Fuzzy-Logic Approach for Traffic Light Control Based on IoT Technology

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Abstract **- Traffic congestion is an extremely common phenomenal issue, it occurs in many cities around the world, especially in those cities with high car ownership. Traffic congestion not only causes air pollution and fuel wastage, but it also leads to an increased commuting time and reduces the work time availability. Due to these reasons, traffic congestion needs to be controlled and reduced. The traffic light is the most widely adopted method to control traffic, however, most traffic lights in use are designed based on the predefined interval, which cannot cope with traffic volume change very well. Therefore, Internet of Things (IoT) based traffic lights or adaptive traffic lights are developed in the recent years as a complement of the traditional traffic lights. The adaptive traffic light can be built based on monitoring current traffic situation or using Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication. In this paper, a new design of adaptive traffic light is proposed, this traffic light system is based on fuzzy logic and it introduces volunteer IoT agent mechanism, which introduces more accurate results.**

Index Terms - Internet of Things. Traffic control. Fuzzy logic.

I. INTRODUCTION

Traffic congestion refers to the phenomenon of a road traffic bottleneck that produced by heavy car's traffic that heading to congested intersections with a slow speed. This case is usually occurring during rush hours and holidays. This situation often occurs in major metropolitan areas around the world, areas with high automobile usage, and highways connecting two cities.

Frequent traffic congestion leads to an increased commuting time and it reduces the time available for work, resulting in economic losses due to workers delay getting their working places on time, delay of delivering goods on time and so many other factors. It also causes drivers to feel irritated and impatient, which increases their stress and further damages their health. To a certain extent, traffic congestion is also a waste of fuel and pollution: Engines keep running during traffic congestions, which consumes extra fuel, and at the time of congestion, drivers always accelerate and brake back and forth, which further increases fuel consumption. Traffic congestion therefore not only wastes energy, but also causes air pollution.

Therefore, in this paper, a design of adaptive traffic light is proposed, this traffic light system is based on fuzzy logic and it introduces volunteer IoT agent mechanism to make sure the system gives a more accurate result.

II. RELATED WORK

There are many studies, which have examined different methods on traffic management. The authors of [1] proposed a traffic con-gestion detection system in their paper, their system consists of I2I (infrastructure-to-infrastructure) communication method, V2I (vehicle-to-infrastructure) communication method, V2V (vehicle-to-vehicle) communication method, and big data cluster. The system uses abovementioned three communication method to collect all the vehicular information such as vehicle's latitude, vehicle's longitude, and vehicle's speed. Then data is encapsulated in DATA packets by using the LORA-CBF algorithm and transmitted to the big data cluster.

In big data cluster, received data is interpreted and further analyzed by using algorithm based on Binary Traffic Output (BTO) algorithm proposed by [2] to identify potential traffic events such as traffic congestion and traffic accident. Similar work has been done in [3], this proposed system employs V2I communication technology based on WAVE IEEE 802.11p standard and uses fuzzy logic to coordinate vehicles on the road. Fuzzy control system considers each vehicle's comfortable and safe distance and speed adjustment to prevent collisions in advance and improve traffic flow. This traffic management system can analyze received information and sending warning or recommendation commands to the vehicles.

In the article [4], authors built an IoT based traffic junction model, with several ultrasonic sensors placed on sides of road to count the number of cars and connect sensors to Arduino microcontroller, then data is transmitted to Raspberry Pi3 microcontroller through Wi-Fi module, where analysis been carried out. The traffic was categorized as heavy and normal traffic, as well as based on the traffic density, traffic signal time has been changed accordingly. Azura che soh, Lai Guan Rhung and Haslina Md. Sarkan have conducted a research on adaptive traffic light system by using Matlab simulation, in their research paper [5] they developed a fuzzy traffic controller based on vehicles queue length and waiting time at cur-rent green phase. They compared fuzzy traffic controller (FTC) with vehicle-actuated controller (VAC) and found that the fuzzy controller distinctly reduces average waiting time, average queue length and delay time. In another research done by authors of [6], it divides the status of intersections into four categories. Then based on the evaluation of the status, it adopts a fuzzy reasoning method to evaluate the traffic operation status of intersections and formulate corresponding traffic management method for traffic congestion.

III. Proposed Approach

Since traffic congestion has many negative influences on people's daily life, the objective of this paper is to build a traffic light control system based on fuzzy logic. The system should be able to determine the duration of traffic light's green time based on given inputs, which are traffic saturation, queue length and traffic status from volunteer IoT agent. The system will monitor traffic condition during current traffic light cycle (one traffic light cycle contains three different phases, green light phase, yellow light phase and red-light phase), then the system will adjust the duration of green light phase in the next traffic light cycle. Eventually, this system can help to improve traffic efficiency in a traffic junction and manage traffic more effectively by adjusting traffic light's green time. Fig 1 shows how system's architecture at a traffic junction.

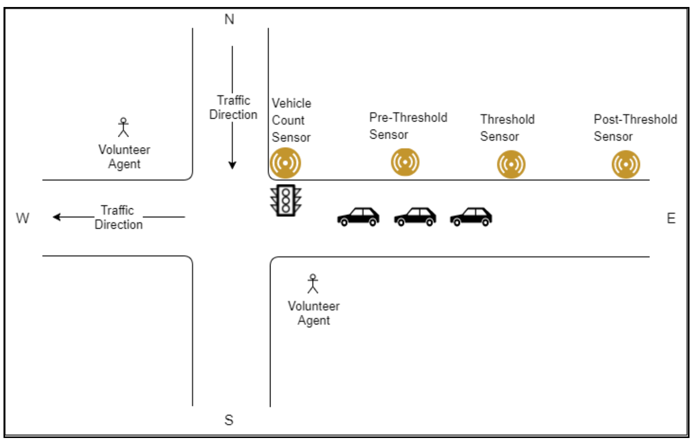

Fig. 1 Working scenario of the system

In figure 1, four sensors are deployed on the side of the road. Vehicles count sensor is placed right next to the traffic light. During the green light phase, every time a car passes through the intersection the movement can be captured by this sensor. The total vehicle count is the actual traffic volume in the intersection, after getting the total vehicle count, this value is then used to calculate traffic saturation, which is explained in sub-section ii.

Pre-threshold, threshold and post-threshold sensors are used to detect vehicle queue length during the red-light phase. If queue length ≤ 40M, the pre-threshold sensor will be triggered. If (40M< queue length <60M), the threshold sensor will be triggered. While, if the queue length ≥60M, the post threshold sensor will be triggered.

In figure 1, there are two volunteer IoT based agents at the intersection, volunteer agents can observe and evaluate traffic situation and send traffic situation value (e.g. minor congestion, severe congestion) to the control system, details of volunteer agent are discussed in sub-section iv. In the real life, there can be multiple volunteer IoT agents in one intersection observe and send traffic situation data at the same time. However, this paper will assume only one volunteer IoT agent is allowed. Another assumption in the paper is that there are no turns involved, only straight through traffic, vehicles can only move from East to West or from North to South as shown in Fig 1.

Since the proposed method in this paper is built by using simulation, all the inputs will be retrieved from a created input file, input file contains pre-defined possible values for inputs variables. Input files for each parameter are discussed in section A.

A. Design of Fuzzy Inference System

The fuzzy inference system (FIS) consists of fuzzification, knowledge base (membership functions and fuzzy rules) and defuzzification [7]. FIS takes crisp inputs and converts them into fuzzy inputs by using membership functions, then it combines fuzzy inputs together to come up with a fuzzy output based on fuzzy rules and output membership functions. Fig 2 [7] illustrates the workflow of fuzzy inference system in this paper.

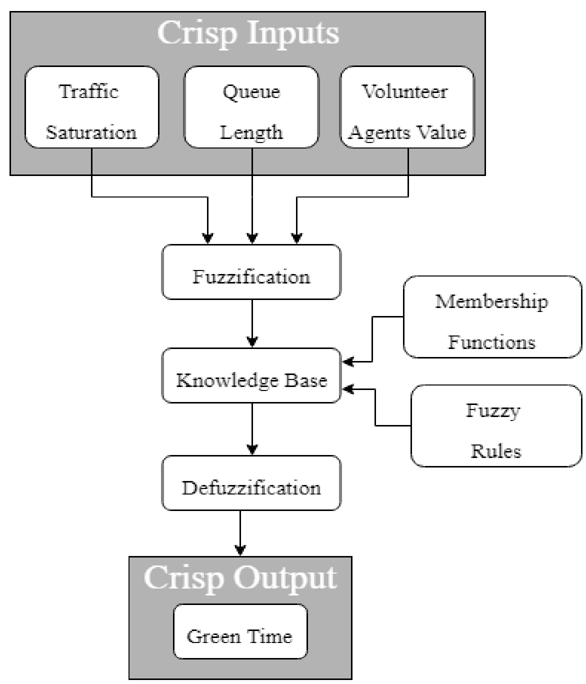

Fig. 2 Computation of output Green Time

i. Fuzzification of Inputs and Outputs

The fuzzy inference system takes three inputs, which are discussed in detail by the following sub-sections:

ii. Traffic saturation

This input metric indicating the degree of saturation of an intersection under traffic signal control is a measure of how much demand it is experiencing compared to its total capacity. Road saturation refers to the ratio of actual traffic volume and capacity of the road, it can be represented by x, and calculated by using equation $x = \frac{q}{Q}$, where q is actual traffic volume and Q is total capacity. x can be any value between 0 and 1. If x is greater than 0.9, the traffic condition at the intersection deteriorated sharply, and traffic congestion is very likely to occur [8]. In this paper, the total capacity of the intersection is assumed to be 100 ($Q = 100$), which means during one green light phase, the maximum number of vehicles to pass the intersection is 100. Membership function of traffic saturation is shown in Fig 3. Y-axis indicates the degree of membership; X-axis indicates traffic saturation during the current green light phase.

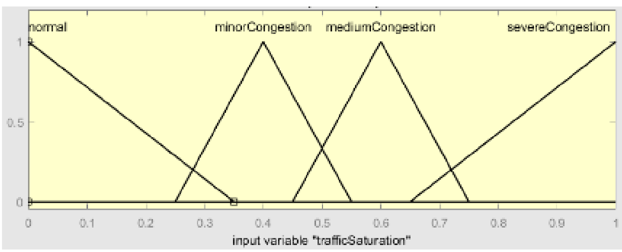

Fig 3. Membership function for traffic saturation

Input file for traffic saturation is named Green Phase Car Count Input File, this file contains all the integer numbers from 0 to 100, in each green light phase, system will randomly retrieve one number from the file as the actual traffic volume (e.g. $q = 50$) during that green light phase, then q is substituted into equation $x = \frac{q}{Q}$ to calculate road saturation x.

iii. *Queue* length

The queue length input metric refers to the length of space occupied by the stopped vehicles; it can reflect the traffic flow at the intersection. It is of great significance for evaluating the operation status of the intersection, measuring the severity of traffic congestion, and evaluating the existing signal timing plan. In general, the more severe the congestion, the longer the length of the queue. The membership function of traffic saturation is shown in Fig 4. Y-axis indicates the degree of membership; X-axis indicates queue length which is measured in meters.

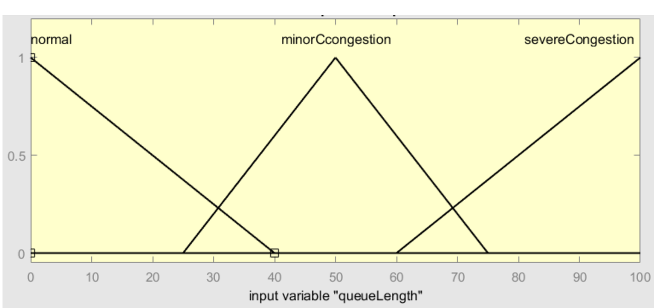

Fig. 4 Membership function for queue length

As mentioned above, pre-threshold, threshold and post-threshold sensors are used to detect vehicle queue length. If the pre-threshold value is triggered, it is considered as normal traffic condition, if the threshold is triggered, it is considered as minor congestion, if the post-threshold value is triggered, it is considered as severe congestion.

Input file for queue length is named Queue Length Input File, as indicated in Fig 4, the minimum queue length is 0 meter and maximum queue length is 100 meters. Therefore, this file contains all the integer numbers from 0 to 100, during each red-light phase, the system will randomly retrieve one number from the file as queue length during that red light phase.

iv. *Traffic status from volunteer IoT agent*

Traffic information will be also gathered from volunteer agents, which could be any person from nearby traffic junction, they can observe and provide traffic situation information to the control system by mobile application. With the help of volunteer agents, the system takes account of nearby traffic junctions. For example, in case both current and next traffic junctions are having severe congestion, if the control system gives green light to current traffic junction, vehicles from current traffic junction will flood into next traffic junction and cause even worse traffic congestion. One solution can be extending the green time in next junction to clear out vehicles, while current traffic junction can extend red time to hold vehicles, after the vehicles in the next junction have been cleared out, the current junction can open green light to let vehicles to pass. However, in this paper we will assume all volunteer agents come from current junction, which means the system will only consider traffic situation at the current intersection.

Volunteer agent uses a scale of 1 to 5 as an indication of the traffic situation, 1 stands for no congestion while 5 stands for severe congestion. Meanwhile, a trust level is assigned to each volunteer agent. Trust levels have values of high, medium, and low trust level, each trust level has its own weight, high=20, medium=15 and low=10.

Calculation of a volunteer agent's value involves following steps:

Step1: volunteer agent provides a number (e.g. 4) to indicate current traffic situation.

Step2: system identifies volunteer agent's trust level. (e.g. medium)

Step3: multiply number provided in step1 (in this case=4) with the corresponding weight associated with trust level (in this case=15), 4*15=60.

The result of step 3 (which is 60 in this case), is then used to evaluate traffic situation by using membership function as shown in Fig 5.

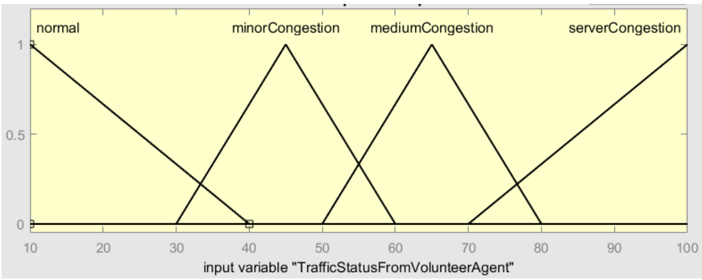

Fig 5. Membership function for traffic status from volunteer agent.

Traffic status from volunteer agent has two input files, one file is called Volunteer Agent Value Input File, which contains integer numbers from 1 to 5, these numbers are used by volunteer agent as a scale to indicate traffic situation. Another file is called Volunteer Agent Trust Level Input File, since there are three trust levels, high, medium, and low. Thus, this file contains 3 numbers 20, 15 and 10, each number represent high trust level, medium trust level and low trust level, respectively. During each green light phase, the system will randomly choose one number from each file to calculate volunteer agent's value.

The output of the system is a variable called GreenTime, which indicates how long the green traffic light will glow on next traffic light cycle. Membership function for output is shown in Fig 6.

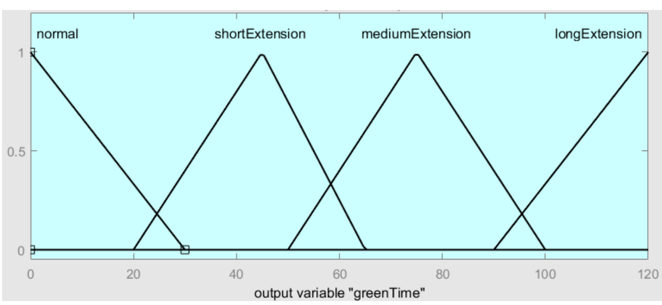

Fig. 6 Membership function for green time.

In the above figure, X-axis indicates the duration of the next green light phase, which is measured in seconds, maximum duration is 120 seconds.

B. Fuzzy Inference Engine

This section explains how fuzzy rules are derived. Fuzzy inference engine consists of a group of rules. There are 3 input parameters in this paper, both traffic saturation and traffic status from volunteer agent have 4 membership functions, so they both have 4 possible values: normal, minor congestion, medium congestion, and severe congestion. The other input, queue length, has 3 membership functions, so it has 3 possible values: normal, minor congestion and severe congestion. Therefore, there are 4*4*3=48 rules in total.

First, since all the inputs have the same weight, and order of inputs does not matter, thus, 48 rules can be classified into 19 different patterns, each pattern is assigned with an output value as shown in Table 1. This table is then used to identify output for each rule.

Table 1. Classification of fuzzy rules

Pattern Number	Input Value	Output
1.	3 normal	Normal
2.	3 minors	Short extension
3.	3 severe	Long extension
4.	2 normal, 1 minor	Normal
5.	2 normal, 1 medium	Short extension
6.	2 normal, 1 severe	Short extension
7.	2 minors, 1 normal	Short extension
8.	2 minors, 1 medium	Medium extension
9.	2 minors, 1 severe	Medium extension
10.	2 mediums, 1 normal	Short extension
11.	2 mediums, 1 minor	Medium extension
12.	2 mediums, 1 severe	Medium extension
13.	2 severe, 1 normal	Long extension
14.	2 severe, 1 minor	Long extension
15.	2 severe, 1 medium	Long extension
16.	1 normal, 1minor, 1 medium	Short extension
17.	1 normal, 1minor, 1 severe	Medium extension
18.	1 normal, 1 medium, 1 severe	Medium extension
19.	1 minor, 1 medium, 1 severe	Medium extension

IV. Implementation and Initial Results

Our implemented adaptive traffic light system consists of a main class, a fuzzy inference system, an interface file, a get input class and 4 input files. Main class controls traffic light cycles and retrieves input data from input files by using data retrieving method in getInput class, and feed data, which are traffic saturation, queue length and traffic status from volunteer agent, into fuzzy inference system, fuzzy inference system will return an output which is green time, then main class will update user interface according to green time. Fig 7 shows internal design of the whole system.

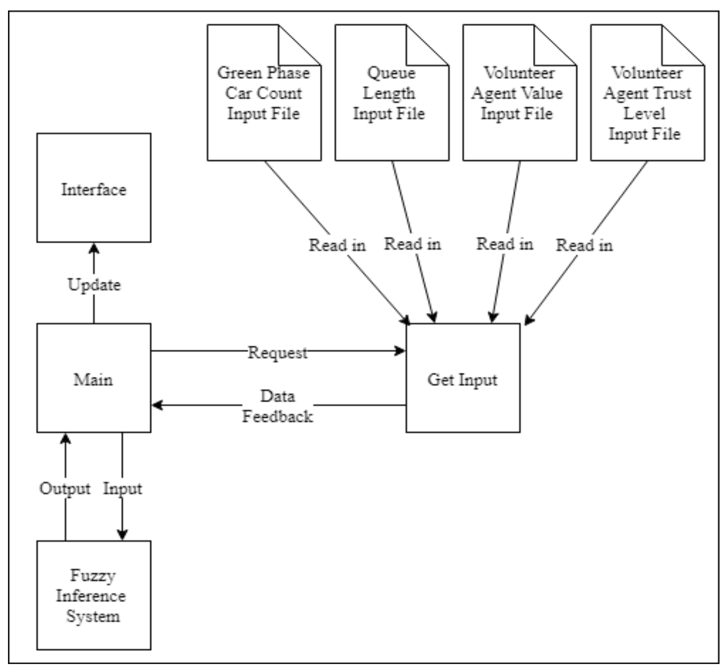

Fig. 7 System internal design

A user interface has also been developed for visualizing purpose. With the help of simulation, people can better understand how the system works and see what is happening right now.

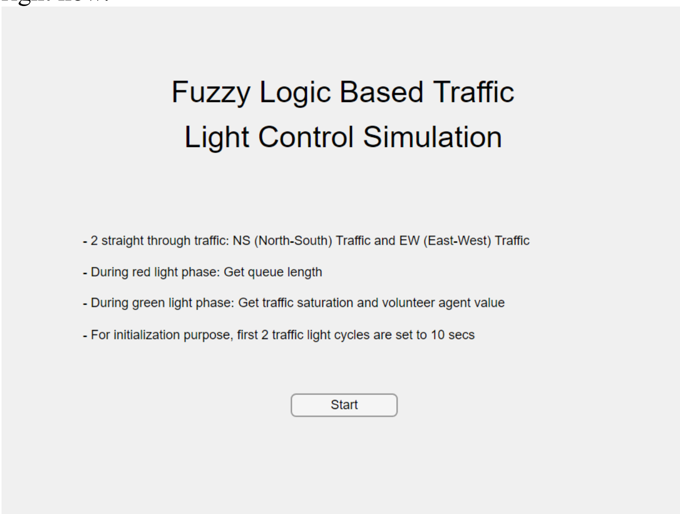

Fig. 8 Starting screen of the external design.

Fig 8 is the starting screen of the paper, it is the main entrance of the program, starting screen shows the method's title and some explanations about the proposed technique and its parameter settings. When the Start button is clicked, the callback function of the Start button will be invoked, new simulation screen will be showing, and the system will start running.

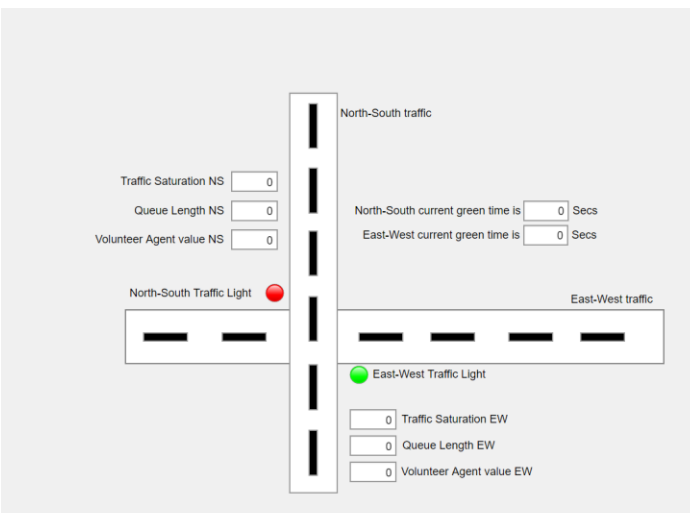

Fig. 9 Simulation screen before program running.

Fig 9 is the simulation screen before the program starts running, there are two traffic direction, North-South traffic, and East-West traffic. Each traffic direction has its own traffic light, which are North-South Traffic Light and East-West Traffic Light. Traffic Saturation NS/EW, Queue Length NS/EW, and Volunteer Agent Value NS/EW text boxes are used to display values of input data. Duration of the current traffic light is displayed on the top right.

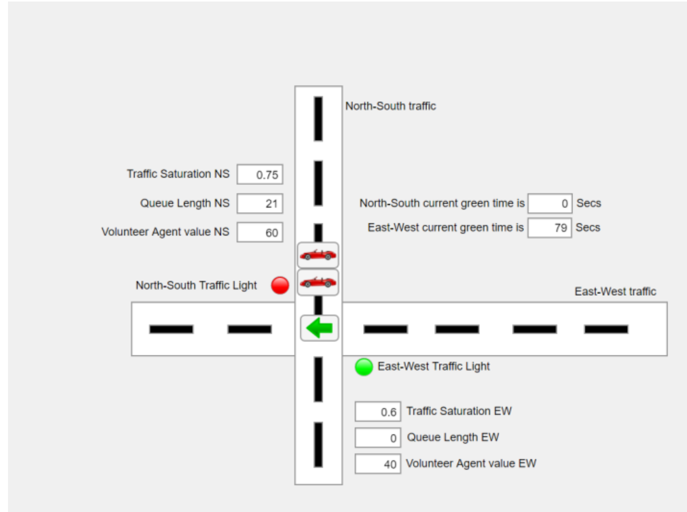

Fig. 10 Simulation screen with pre-threshold sensor has triggered.

Fig 10 shows what will the simulation screen look like after the program is running and the pre-threshold sensor is triggered. A green arrow is showing to indicate the current green light direction, which is East-West traffic, so the duration of East-West green light is displayed on the top right, this duration is calculated based on Traffic Saturation EW, Queue Length EW, and Volunteer Agent Value EW, however, since currently East-West direction is green light, thus, Queue Length EW is set to zero.

In order to quantitatively evaluate the testing result, the Highway Capacity Manual 2010 [9] is used as a comparison, HCM 2010 is a publication of the Transportation Research Board of the National Academies of Science in the United State, which has categorized signalized intersections to different Level of Service (LOS) by control Delay. LOS and control delay defined in this manual is summarized in Table 2 (Highway capacity manual 2010, 2010). Control delay is the result of a control signal causes vehicles to reduce speed or to stop, the inherent concept of control delay is the same as waiting time. Therefore, control delay is used as a comparison with average waiting time.

Table 2. LOS criteria for signalized intersections

Level of Service (LOS)	Control Delay Per vehicle (s/veh)
A	≤10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

V. CONCLUSION

In this paper, a fuzzy logic based adaptive traffic light system is proposed, the signalized traffic model and fuzzy traffic controller have been developed using MATLAB software. The best of our knowledge, this was the first-time volunteer agent concept was integrated into a fuzzy based inference system for managing smart traffic light system based on IoT networks. The effectiveness of the proposed method has been tested by running the system for a long time. Overall, the result of the testing shown that the system has a good performance, therefore, it is feasible and effective to use such adaptive traffic light system at a traffic junction in the smart cities.

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