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A New Traffic Light Controller Using Fuzzy Logic for a Full Single Junction Involving Emergency Vehicle Preemption

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Abstract

Fuzzy argument has become a considerable intelligent control approach for traffic operation. This paper's contribution is to present a new fuzzy signal control system for control of a full single junction involving emergency vehicle preemption. This study not only presents a novel fuzzy control system but also simultaneously considers either emergency vehicle preemption or control of a full junction with turning movements. The proposed control system includes two main functions: fuzzy phase selector and fuzzy green phase extender. The first one specifies the next green phase and function of green extender controller makes the decision whether to extend or terminate the current green phase. Performance of the proposed system is evaluated by using simulation. Finally, the proposed control system is compared with pre-timed control system and simulation results show significant improvement over pre-timed control strategy.

Keywords: fuzzy control system, emergency vehicle preemption, full single junction, fuzzy argument

1 Introduction

As the number of vehicles and the needs for greater transportation has grown in recent years, city streets and highways frequently face serious road traffic congestion problems.

Generally, traffic signal controls are implemented with pre-timed or actuated control. In a pre-timed controller (PTC) type (conventional), green/red phase for each traffic signal cycle is constant. Although this operation mode is simple, its performance is generally poor for heavy traffic. An actuated controller computes phase durations based on real-time traffic demand obtained from the detection of passing and stopping traffic on all lanes leading into an intersection.

Traffic flow is usually characterized by randomness and uncertainty, thus designing an intelligent controller instead of a pre-timed traffic light control system can be a sensible alternative. Fuzzy logic is known to be suited for modeling and control in such problems. Zadeh [20] introduced this concept called fuzzy logic; this technique has been successfully applied to solve many engineering problems. Rahman and Ratrout [16] provided an overview of the applications of fuzzy logic in traffic engineering. They illustrated the evolution of fuzzy-logic based traffic signal control and they also addressed the prospect of using this kind of traffic signal control in Saudi Arabia.

There are number of literatures applying set theory in the traffic signal control. The most famous and pioneering one was proposed by Pappis and Mamdani [14]. They built a good model for a two way traffic junction where each way has a single lane of traffic flow. Their model used vehicle loop detectors, which were placed upstream of the intersection on each approach, to measure approach flows and estimate queues. These data were used to decide, at regular time intervals, whether to extend or terminate the current signal phase. Teodorovic [17] extensively worked on the application of fuzzy logic in modeling traffic and transportation processes and found out that fuzzy set theory and fuzzy logic present a promising mathematical approach to model complex traffic and transportation processes which are usually subjective, ambiguous, uncertain, and imprecise in nature. The controller of a pedestrian crossing signal was studied by Niittymaki and Kikuchi [11].

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Bingham [3] used the same intersection configuration as in the Pappis and Mamdani [14] simulation. In her study, the parameters of a Mamdani type fuzzy traffic signal controller were determined by reinforcement learning algorithm based on simulation environment. The objective was to minimize vehicular delay. She found that the proposed fuzzy controller exhibited successful performance at constant traffic volumes. Niittymaki and Pursula [12] simulated an isolated intersection. They reported that fuzzy logic controller lead to shorter vehicle delay and lower stops percent.

Zaied and Al Othman [21] developed a fuzzy logic traffic system that considered the two two-way intersections and was able to adjust changes in time intervals of a traffic signal based on traffic situation level. They applied and tested their system using real data collected from signalized intersection in Hawalli governorate in the State of Kuwait. They observed that the proposed system implementation found to be useful in reducing vehicle delay and saving time compared to the existing system. Trabia et al. [18] presented the design and evaluation of a fuzzy logic traffic signal controller for an isolated intersection. They designed this controller to be responsive to real-time traffic demands. They compared the performance of this controller to that of a traffic-actuated controller for different traffic conditions on a simulated four-approach intersection. Their controller produced lower vehicle delays than the traffic-actuated controller.

Wong and Woon [19] presented a refinement of the method which is based on iteratively re-estimating the Time-Of-Day (TOD) intervals. They conducted experiments to test the usefulness of their method. Angulo et al. [1] presented a methodology for adaptive control of traffic light intersections with monitoring technologies. They used Fuzzy Logic based techniques to represent the prototypes in their prediction model. In Jian et al. [7] a two-stage fuzzy logic control model for an isolated signalized intersection is proposed, where both traffic efficiency and fairness are considered simultaneously. Niittymäki and Turunen [13] introduced a new fuzzy IF–THEN control algorithm. The algorithm was seeking for the most similar IF-part to the actual input value, and the corresponding THEN-part is then fired. They concluded that similarity-based inference systems offer a competitive method for control in traffic signal design. Niittymäki [10] described the installation of a fuzzy signal controller (FSC) at a real intersection. His results proved that the FSC can be installed in a real infrastructure and the fuzzy algorithm can be more effective than traditional vehicle-actuated control. Quek et al. [15] described the application of a specific class of neuro-fuzzy system known as the Pseudo Outer-Product Fuzzy-Neural Network using Truth-Value-Restriction method (POPFNN-TVR) for modelling traffic behavior.

Kosonen [8] presented a traffic signal control system based on real-time simulation, multi-agent control scheme, and fuzzy inference. In his control technique, each signal operates individually as an agent, negotiating with other signals about the control strategy, and the decision making of the agents is based on fuzzy inference that allows a combination of various aspects like fluency, economy, environment and safety. Murat and Gedizlioglu [9] presented Mamdani structured fuzzy signal control model comprised of a fuzzy phase green duration model and fuzzy phase sequence model. They compared their models using simulations for an isolated four-armed intersection. They used triangular memberships function for inputs and output. Zarandi and Rezapour [22] proposed a new fuzzy control system for signal control of incomplete intersection with two-way streets and left-turn lanes, which made decision based on the fuzzy rules and real time traffic information.

Chou and Teng [5] presented a fuzzy logic based traffic junction signal controller (FTJSC). In order to design a more practical controller, they simulated an environment that meets the traffic situations more than ever. Their experimental results confirm the performance of the proposed FTJSC. Barzegar et al. [2] studied a hybrid adaptive model, based on a combination of colored Petri nets, fuzzy logic and learning automata, to efficiently control traffic signals. They showed that in comparison with results found in the literature, vehicle delay time is significantly reduced using their method.

Fan and Liu [6] presented a fifth layered neuro-fuzzy phase sequence-changeable controller for a single intersection. They used back-propagation to train the controller with pre-determined training samples. They concluded that their control method could significantly reduce the average delay of vehicles based on simulation results they obtained. Chong et al. [4] investigated performances of four different neuro-fuzzy architectures for traffic lights control at an isolated four-arm simple traffic intersection based on Green Light District (GLD) traffic light simulation software.

The reviewed researches generally concluded a better performance of fuzzy logic controllers compared to pre-timed and actuated controllers. However, most of the researches considered either one-way streets or intersections without turning movements, and they did not consider emergency vehicle preemption. Moreover, fuzzy rules were determined mainly by traffic conditions on the subject approaches without taking into account the traffic conditions on competing approaches and the phase sequence they chose are in most situations fixed. Furthermore in reviewed researches, authors usually did not consider a full intersection for their model implementation. This paper presents a new fuzzy traffic signal control which includes two main rule-base functions: fuzzy phase selector and fuzzy green phase extender. The first one specifies the next green phase and function of green extender controller makes the decision whether to extend or terminate the current green phase. To the best knowledge of the authors, not only the presented signal control system's structure is a novel one but also no previous research has simultaneously considered either emergency vehicle preemption or control of a full junction with turning movements by such fuzzy control system. This paper proposes a newly changeable phase-sequences signal control method and its performance is evaluated by simulation. This paper is organized as follows: Section 2 presents two functions of fuzzy signal control system (FSCS), fuzzy green extender function and fuzzy phase selector function. In Section 3, the performance of this new controller is evaluated by simulations. Section 4 presents our results.

2 Proposed Fuzzy Control System

Figure 1 presents the proposed fuzzy control system. As it can be seen, fuzzy phase selector function and fuzzy green phase extender function are located in different levels of the multi-level signal control system. The green extender function is working on the green extension decision, while the phase selector function works concern with the sequence level of the signal control system. This signal control system's structure is shown in Figure 1.

We define parameter T_{MAXG} to prevent the excessive green phase prolonged also we define parameter T_{MAXRi} to prevent the excessive red phase prolonged for each lane with red. Two control parameters which are used in this algorithm are:

$$T_{MAXG} = maximum\ green\ time\ for\ each\ phase, in\ sec.$$
$$T_{MAXRi} = maximum\ red\ time\ for\ red\ phase\ i, in\ sec.\ (T_{MAXG} < T_{MAXRi}).$$

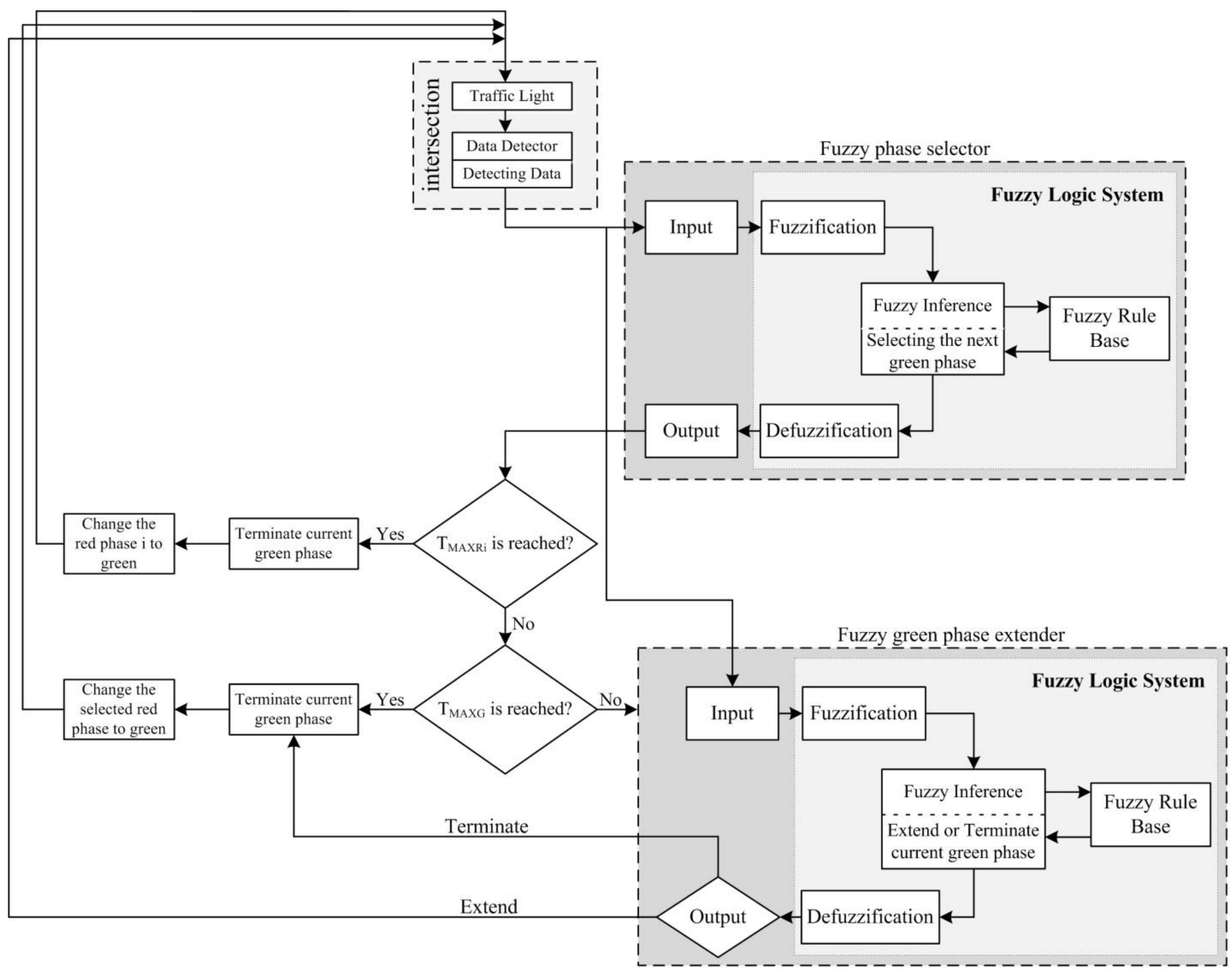

Figure 1: Fuzzy traffic signal control structure

The procedure of signal control system is as follows.

Step 1: System gets the necessary data from the detectors of junction.

Step 2: Specifies that which of the current red phases should switch to green in the next phase (fuzzy phase selector function).

Step 3: Checking T_{MAXRi}

Step 3.1: If T_{MAXRi} is reached, then terminates the current green phase and switches the red phase i to green and goes to Step 1.

Step 3.2: If T_{MAXRi} is not reached, then goes to Step 3.

Step 4: Checking T_{MAXG}

Step 4.1: If T_{MAXG} is reached, then terminates the current green phase and switches the selected red phase (in Step 2) to green and goes to Step 1.

Step 4.2: If T_{MAXG} is not reached, then goes to Step 5.

Step 5: Specifies whether current green phase should extend or terminate (fuzzy green phase extender function).

Step 5.1: If the current green phase should terminate, then terminates the current green phase and switches the selected red phase (in Step 2) to green and goes to Step 1.

Step 5.2: If current green phase should extend, then goes to Step 1.

2.1 Fuzzy Phase Selector Function

In order to determining the most suitable phase order for the traffic conditions, the phase selector function, which is a rule-base function, chooses the next green phase. Figure 2 presents the phases of the simulated junction, in which the control function is tested and the layout of this junction is illustrated in Figure 3.

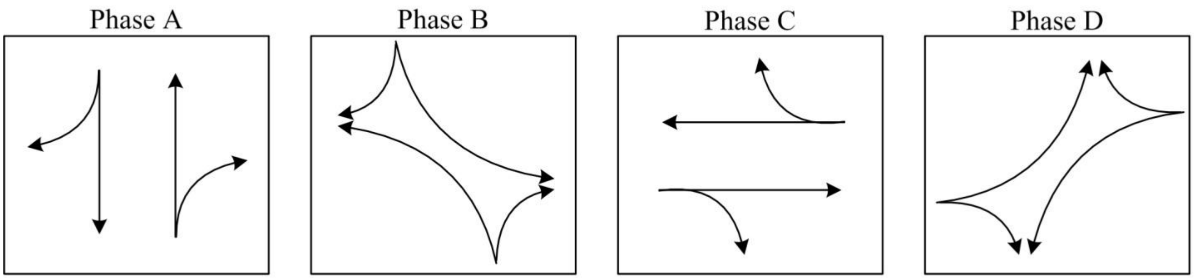

Figure 2: Phases of four-phase signal

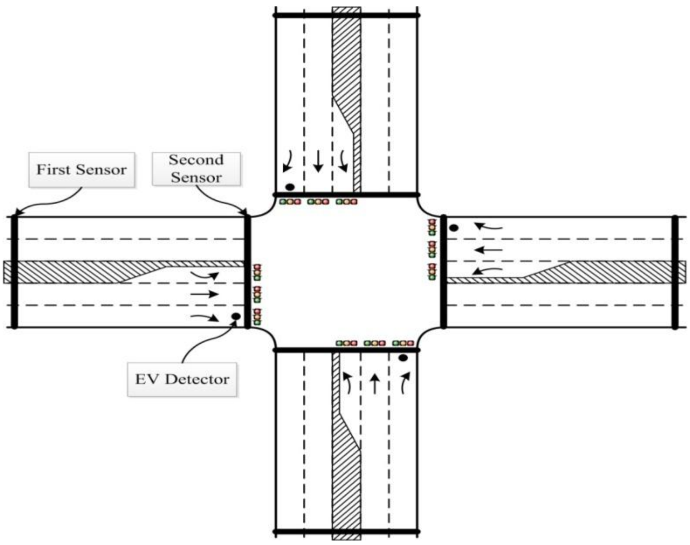

Figure 3: Simulated junction geometry

Decision making in this fuzzy control system is based on weights W (p_i) of each phase p_i =A, B, C, D. The weights usually define by the total waiting time of the vehicles, or by the number of queuing vehicles waiting for the green signal in each red phase. In this paper the number of queuing vehicles is used for defining weights. The designed rules give priority to the phase with highest demand for green time. If the current green phase A is to be terminated, the phase selector decides whether to launch next the phase B or C or D.

For example, if the phase A is terminated, fuzzy rules which perform the phase selection of B or C or D are presented in Table 1. If the phases B, C, or D are terminated, the phase selection rules are similar to presented rules.

The set of control parameters is:

$$QC = Average\ queue\ length\ on\ the\ lanes\ served\ by\ the\ current\ green, in\ veh/lane;$$
$$QN = Average\ queue\ length\ on\ lane\ i\ with\ red\ which\ may\ receive\ green\ in\ the\ next\ phase, in\ veh/lane;$$
$$AR = Average\ arrival\ rate\ on\ lanes\ with\ the\ current\ green, in\ veh/sec/lane.$$

$$\begin{cases} E_A = 1 & \text{if EV appears in phase A lanes} \\ E_A = 0 & \text{otherwise;} \end{cases}$$

$$\begin{cases} E_B = 1 & \text{if EV appears in phase B lanes} \\ E_B = 0 & \text{otherwise;} \end{cases}$$

$$\begin{cases} E_C = 1 & \text{if EV appears in phase C lanes} \\ E_C = 0 & \text{otherwise;} \end{cases}$$

$$\begin{cases} E_D = 1 & \text{if EV appears in phase D lanes} \\ E_D = 0 & \text{otherwise.} \end{cases}$$

These rules were proposed by traffic experts and for each case in real world can be different. The rule editor of the fuzzy rules phase selector A or B or C is shown in Figure 4.

For example, the third line of Table 1 can be expressed as:

IF *Average queue length on lane D with red is medium AND*
Average queue length on lane C with red is very long AND
Average queue length on lane B with red is very long
THEN *lane C is chosen as next green phase*

Table 1：Fuzzy rules of phase selector B or C or D

	Queue length		Queue length		Queue length		Chosen phase
IF	QN_D = very long	AND	QN_C = very long	AND	QN_B = very long	THEN	C
IF	QN_D = long	AND	QN_C = very long	AND	QN_B = very long	THEN	C
IF	QN_D = medium	AND	QN_C = very long	AND	QN_B = very long	THEN	C
IF	QN_D = short	AND	QN_C = very long	AND	QN_B = very long	THEN	C
IF	QN_D = very long	AND	QN_C = long	AND	QN_B = very long	THEN	D
IF	QN_D = long	AND	QN_C = long	AND	QN_B = very long	THEN	B
IF	QN_D = medium	AND	QN_C = long	AND	QN_B = very long	THEN	B
IF	QN_D = short	AND	QN_C = long	AND	QN_B = very long	THEN	B
IF	QN_D = very long	AND	QN_C = medium	AND	QN_B = very long	THEN	D
IF	QN_D = long	AND	QN_C = medium	AND	QN_B = very long	THEN	B
IF	QN_D = medium	AND	QN_C = medium	AND	QN_B = very long	THEN	B
IF	QN_D = short	AND	QN_C = medium	AND	QN_B = very long	THEN	B
IF	QN_D = very long	AND	QN_C = short	AND	QN_B = very long	THEN	D
IF	QN_D = long	AND	QN_C = short	AND	QN_B = very long	THEN	B
IF	QN_D = medium	AND	QN_C = short	AND	QN_B = very long	THEN	B
IF	QN_D = short	AND	QN_C = short	AND	QN_B = very long	THEN	B
IF	QN_D = very long	AND	QN_C = very long	AND	QN_B = long	THEN	C
IF	QN_D = long	AND	QN_C = very long	AND	QN_B = long	THEN	C
IF	QN_D = medium	AND	QN_C = very long	AND	QN_B = long	THEN	C
IF	QN_D = short	AND	QN_C = very long	AND	QN_B = long	THEN	C
IF	QN_D = very long	AND	QN_C = long	AND	QN_B = long	THEN	D

IF	QN_D = long	AND	QN_C = long	AND	QN_B = long	THEN	C
IF	QN_D = medium	AND	QN_C = long	AND	QN_B = long	THEN	C
IF	QN_D = short	AND	QN_C = long	AND	QN_B = long	THEN	C
IF	QN_D = very long	AND	QN_C = medium	AND	QN_B = long	THEN	D
IF	QN_D = long	AND	QN_C = medium	AND	QN_B = long	THEN	D
IF	QN_D = medium	AND	QN_C = medium	AND	QN_B = long	THEN	B
IF	QN_D = short	AND	QN_C = medium	AND	QN_B = long	THEN	B
IF	QN_D = very long	AND	QN_C = short	AND	QN_B = long	THEN	D
IF	QN_D = long	AND	QN_C = short	AND	QN_B = long	THEN	D
IF	QN_D = medium	AND	QN_C = short	AND	QN_B = long	THEN	B
IF	QN_D = short	AND	QN_C = short	AND	QN_B = long	THEN	B
IF	QN_D = very long	AND	QN_C = very long	AND	QN_B = medium	THEN	C
IF	QN_D = long	AND	QN_C = very long	AND	QN_B = medium	THEN	C
IF	QN_D = medium	AND	QN_C = very long	AND	QN_B = medium	THEN	C
IF	QN_D = short	AND	QN_C = very long	AND	QN_B = medium	THEN	C
IF	QN_D = very long	AND	QN_C = long	AND	QN_B = medium	THEN	D
IF	QN_D = long	AND	QN_C = long	AND	QN_B = medium	THEN	C
IF	QN_D = medium	AND	QN_C = long	AND	QN_B = medium	THEN	C
IF	QN_D = short	AND	QN_C = long	AND	QN_B = medium	THEN	C
IF	QN_D = very long	AND	QN_C = medium	AND	QN_B = medium	THEN	D
IF	QN_D = long	AND	QN_C = medium	AND	QN_B = medium	THEN	D
IF	QN_D = medium	AND	QN_C = medium	AND	QN_B = medium	THEN	C
IF	QN_D = short	AND	QN_C = medium	AND	QN_B = medium	THEN	C
IF	QN_D = very long	AND	QN_C = short	AND	QN_B = medium	THEN	D
IF	QN_D = long	AND	QN_C = short	AND	QN_B = medium	THEN	D
IF	QN_D = medium	AND	QN_C = short	AND	QN_B = medium	THEN	D
IF	QN_D = short	AND	QN_C = short	AND	QN_B = medium	THEN	B
IF	QN_D = very long	AND	QN_C = very long	AND	QN_B = short	THEN	C
IF	QN_D = long	AND	QN_C = very long	AND	QN_B = short	THEN	C
IF	QN_D = medium	AND	QN_C = very long	AND	QN_B = short	THEN	C
IF	QN_D = short	AND	QN_C = very long	AND	QN_B = short	THEN	C
IF	QN_D = very long	AND	QN_C = long	AND	QN_B = short	THEN	D
IF	QN_D = long	AND	QN_C = long	AND	QN_B = short	THEN	C
IF	QN_D = medium	AND	QN_C = long	AND	QN_B = short	THEN	C
IF	QN_D = short	AND	QN_C = long	AND	QN_B = short	THEN	C
IF	QN_D = very long	AND	QN_C = medium	AND	QN_B = short	THEN	D
IF	QN_D = long	AND	QN_C = medium	AND	QN_B = short	THEN	D
IF	QN_D = medium	AND	QN_C = medium	AND	QN_B = short	THEN	C
IF	QN_D = short	AND	QN_C = medium	AND	QN_B = short	THEN	C
IF	QN_D = very long	AND	QN_C = short	AND	QN_B = short	THEN	D
IF	QN_D = long	AND	QN_C = short	AND	QN_B = short	THEN	D
IF	QN_D = medium	AND	QN_C = short	AND	QN_B = short	THEN	D
IF	QN_D = short	AND	QN_C = short	AND	QN_B = short	THEN	C
IF	$E_C = 1$					THEN	C
IF	$E_B = 1$					THEN	B
IF	$E_D = 1$					THEN	D

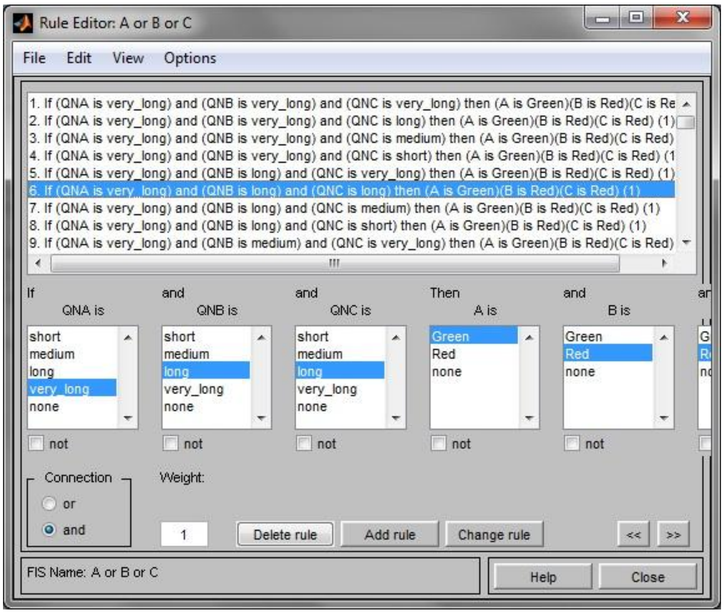

Figure 4: The rule editor of the fuzzy rules phase selector A or B or C

2.2 Fuzzy Green Extender Function

This signal control is a process for specifying whether to extend or terminate the current green phase based on a set of fuzzy rules. The fuzzy rules decide whether to extend or terminate the current green phase by comparing traffic conditions with the current green phase and traffic conditions with the next candidate green phase. The other set of control parameters which are used in this function is:

$$\begin{cases} E_g = 1 & \text{if EV appears in green phase lanes} \\ E_g = 0 & \text{otherwise;} \end{cases}$$

$$\begin{cases} E_r = 1 & \text{if EV appears in red phase lanes} \\ E_r = 0 & \text{otherwise;} \end{cases}$$

$$T_{MIN} = \textit{minimum green time for each phase, in sec.}$$

In this paper we assume that arrival rate of emergency vehicles is 2 percent of times and they enter the system accidentally. Assume that phase A is green at start time, it is necessary to note that it's a changeable assumption; the phase selector selects the next green phase. After a minimum green time of T_{MIN} which has been displayed, T_{MAXRi} will be checked. If it has been reached, then the current green phase will be terminated and control system changes the red phase i to green, otherwise, T_{MAXG} will be checked. If it has been reached, then the current green phase will be terminated and control system changes the selected red phase to green, otherwise, the fuzzy green extender function determines whether to extend or terminate the current green phase. If it decides to terminate the current phase, control system will terminate the current green phase. If not, the current green phase will be extended and after a time interval Δt, data will input from traffic light detectors to fuzzy logic system and the fuzzy phase selector will select the next green phase again. The interval Δt may vary from 0.1 to 10 second, depending on the controller processor's speed. In this study, we choose Δt = 5 second.

The parameters QC, QN and AR are characterized by trapezoidal fuzzy numbers depicted in Figures 5 and 6.

The decision making process is based on a set of fuzzy rules in Table 2, where E is short for Extension, and T is short or Terminate. For example, the second line of Table 4 can be expressed as:

IF *Average queue length on lanes with green is short AND*
Average traffic volume on lanes with green is low AND
Average queue length on lanes with red is medium
THEN *Terminate the current green phase*

The max-min composition method is applied for making inferences. The membership grades for E (Extend) and T (Terminate) are compared. The one with the highest membership grade is chosen as the control action.

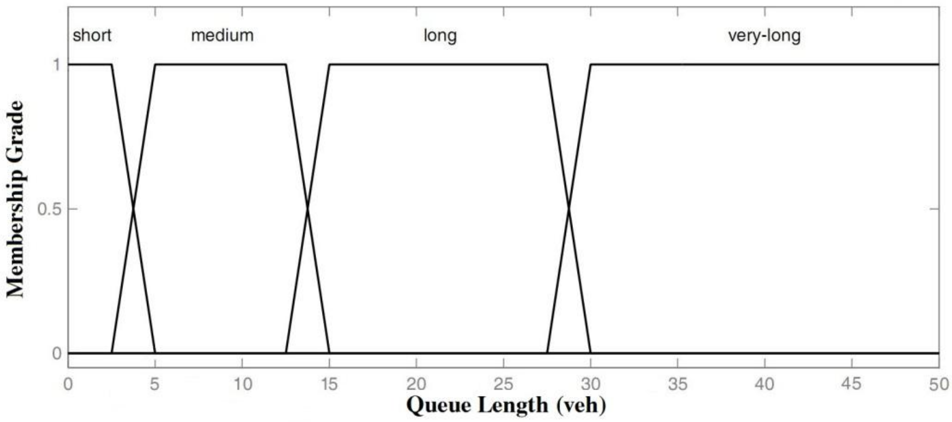

Figure 5: Fuzzy membership functions for QC and QN

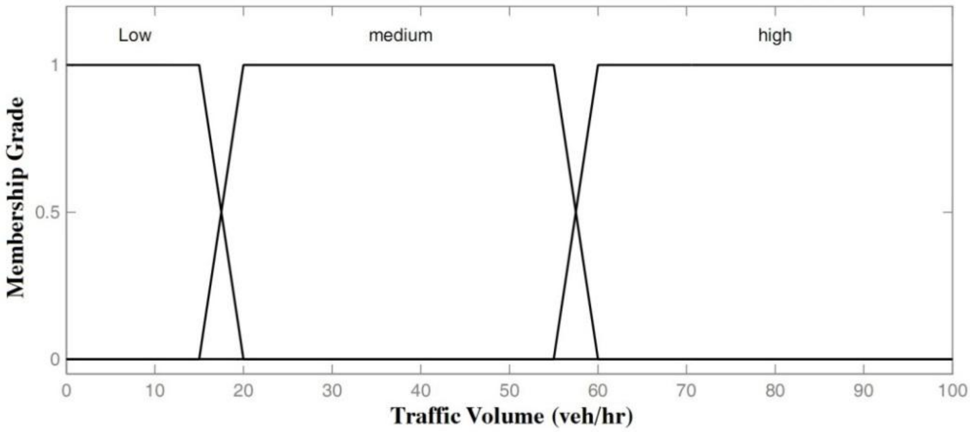

Figure 6: Fuzzy membership functions for TV

Table 2: Fuzzy rules of green extender

	Queue length		Arrival rate		Queue length		T or E
IF	QN is short	AND	AR is low	AND	QC is short	THEN	T
IF	QN is medium	AND	AR is low	AND	QC is short	THEN	T
IF	QN is long	AND	AR is low	AND	QC is short	THEN	T
IF	QN is very long	AND	AR is low	AND	QC is short	THEN	T
IF	QN is short	AND	AR is medium	AND	QC is short	THEN	E
IF	QN is medium	AND	AR is medium	AND	QC is short	THEN	T
IF	QN is long	AND	AR is medium	AND	QC is short	THEN	T
IF	QN is very long	AND	AR is medium	AND	QC is short	THEN	T
IF	QN is short	AND	AR is high	AND	QC is short	THEN	E
IF	QN is medium	AND	AR is high	AND	QC is short	THEN	E
IF	QN is long	AND	AR is high	AND	QC is short	THEN	T
IF	QN is very long	AND	AR is high	AND	QC is short	THEN	T
IF	QN is short	AND	AR is low	AND	QC is medium	THEN	E
IF	QN is medium	AND	AR is low	AND	QC is medium	THEN	T
IF	QN is long	AND	AR is low	AND	QC is medium	THEN	T
IF	QN is very long	AND	AR is low	AND	QC is medium	THEN	T
IF	QN is short	AND	AR is medium	AND	QC is medium	THEN	E
IF	QN is medium	AND	AR is medium	AND	QC is medium	THEN	T
IF	QN is long	AND	AR is medium	AND	QC is medium	THEN	T
IF	QN is very long	AND	AR is medium	AND	QC is medium	THEN	T
IF	QN is short	AND	AR is high	AND	QC is medium	THEN	E

IF	QN is medium	AND	AR is high	AND	QC is medium	THEN	E
IF	QN is long	AND	AR is high	AND	QC is medium	THEN	E
IF	QN is very long	AND	AR is high	AND	QC is medium	THEN	T
IF	QN is short	AND	AR is low	AND	QC is long	THEN	E
IF	QN is medium	AND	AR is low	AND	QC is long	THEN	E
IF	QN is long	AND	AR is low	AND	QC is long	THEN	T
IF	QN is very long	AND	AR is low	AND	QC is long	THEN	T
IF	QN is short	AND	AR is medium	AND	QC is long	THEN	E
IF	QN is medium	AND	AR is medium	AND	QC is long	THEN	E
IF	QN is long	AND	AR is medium	AND	QC is long	THEN	E
IF	QN is very long	AND	AR is medium	AND	QC is long	THEN	T
IF	QN is short	AND	AR is high	AND	QC is long	THEN	E
IF	QN is medium	AND	AR is high	AND	QC is long	THEN	E
IF	QN is long	AND	AR is high	AND	QC is long	THEN	E
IF	QN is very long	AND	AR is high	AND	QC is long	THEN	T
IF	QN is short	AND	AR is low	AND	QC is very long	THEN	E
IF	QN is medium	AND	AR is low	AND	QC is very long	THEN	E
IF	QN is long	AND	AR is low	AND	QC is very long	THEN	E
IF	QN is very long	AND	AR is low	AND	QC is very long	THEN	E
IF	QN is short	AND	AR is medium	AND	QC is very long	THEN	E
IF	QN is medium	AND	AR is medium	AND	QC is very long	THEN	E
IF	QN is long	AND	AR is medium	AND	QC is very long	THEN	E
IF	QN is very long	AND	AR is medium	AND	QC is very long	THEN	T
IF	QN is short	AND	AR is high	AND	QC is very long	THEN	E
IF	QN is medium	AND	AR is high	AND	QC is very long	THEN	E
IF	QN is long	AND	AR is high	AND	QC is very long	THEN	E
IF	QN is very long	AND	AR is high	AND	QC is very long	THEN	E
IF	Eg = 1					THEN	E
IF	Er = 1					THEN	T

3 Simulation Results

Performance of the fuzzy logic controller is evaluated by comparing it with one of the existing methods. We choose the pre-timed control method in order to The average values of delays and length of queues is used as criteria in order to make comparisons between the fuzzy logic and pre-time controllers. The best control strategy is the one that provides the lowest delay and the shortest average queue length. In this paper, average delays are calculated by using the weighted average method, considering the traffic volumes on the lanes.

The traffic volume and number of vehicles in each lane are determined by detectors at the upstream and stop-lines of lane which are shown in the geometry of this intersection in Figure 3. Simulation have been performed two times, in first simulation, traffic volumes for each phase are approximately close to each other, and they increasingly change from 0 to 6000 vehicle per hour. In this case, as is shown in Table 3 and Figures 7 & 8, simulation results illustrate that the fuzzy logic controller perform better than pre-timed control strategy in terms of average values of delays and queue length. As the Figure 9 shows, the fuzzy logic controller lead to an average of about 69% reduction in queue length compared to the pre-timed controller and as the traffic volume increases, the improvement percentage increases too. Also the fuzzy logic controller can reduce the average delays between 57% and 67% compare to the pre-timed controller. In the second simulation, traffic volumes for each phase are significantly different from each other. As it can be seen in Table 4, fuzzy logic controller can perform better than pre-timed controller in terms of either queue length or average delays even when traffic volumes of each phase are significantly different from each other; Figures 10 and 11 illustrate the fuzzy logic controller's more performance schematically.

In this case, as is shown in Figure 12, the fuzzy logic controller lead to between 68.5% and 70% reduction in queue length compared to the pre-timed controller. Also the fuzzy logic controller can reduce the average delays between 65% and 68% compare to the pre-timed controller.

Each simulation is run by MATLAB software for 30 minutes. The vehicle numbers between the upstream detector and stop-line detector are considered as the vehicle queue lengths of each lane. Arrivals of the emergency vehicles will be recognized by detectors which are installed both at intersection and on EVs.

It is necessary to note that TMIN, TMAXG and TMAXRi in our simulations are equal to 5, 30 and 60 seconds, respectively.

Table 3: Simulation results for close traffic volumes

Range of arrival rates (veh/hr)	Phase	Average of arrival rate (veh/hr)	Average queue length get by PTC	Average queue length get by FSCS	Average delays get by PTC (sec/veh)	Average delays get by FSCS (sec/veh)
0-300	A	149.334	0.5894	0.1927	22.5677	9.5019
	B	147				
	C	151.836				
	D	145.5				
300-900	A	630.834	2.3889	0.7794	32.0596	10.2276
	B	593.166				
	C	582.168				
	D	585.666				
900-1800	A	1335	5.4297	1.7607	32.2086	10.2685
	B	1357.5				
	C	1340.502				
	D	1342.332				
1800-2700	A	2239.164	9.0354	2.8860	32.2199	10.3562
	B	2265.498				
	C	2243.664				
	D	2254.002				
2700-3600	A	3148.164	13.1644	4.0596	32.2757	10.3758
	B	3141.834				
	C	3168				
	D	3141.834				
3600-4800	A	4178.502	18.1539	5.4910	32.3621	10.4233
	B	4235.166				
	C	4202.832				
	D	4197.666				
4800-6000	A	5426.832	24.4978	7.2360	32.4461	10.5046
	B	5395.836				
	C	5395.668				
	D	5362.998				

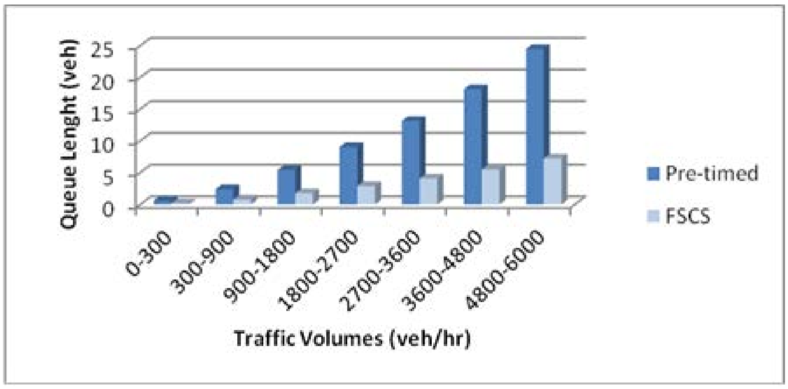

Figure 7: Pre-timed and FSCS queue length for close traffic volume

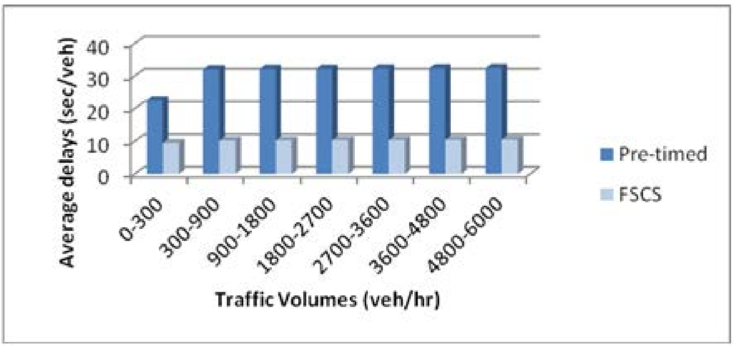

Figure 8: Pre-timed and FSCS delay for close traffic volume

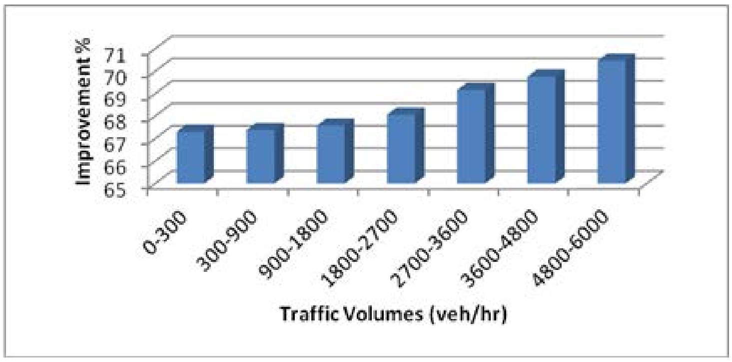

Figure 9: Improvement percentage of queue length for close traffic volume

Table 4: Simulation results for different traffic volumes

Cycle Number	Phase	Average of arrival rate (veh/hr)	Queue length get by PTC		Queue length get by FSCS		Average delays get by PTC (sec/veh)	Average delays get by FSCS (sec/veh)
1	A	313.5	1.2159	7.3939	0.4537	2.2918	30.4908	10.5721
	B	1169.334	4.5346		1.5745			
	C	1798.332	7.2161		2.3407			
	D	3888.168	16.609		4.7983			
2	A	2898	11.6964	6.1051	3.5302	1.9213	31.2988	10.2719
	B	439.668	1.7392		0.5708			
	C	1191	4.8396		1.585			
	D	1517.502	6.1452		1.9992			
3	A	1819.998	7.2066	6.0970	2.4481	1.9019	29.2614	10.253
	B	3328.002	14.0312		4.0087			
	C	623.502	2.5508		0.9234			
	D	152.832	0.5997		0.2274			
4	A	4143.336	18.0571	8.6732	5.3039	2.6529	32.0733	10.2574
	B	2152.5	8.7435		2.8285			
	C	451.998	1.9104		0.631			
	D	1454.502	5.982		1.8482			
5	A	2301.168	9.2985	8.8162	2.9302	2.6845	30.9093	10.456
	B	1483.332	5.599		1.7957			
	C	3999.336	17.269		4.9701			
	D	758.334	3.0983		1.042			
6	A	3929.334	16.9277	10.4117	4.9179	3.1337	32.4572	10.4407
	B	2311.002	9.2307		2.8364			
	C	926.502	3.6659		1.137			
	D	2797.5	11.8226		3.6435			

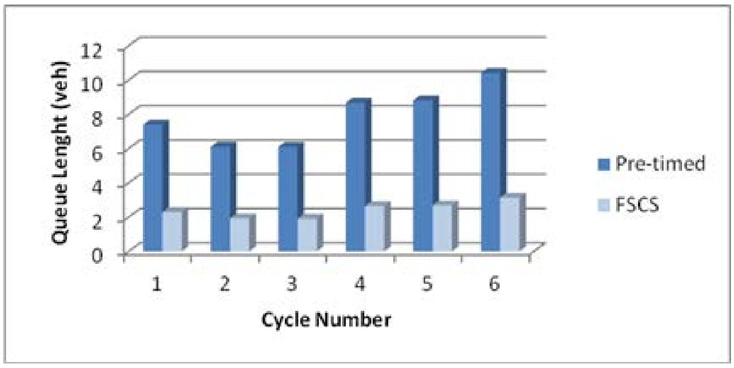

Figure 10: Pre-timed and FSCS queue length for different traffic volume

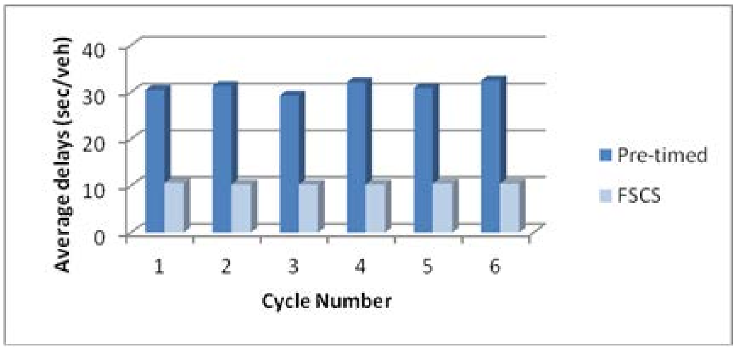

Figure 11: Pre-timed and FSCS delay for different traffic volume

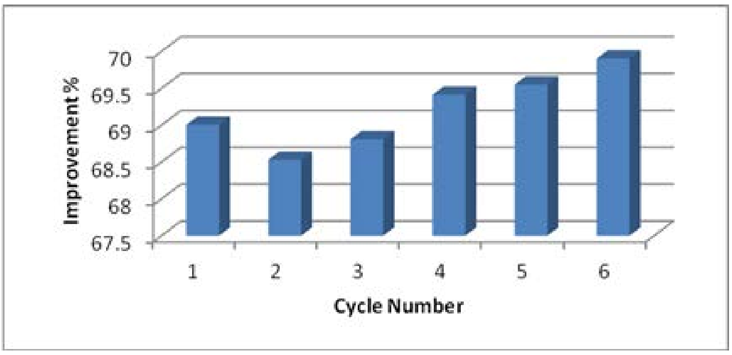

Figure 12: Improvement percentage of queue length different traffic volume

4 Conclusions

Traffic congestion is a real-life problem. To deal with this problem, it is important that the traffic signal controller is realizable. In order to design a more practical controller, we proposed a fuzzy control system for signal control of full intersection involving emergency vehicle preemption with two-way streets and left-turn lanes, which made decision based on the fuzzy rules and real time traffic information. Proposed fuzzy control system contained phase selector and green phase extender, which are located in different levels of the multi-level signal control strategy. The phase selector was working on the sequence level, while the green extender belonged to the green extension of the signal control system.

In the pre-time controller, being an open-loop system, the green time is not extended whatever the density of cars at the junction. In the fuzzy logic controller, the extension time is not a fixed value. The number of cars sensed at the input of the fuzzy controllers is also converted into fuzzy values. In addition to the fuzzy variables as mentioned, the fuzzy controller also has an advantage of performing according to linguistic rules in the manner of how a human would use. The reasoning method in the fuzzy controller is also similar to that of the policeman handling the traffic flow at a typical junction.

A simulation was carried out to compare the performance of the fuzzy logic controller with a fixed-time conventional controller. It can be observed from the results that FSCS controller produces significant improvements in the average delays and queues length over the pre-timed control strategy. Less waiting time not only reduces the fuel consumption but also reduces air and noise pollution.

References

[1] Angulo, E., Romero, F.P., García, R., Serrano-Guerrero, J., and J.A. Olivas, An adaptive approach to enhanced traffic signal optimization by using soft-computing techniques, *Expert Systems with Applications*, vol.38, no.3, pp.2235–2247, 2011.

[2] Barzegar, S., Davoudpour, M., Meybodi, M.R., Sadeghian, A., and M. Tirandazian, Formalized learning automata with adaptive fuzzy coloured Petri net; an application specific to managing traffic signals, *Scientia Iranica*, vol.18, no.3, pp.554–565, 2011.

[3] Bingham, E., Reinforcement learning in neuro fuzzy traffic signal control, *European Journal of Operational Research*, vol.131, no.2, pp.232–241, 2001.

[4] Chong, Y., Quek, C., and P. Loh, A novel neuro-cognitive approach to modeling traffic control and flow based on fuzzy neural techniques, *Expert Systems with Applications*, vol.36, pp.4788–4803, 2009.

[5] Chou, C.H., and J.C. Teng, A fuzzy logic controller for traffic junction signals, *Information Sciences*, vol.143, nos.1-4, pp.73–97, 2002.

[6] Fan, X., and Y. Liu, Alterable-phase fuzzy control based on neural network, *Journal of Transportation Systems Engineering and Information Technology*, vol.8, no.1, pp.80–85, 2008.

[7] Jian, Q., Naiding, Y., and G. Jie, Two-stage fuzzy logic controller for signalized intersection, *IEEE Transactions on Systems Man, and Cybernetics, Part A: Systems and Humans*, vol.41, no.1, pp.178–184, 2011.

[8] Kosonen, L., Multi-agent fuzzy signal control based on real-time simulation, *Transportation Research Part C*, vol.11, no.5, pp.389–403, 2003.

[9] Murat, S.Y., and E. Gedizlioglu, A fuzzy logic multi-phased signal control model for isolated junctions, *Transportation Research Part C: Emerging Technologies*, vol.13, no.1, pp.19–36, 2005.

[10] Niittymäki, J., Installation and experiences of field testing a fuzzy signal controller, *European Journal of Operational Research*, vol.131, no.2, pp.273–281, 2001.

[11] Niittymaki, J., and S. Kikuchi, Application of fuzzy logic to the control of a pedestrian crossing signal, *Transportation Research Record: Journal of the Transportation Research Board*, vol.1651, pp.30–38, 1998.

[12] Niittymaki, J., and M. Pursula, Signal control using fuzzy logic, *Fuzzy Sets and Systems*, vol.116, no.1, pp.11–22, 2000.

[13] Niittymäki, J., and E. Turunen, Traffic signal control on similarity logic reasoning, *Fuzzy Sets and Systems*, vol.133, no.1, pp.109–131, 2003.

[14] Pappis, C.P., and E.H. Mamdani, A fuzzy logic controller for a traffic junction, *IEEE Transactions on Systems, Man, and Cybernetics*, vol.7, no.10, pp.707–717, 1977.

[15] Quek, C., Pasquier, M., and B. Lim, A novel self-organizing fuzzy rule-based system for modelling traffic flow behaviour, *Expert Systems with Applications*, vol.36, no.10, pp.12167–12178, 2009.

[16] Rahman, S.M., and N.T. Ratrout, Review of the fuzzy logic based approach in traffic signal control: prospects in Saudi Arabia, *Journal of Transportation Systems Engineering and Information Technology*, vol.9, no.5, pp.58–70, 2009.

[17] Teodorovic, D., Fuzzy logic systems for transportation engineering: the state of the art, *Transportation Research Part A*, vol.33, no.5, pp.337–364, 1999.

[18] Trabia, M.B., Kaseko, M.S., and M. Ande, A two-stage fuzzy logic controller for traffic signals, *Transportation Research Part C*, vol.7, no.6, pp.353–367, 1999.

[19] Wong, Y.K., and W.L. Woon, An iterative approach to enhanced traffic signal optimization, *Expert Systems with Applications*, vol.34, no.4, pp.2885–2890, 2008.

[20] Zadeh, L.A., Fuzzy sets, *Information and Control*, vol.8, no.3, pp.338–353, 1965.

[21] Zaied, A.N.H., and W. Al Othman, Development of a fuzzy logic traffic system for isolated signalized intersections in the State of Kuwait, *Expert Systems with Applications*, vol.38, no.8, pp.9434–9441, 2011.

[22] Zarandi, M.H.F., and S. Rezapour, A fuzzy signal controller for isolated intersections, *Journal of Uncertain Systems*, vol.3, no.3, pp.174–182, 2009.