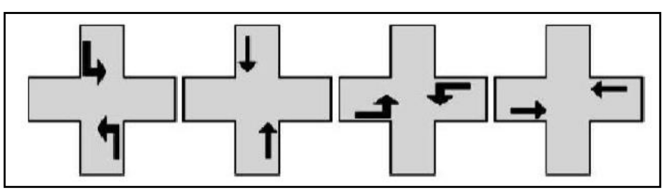

Figure .1 Phases of signal cycle [3]

Green split: a portion of the cycle allowing passage of vehicles.

Yellow time: safety interval that indicate the change of traffic light (green to red and vice versa)

Red time: notify stoppage of movement.

The traffic lights management systems at intersections can be classified into three categories:

- Pre timed Control: Use traffic signal plans based on predefined time.
- Dynamic time Control: based on sensors to collect traffic data per period. This data is used to develop and optimize traffic signal plans.
- Real-time control: same principle as the second, except that it works in real time.

The dynamic systems can be classified into two types:

- Reactive control: the system put in place a new configuration in response to the collected information. UTCS (urban traffic control software) appeared in the U.S. in the late 80s is an example of this type of system.
- Adaptive Control: based on parameters collected in real time to set traffic signals plans dynamically. This solution is complex.

Some adaptive control systems are implemented at the intersections all over the world. The most important are:

- SCOOT (split cycle offset optimization technique) [20]: reactive and adaptive system, fully centralized, developed by TRL (Traffic Research Laboratory: English research center on transport.). SCOOT acts on the phase’s duration in function of a performance index calculated based on average wait time, lengths of queues and stops on the network. It uses magnetic loops to take measures relating to traffic, but also information from databases (historical).
- SCATS (Sydney adaptive traffic system) [20]: adaptive system uses the information to select a plan from a large library. The arrangement of the sensors is not the same as that used in SCOOT. The decision period is a cycle for SCOOT and SCATS.

The design of mechanisms to control traffic signals must consider some metrics such as average waiting time, length of queues, fuel consumption and pollutant emissions.

In the literature, several models of dynamic systems are proposed, some based on fuzzy logic as in [7], [11], [13], [15] and [22], which is a simple theory, robust to uncertainties, but its disadvantage reside in settings implementation‘s techniques, which are empirical. Other systems are based on genetic algorithms [8], [12], [16], [23], and [24] for the time’s optimization in one or more intersections. The disadvantage of these systems is complexity, difficulty setting (the population size), and a high convergence time (it depends on the mutation rate, generation gap and fitness function choosing). Based learning, neural networks systems are studied in [9], [14], [17], [18], [19], [25], [26], and [27]; their problem is the high cost calculations.

Other theories are used to study, design and optimize dynamic systems. There may be mentioned, the queues theory, game theory and fluid mechanics.

III. RED algorithm

RED means: Random Early Detection was first proposed by Sally Floyd and Van Jacobson in [1] for Active Queue Management (AQM) and then standardized as a recommendation by IETF in RFC 2309. The main goal is to provide congestion avoidance, maintain high throughput as well as a low delay and achieve fairness over multiple TCP connections.

Essentially, RED algorithm has two separate parts. One is for computing the average queue size, avg, which determines the degree of burstiness that will be allowed in the router queue. It takes into account the period when the queue is empty (the idle period) by estimating the number m of small packets that could have been transmitted by the router during the idle period. After the idle period, the router computes the average queue size as if m packets had arrived to an empty queue during that period. The other is used to calculate the packet-dropping probability Pa, and then determine how frequently the router drops packets, given the current level of congestion.

The operating principle of the algorithm is as follow:

Determine avg load
If $min_{th} \leq avg < max_{th}$
  Determine Pa
  with probability Pa:
  drop the arriving packet
Else if $max_{th} < avg$
  drop the arriving packet

where:
min_{th}: minimum threshold for queue
max_{th}: maximum threshold for queue;
rule of thumb: $max_{th} = 2 * min_{th}$

IV. RED approach for traffic lights management

Given the advanced Internet technologies in traffic management, we propose a RED based system. Our contribution is within the scope of dynamic traffic lights management systems and consists of the RED mechanism's adaptation to the ITS context. We propose to apply this mechanism for traffic lights management in order to contribute to the decrease of waiting times, fuel consumption and pollution. As it was explained before, the RED method calculates the average queue size by using a low-pass filter with an exponential weighted moving average. The average queue size is compared to two thresholds (1) S_1 a minimum threshold and (2) S_2 a maximum threshold. When the average queue size is less than the minimum threshold, no packets are dropped. When the average queue size is greater than the maximum threshold, every arriving packet is dropped. When the average queue size is between the minimum and the maximum threshold, each arriving packet is dropped with probability P_a, where P_a is a function of the average queue size Avg. We propose a complete adaptation of the RED method to the context of the intelligent transport systems.

In this context, as shown by the Figure.2, our approach is structured around four main phases: the Learning phase and traffic estimation (I), the Setup phase (II) Load ($C_{ri}(t)$) Measurement (III) and the RED algorithm application (IV). In coming subsections we will present a detailed description of these phases.

- 1st phase: For an optimized planning we should have a control on the design and the management of the transport network resources under our own administrative domain; thus, an important need would be to evaluate traffic demand. To do that, we propose to make measurements in all lanes of the studied intersection. These measurements will make at our disposition statistics concerning the temporal distribution of each lane's load $C_{ri}(t)$.
- 2nd phase: phase two processing is based on obtained results in the first phase. Thus, according to the temporal distribution of each lane's load $C_{ri}(t)$ we propose to split the day in many time slots. Each one is characterized by a stationary average load. As the proposed system is based on the RED algorithm, it is very important to specify for each time slot thresholds values S_{1i}, S_{2i} and $P_i(T)$. These values will be used for determining the used ratio for vehicles' evacuation which will satisfy constraints design such as the decrease of waiting times, fuel consumption and pollution….
- 3rd phase: this phase consists on the measurement of the real load $C_{ri}(t)$ for each lane i. This measurement could be done via magnetic loops, sensors or VANET communication. $C_{ri}(t)$ will serve to determinate the most loaded lane (1) and for RED to parameters will be calculate the vehicles evacuation ratio for each lane (2).
- 4th phase: The RED process calculates the average load $L_{avg}(i)$ of each lane i, using a low-pass filter with an exponential weighted moving average. The $L_{avg}(i)$ value is compared to thresholds S_{1i} and S_{2i}. When $L_{avg}(i)$ is less than S_{1i}, the static mode is used to manage the light system. When $L_{avg}(i)$ is greater than S2i, all queued vehicles will be evacuated. In the case where $L_{avg}(i)$ is between S_{1i} and S_{2i}, vehicles are then evacuated with a ratio equal to $P_i(T)$, where $P_i(T)$ is a function of the average load $L_{avg}(i)$ as described in phase 2 .

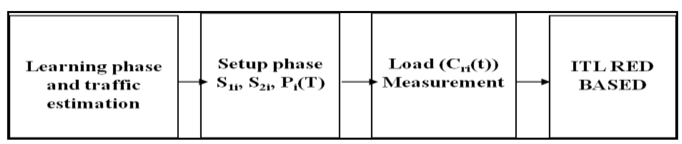

Figure .2 main phases of the proposed approach[21]

It is important to note that our traffic light management system serves the most loaded lane first. Operating principle of RED functioning is shown in Figure.3, and our system functioning is described by the chart in Figure.4.

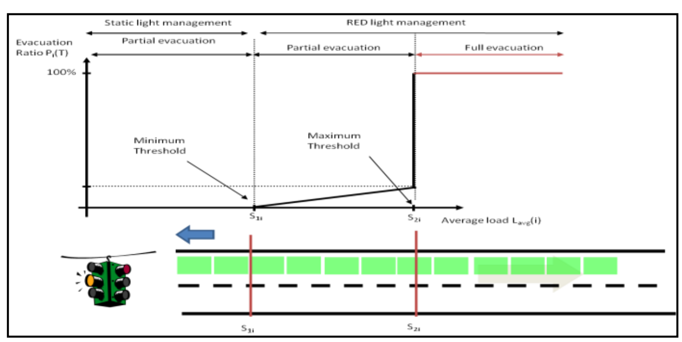

Figure .3 operating principle of RED functioning[21]

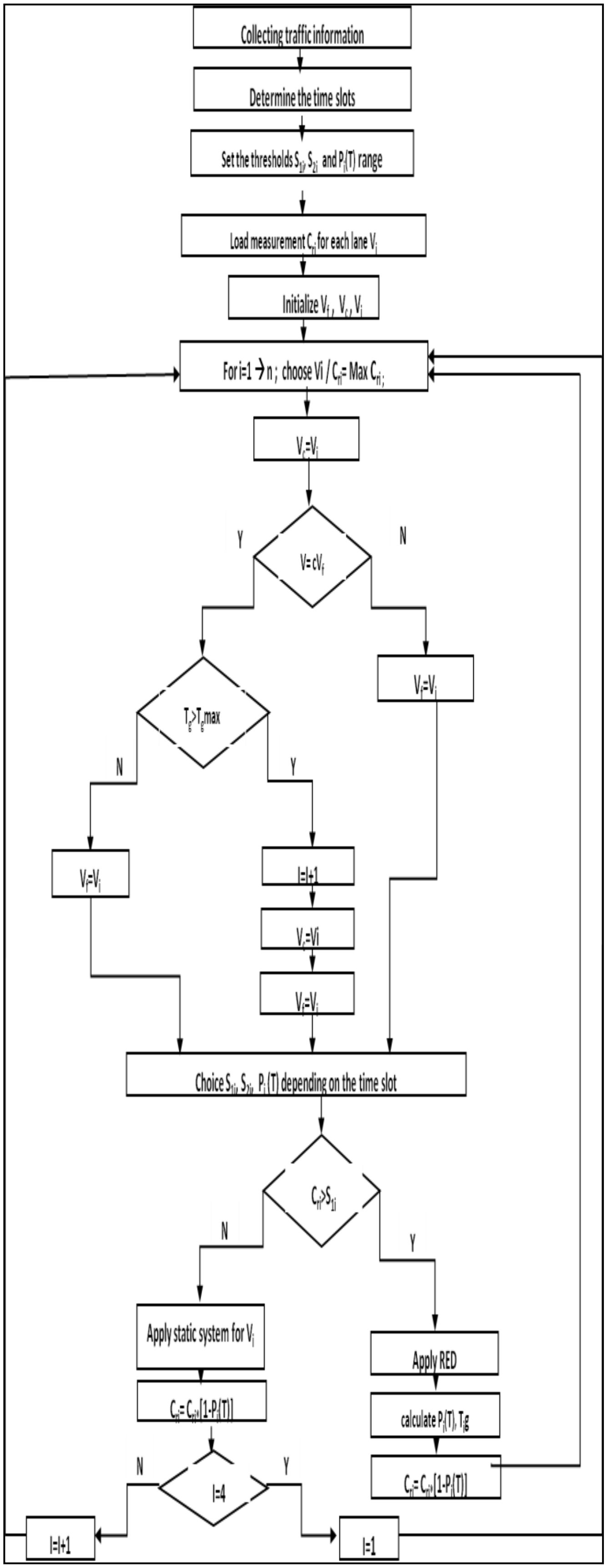

Figure .4 System operating flowchart

For each lane of the intersection a queue is assigned. In our approach we propose that the road side unit called RSU(road side unit), will be in charge of the traffic light control. Thus, the RSU will execute mechanisms for measuring the rate of the queue filling. The RED mechanism is then applied to evacuate vehicles from the considered lane.

Every traffic light management system is based on an important parameter which is the green phase duration T_g. This phase duration is highly correlated to the evacuated vehicles ratio. Thus, the last function of our proposed system is to make a mapping of the desired evacuation ratio to green phase duration. To do that, RED is applied to determine the evacuation's ratio $P_i(T)$. This ratio will be used to calculate T_g, taking in consideration predefined parameters; the distance between adjacent vehicles, vehicle's length and the vehicle's speed during the evacuation.

T_g is given by the formula (2) :

$$T_g = \frac{(D_{ij} + L)}{(P_i(T).V_{avg})} \quad (2)$$

With:

L: average vehicle length,
D_{ij}: average distance between adjacent vehicles.
V_{avg}: average speed of vehicles during evacuation.
$P_i(T)$: discharge rate of the queue
V_c: the most loaded lane chosen
V_f: final lane chosen after verification
V_i: lane number i.
T_{gmax}: max green light duration.

V. RED application:

RED is used to determine the extension time needed for the pre-timed green light.

The real time queue length is measured using sensors and/or inter-vehicular communications. Using this parameter and historical information we calculate the average queue length Q_{avg} .

If Q_{avg} is less than Minth , there is no extension.

If Q_{avg} is greater than Maxth, the extension is maximum (Tgmax).

If $Min_{th} < Q_{avg} < Max_{th}$, a fuzzy logic controller is used to determine the evacuation percentage, and then the extension time.

A. Fuzzy logic controller:

The fuzzy logic, as a mathematical tool for dealing with uncertainty, is used only in a part of our system. This makes it different with other proposed systems, and it also, limits the drawback of fuzzy logic technique. The controller we propose has two inputs and one output. Mamdani-Type fuzzy inference system (FIS) editor is used to develop fuzzy rules, input and output membership functions. (Figure. 5)

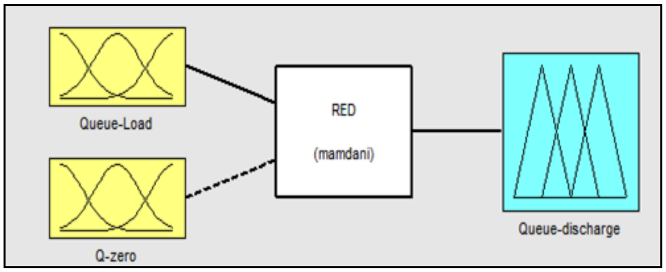

Figure .5 Basic structure of FIS.

Two fuzzy input variables are chosen:

- Quantity of traffic (Queue's load), with range [5 - 25] (Figure 6)
- The arrivals rate of traffic, informed by the length of remaining queue at the end of green time (Q_0), with range [0 - 15] (Figure 7)

The output fuzzy variable would be the vehicle evacuation rate, with range [0 - 1]. (Figure 8)

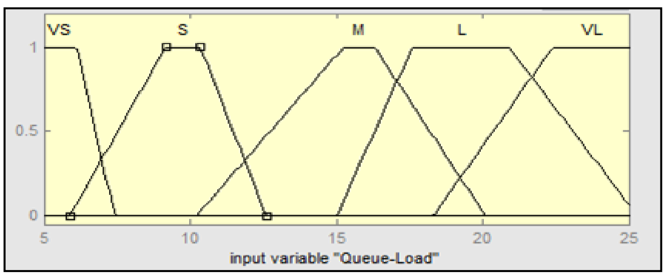

Figure .6 Queue's load membership

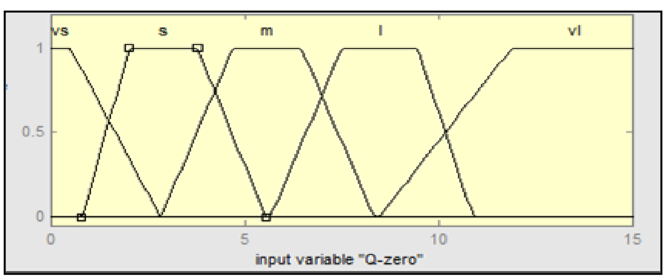

Figure .7 Q_0 membership

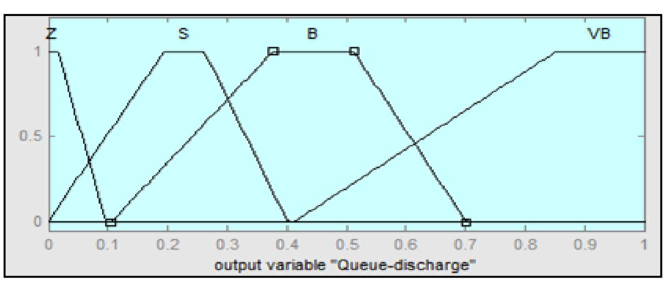

Figure .8 Evacuation rate membership

B. Membership functions and fuzzy parameters:

For the evacuation rate control, there are five membership functions for each of the input and there are four output fuzzy variable of the system. Table I shows the fuzzy input variables of Q_0, Queue's load and output variable evacuation rate(queue discharge).

Table 1. Fuzzy variables form for evacuation rate control system.

Input variables				**Output variables**		
Range 0-15	**Q_0**	**Range 5-25**	**Queue Load**	**Range**	**Evacuation rate**	
0-3	Very Short (vs)	5-7	Very Short (VS)	0-0.1	Z	Zero
1-6	Short (s)	6-13	Short (S)	0-0.4	S	Small
3-9	Medium (m)	10-20	Medium (M)			
6-11	Large(l)	15-25	Large (L)	0.1-0.7	B	Big
8-15	Very Large(vl)	18-25	Very Large (VL)	0.4-1	VB	Very Big

C. Fuzzy rule set:

In fuzzy control imitates the human brain's thought, by applying the knowledge of fuzzy mathematics. Rules like those used by humans are used by the controller.

The rules implemented by our system are shown in Figure 9. Table II summarizes these rules in a matrix.

1. If (Queue-Load is VS) and (Q-zero is vs) then (Queue-discharge is Z) (1)
2. If (Queue-Load is S) and (Q-zero is vs) then (Queue-discharge is S) (1)
3. If (Queue-Load is M) and (Q-zero is vs) then (Queue-discharge is S) (1)
4. If (Queue-Load is L) and (Q-zero is vs) then (Queue-discharge is B) (1)
5. If (Queue-Load is VL) and (Q-zero is vs) then (Queue-discharge is VB) (1)
6. If (Queue-Load is VS) and (Q-zero is s) then (Queue-discharge is S) (1)
7. If (Queue-Load is S) and (Q-zero is s) then (Queue-discharge is S) (1)
8. If (Queue-Load is M) and (Q-zero is s) then (Queue-discharge is B) (1)
9. If (Queue-Load is L) and (Q-zero is s) then (Queue-discharge is B) (1)
10. If (Queue-Load is VL) and (Q-zero is s) then (Queue-discharge is VB) (1)
11. If (Queue-Load is VS) and (Q-zero is m) then (Queue-discharge is S) (1)
12. If (Queue-Load is S) and (Q-zero is m) then (Queue-discharge is B) (1)
13. If (Queue-Load is M) and (Q-zero is m) then (Queue-discharge is B) (1)
14. If (Queue-Load is L) and (Q-zero is m) then (Queue-discharge is VB) (1)
15. If (Queue-Load is VL) and (Q-zero is m) then (Queue-discharge is VB) (1)
16. If (Queue-Load is VS) and (Q-zero is l) then (Queue-discharge is B) (1)
17. If (Queue-Load is S) and (Q-zero is l) then (Queue-discharge is B) (1)
18. If (Queue-Load is M) and (Q-zero is l) then (Queue-discharge is VB) (1)
19. If (Queue-Load is L) and (Q-zero is l) then (Queue-discharge is VB) (1)
20. If (Queue-Load is VL) and (Q-zero is l) then (Queue-discharge is VB) (1)
21. If (Queue-Load is VS) and (Q-zero is vl) then (Queue-discharge is B) (1)
22. If (Queue-Load is S) and (Q-zero is vl) then (Queue-discharge is VB) (1)
23. If (Queue-Load is M) and (Q-zero is vl) then (Queue-discharge is VB) (1)
24. If (Queue-Load is L) and (Q-zero is vl) then (Queue-discharge is VB) (1)
25. If (Queue-Load is VL) and (Q-zero is vl) then (Queue-discharge is VB) (1)

Figure .9 Fuzzy rules deciding the evacuation rate

Table 2. Fuzzy rules matrix form for evacuation rate control system.

Q_0 → Queue load ↓	vs	s	m	l	vl
VS	Z	S	S	B	B
S	S	S	B	B	VB
M	S	B	B	B	VB
L	B	B	B	VB	VB
VL	B	VB	VB	VB	VB

D. Inference engine and defuzzification

In the fuzzy controller, when the rules are fired, the degree of membership of the output variable, in our case it's the evacuation rate, is determined by encoding the fuzzy subsets, queue's load and Q_0.
The max-min method is used for aggregation and implication.
For the defuzzification, we used the centre of gravity technique. Rule based inference is shown in Figure 10

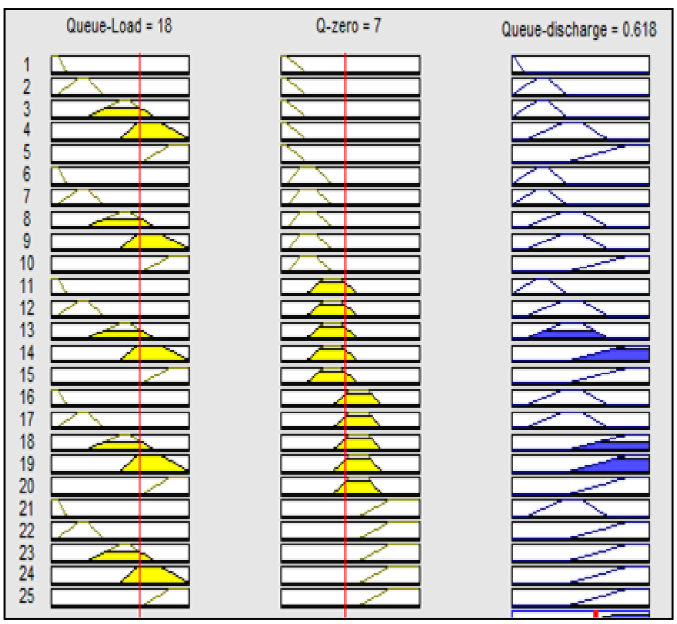

Figure .10 Rule based inference

E. Simulation of the FL controller:

After the evacuation rate controller was carefully designed, we test the system and discuss the impact of the input variables on the output variable. The results are summarized in Table III. The simulation shows the effect of the two inputs on rate of evacuation. The obtained results show that the controller reacts in accordance with the RED principle. (Figure 11, Figure 12 and Figure 13)

Table 3. Evacuation rate at different values of input variables queue load and Q_0.

Queue's Load	Q_0	Evacuation rate
5	3	21.1%
5	4	21%
5	5	21.1%
10	6	42%
10	7	41.6%
10	8	42%
15	9	79.7%
15	10	77%
15	11	77.9%
17	11	77.9%
19	11	77.9%
20	12	79.7%
20	13	79.7%
20	15	79.7%
22	15	78.7%
23	15	79.7%
25	15	79.7%

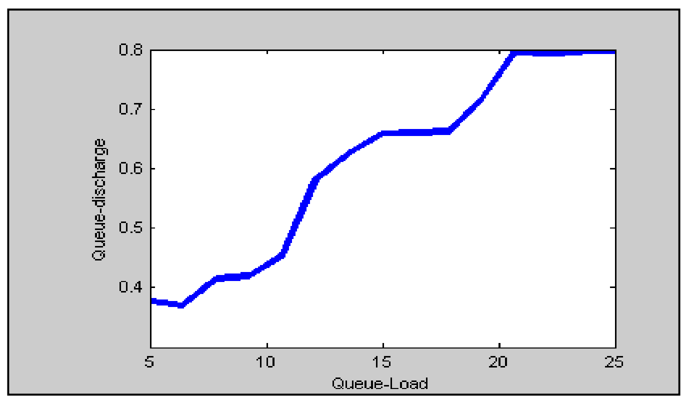

Figure .11 Output based on Input Queue load

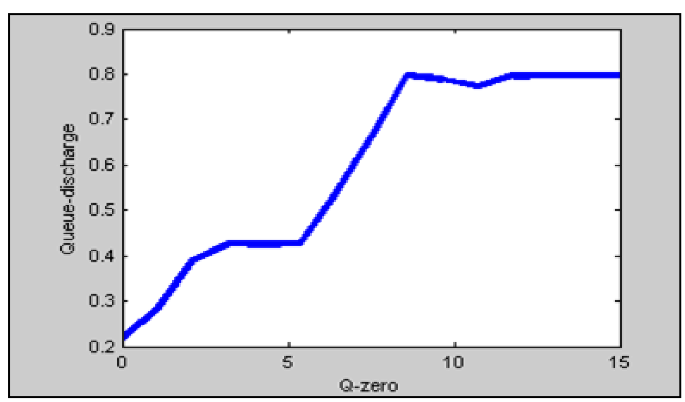

Figure .12 Output based on Input Q0

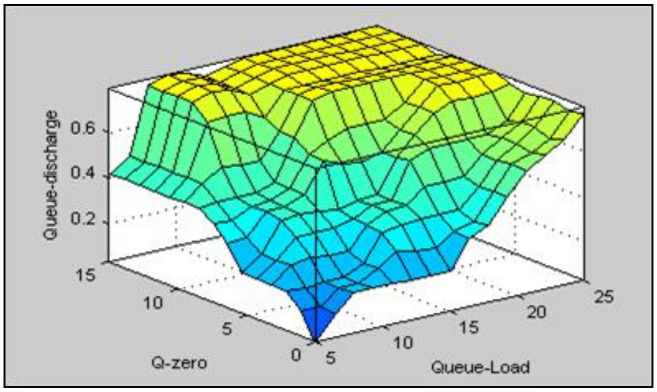

Figure .13 Output based on Inputs Queue load and Q_0

VI. Simulation and results of the whole system:

In this work, we evaluate the performance of our approach 'RED' against pre-timed system using different values of the vehicle arrival probability P, with MATLAB.
The following assumptions are made:

- The simulation involves only one direction of an intersection.
- Traffic moves straight ahead without turning.
- The arrivals of vehicles at the intersection follow a Poisson law.

The simulation parameters are as follow:

- Arrivals probability: P
- RED parameters: minimum threshold (Min_{th}), maximum threshold (Max_{th}) and evacuation probability (P_e).
- Simulated observation period: T= 1H.

The metrics used to compare our system to the pre-timed system are:

- Queue's load
- Discharge rate
- Waiting delays
-
- CO2 emissions.

The result of the simulation for one hour period is shown in the Figure 14, Figure 15, Figure 16, Figure 17, Figure 18 and Figure 19 :

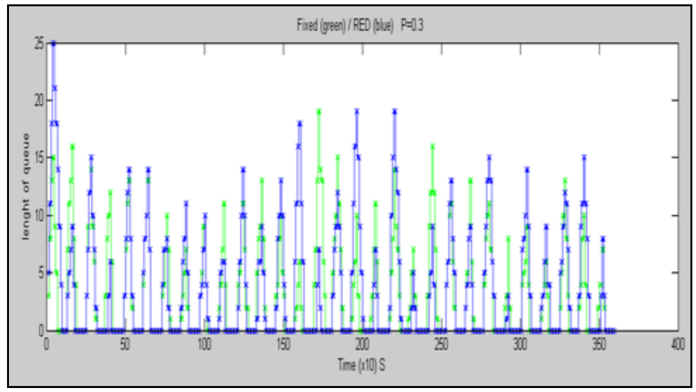

Figure .14 Comparison between Queue length of RED and Fixed time system for P= 0.3 [21]

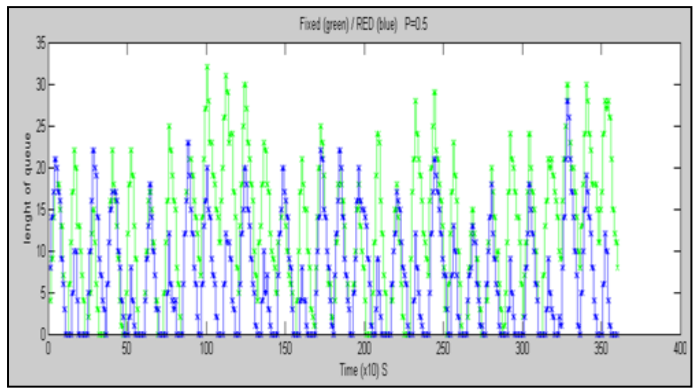

Figure .15 Comparison between Queue length of RED and Fixed time system for P= 0.5 [21]

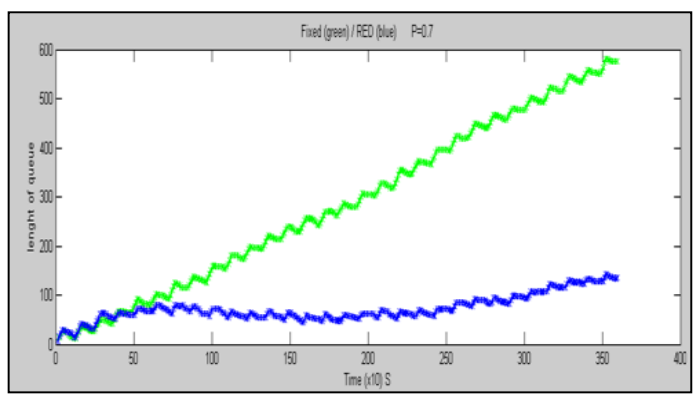

Figure .16 Comparison between Queue length of RED and Fixed time system for P= 0.7 [21]

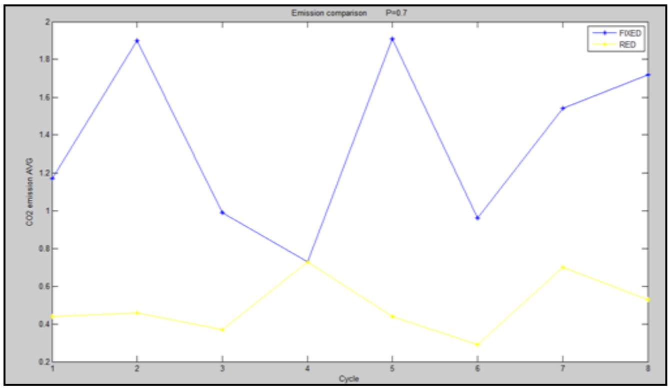

Figure .17 RED/ Fixed CO2 emissions comparison for P=0.7

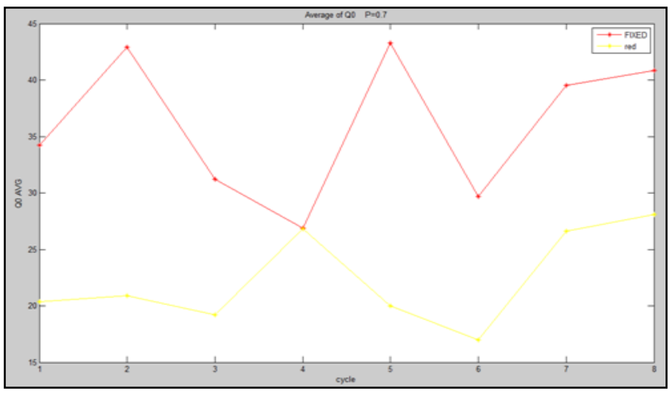

Figure .18 RED/ Fixed Q_0 Queue comparison for P=0.7

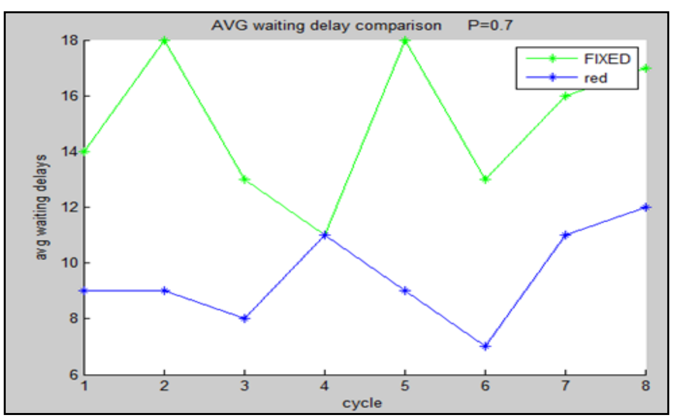

Figure .19 RED/ Fixed waiting delays comparison for P=0.7

The scenario in the Figure 14 shows a low traffic situation. In this case our system 'RED' behaves as pre-timed system.

In the Figure 15, the traffic increases, the 'RED' system is stable, but the pre-timed system tends toward a congestion situation.

The Figure 16 shows the behavior of our systems in a significant increase of traffic. The pre-timed system presents à critical situation, and 'RED' presents a slight increase in load.

In Figure 17, we present the average evolution of the CO2 emissions during eight cycles. With our system RED, we gain a reduction of 63% in CO2 emissions.

The evolution of the average length of the remaining queue after the end of green light time, Q0, is presented in Figure 18. Our system presents an enhancement of 38% comparing with the fixed system.

In Figure 19, we can see the glaring difference regarding the average waiting delays between our system RED and pre-timed system. RED improves these delays 36.6%.

The Table IV, presents the discharge rate extracted in the simulation: different simulations have shown that our system has better performances than the pre-timed system.

The Table V summarizes the improvements on various metrics of our system.

Table 4. Evolution of the discharge rate depending on the arrival probability for pre-timed and Red systems in one hour period [21].

Probability of arrival	Discharge for pre-timed system	Discharge for 'RED' system	Gain RED/pre-timed
0.3	1440	2080	44%
0.5	1440	2080	44%
0.7	1440	2400	66%
0.9	1440	2400	66%

Table 5. RED gain using different metrics.

Metric	Gain (RED/ Fixed time) P=0.7
Queue's load (Q_0)	38%
Discharge rate	66%
Waiting delays	36.6%
CO2 emissions.	63%

VII. Conclusion:

Through this paper, we made a Survey on different techniques proposed in the literature for the traffic management at intersections, which can be summarized into two categories:

- Static, which attribute phases of cycle statically. This kind of system is simple with reasonable cost, but not optimal in terms of delays and queue's load;

- Dynamic, which adapt phases depending on the load of each entry. The major problem of the proposals is the complexity of the proposed systems and the high cost of their deployments.

Our proposal comes in the context of dynamic systems, inspired from the techniques used in data network gateways to relieve congestion; based on the RED mechanism, which aims to anticipate a congestion situation at intersections. This helps to avoid bottling situations. We will proceed in future work to more simulations taking into account several parameters such as the presence of pedestrians, the presence of an emergency vehicle on a particular entry, taking into account several adjacent intersections, and several entries (more than four), also develop load measurement and setting blocks based on optimal control theory and game theory.

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