

CONTROL OF A FULL JUNCTION INVOLVING EMERGENCY VEHICLE PREEMPTION BY USING FUZZY LOGIC

P.Chandrakala¹, Ranjani B², Dr.S.Arunarani³

Faculty, ¹Prince Shri Venkateshwara Padmavathy Engineering College,

²Prince Dr.K.Vasudevan College of Engineering and Technology, College

³Faculty, Prince Shri Venkateshwara Arts and Science College, Gowriwakkam.

Abstract

Fuzzy argument has become a substantial intelligent control approach for traffic operation. This paper's contribution is to present a replacement fuzzy signal system for control of a full single junction involving emergency vehicle preemption. This study not only presents a completely unique fuzzy system but also simultaneously considers either emergency vehicle preemption or control of a full junction with turning movements. The proposed system includes two main functions: fuzzy phase selector and fuzzy green phase extender. The primary one specifies the following green phase and performance of green extender controller makes the choice whether to increase or terminate this green phase. Performance of the proposed system is evaluated by using simulation. Finally, the proposed system is compared with pre-timed 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 Ratrou [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 Niittymäki and Kikuchi [11].

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. Niittymäki 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.

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.

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

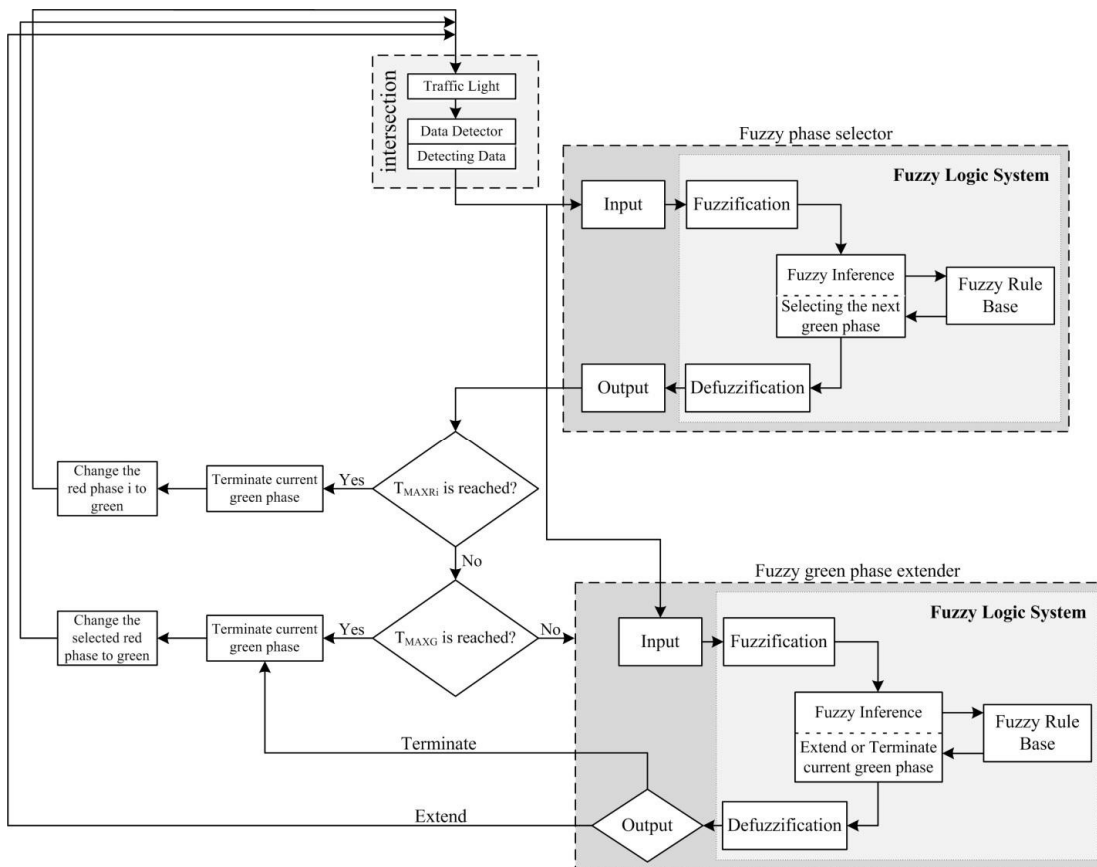


Figure 1: Fuzzy traffic signal control structure

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-based 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.

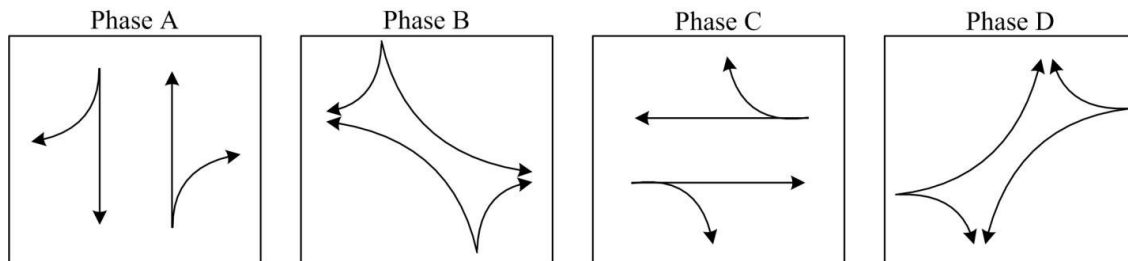


Figure 2: Phases of four-phase signal

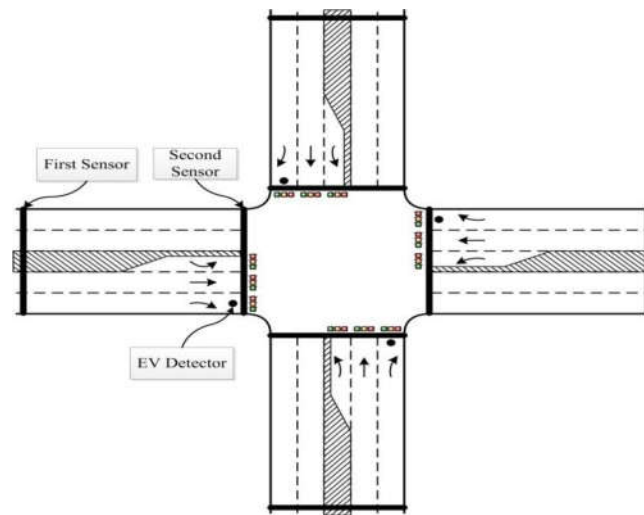


Figure 3: Simulated junction geometry

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.

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

	Queue length		Queue length		Queue length		Chosen phase
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{very long}$	THEN	C
IF	$QN_D = \text{long}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{very long}$	THEN	C
IF	$QN_D = \text{medium}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{very long}$	THEN	C
IF	$QN_D = \text{short}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{very long}$	THEN	C
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{long}$	AND	$QN_B = \text{very long}$	THEN	D
IF	$QN_D = \text{long}$	AND	$QN_C = \text{long}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{medium}$	AND	$QN_C = \text{long}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{short}$	AND	$QN_C = \text{long}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{medium}$	AND	$QN_B = \text{very long}$	THEN	D
IF	$QN_D = \text{long}$	AND	$QN_C = \text{medium}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{medium}$	AND	$QN_C = \text{medium}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{short}$	AND	$QN_C = \text{medium}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{short}$	AND	$QN_B = \text{very long}$	THEN	D
IF	$QN_D = \text{long}$	AND	$QN_C = \text{short}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{medium}$	AND	$QN_C = \text{short}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{short}$	AND	$QN_C = \text{short}$	AND	$QN_B = \text{very long}$	THEN	B
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{long}$	THEN	C
IF	$QN_D = \text{long}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{long}$	THEN	C
IF	$QN_D = \text{medium}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{long}$	THEN	C
IF	$QN_D = \text{short}$	AND	$QN_C = \text{very long}$	AND	$QN_B = \text{long}$	THEN	C
IF	$QN_D = \text{very long}$	AND	$QN_C = \text{long}$	AND	$QN_B = \text{long}$	THEN	D

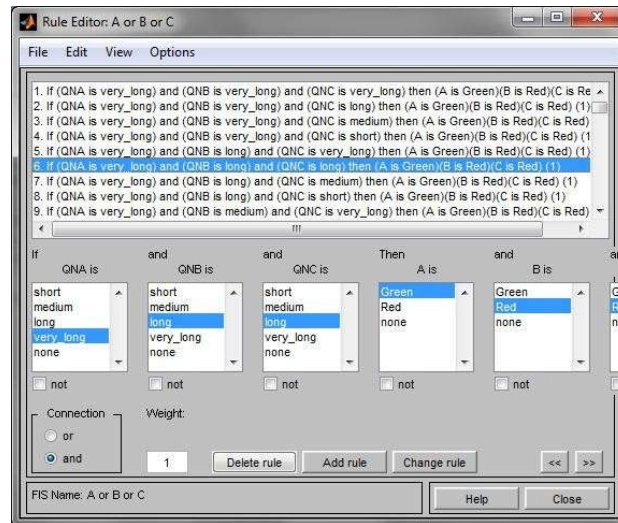


Figure 4: The rule editor of the fuzzy rules phase selector A or B or C

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:

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, will be checked. If it has been reached, then the current green phase will be terminated and control system changes the red phase to green, otherwise, 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 $\Delta t = 5$ second.

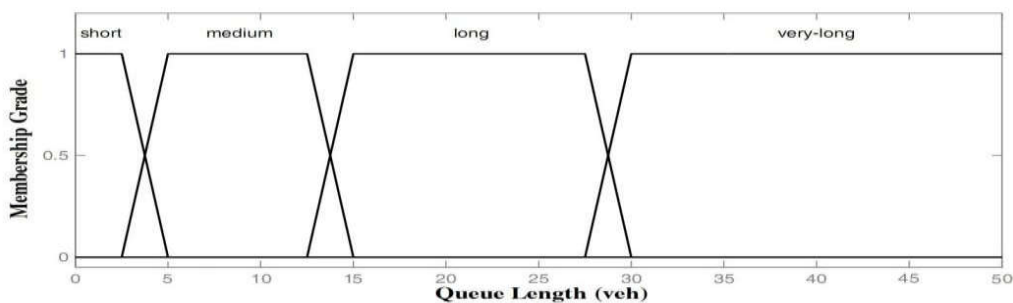


Figure 5: Fuzzy membership functions for QC and QN

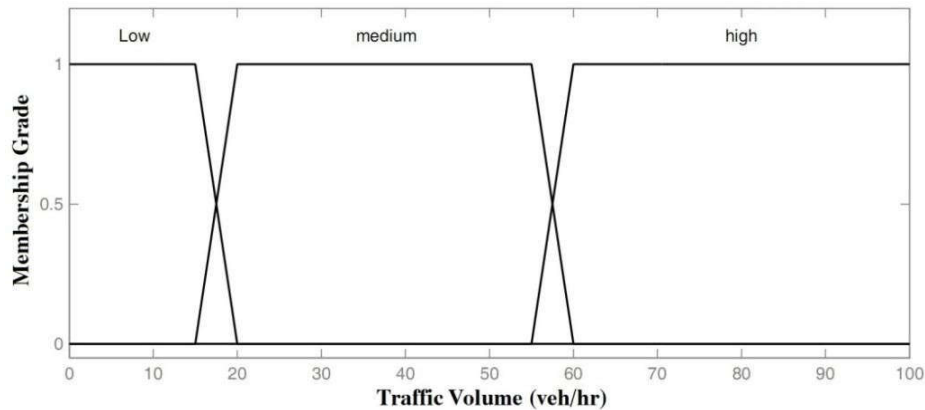


Figure 6: Fuzzy membership

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.

In this case, as is shown in Table 3 , 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 illustrate the fuzzy logic controller’s more performance schematically.

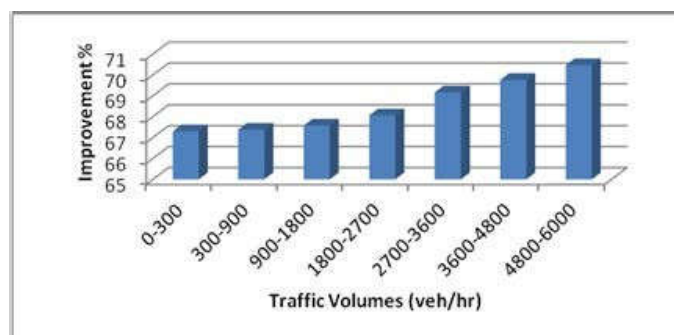


Figure 7: Improvement percentage of queue length for

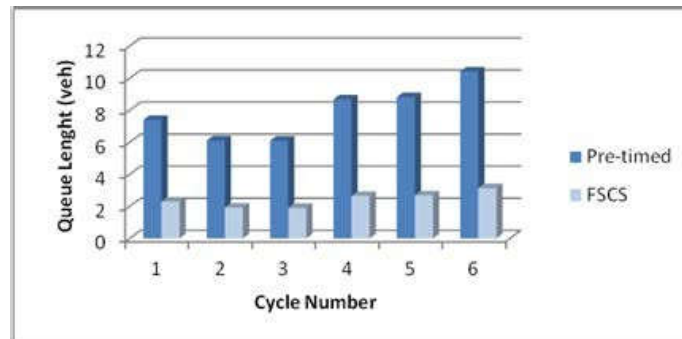


Figure 8: Pre-timed and FSCS queue length for different traffic volume

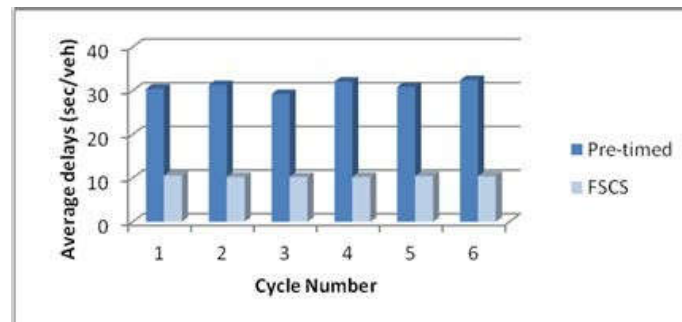


Figure 9: Pre-timed and FSCS delay for different traffic volume

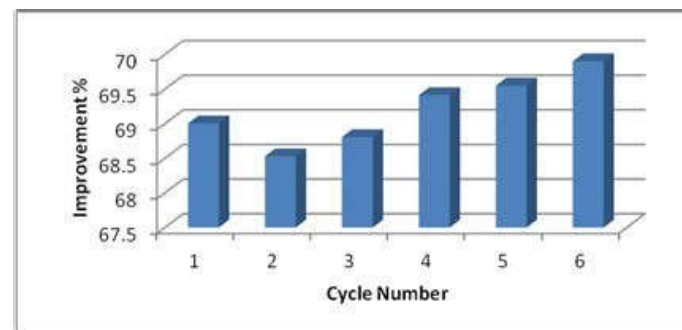


Figure 10: Improvement percentage of queue length different traffic volume

4. Conclusions

Traffic congestion could be a real-life problem. To cope with this problem, it's important that the traffic light controller is realizable. So as to style a more practical controller, we proposed a fuzzy system for signal control of full intersection involving emergency vehicle preemption with two-way streets and left-turn lanes, which made decision supported the fuzzy rules and real time traffic information. Proposed fuzzy system contained phase selector and green phase extender, which are located in several levels of the multi-level signal control strategy. The phase selector was functioning on the sequence level, while the green extender belonged to the green extension of the signal system. In the pre-time controller, being an open-loop system, the green time isn't extended regardless of the density of cars at the junction. Within the formal logic controller, the extension time isn't a hard and fast value. The quantity of cars sensed at the input of the fuzzy controllers is additionally converted into fuzzy values. Additionally to the fuzzy variables as mentioned, the fuzzy controller also has a bonus of performing in keeping with linguistic rules within the manner of how a person's would use. A simulation was administrated to check the performance of the symbolic logic controller with a fixed-time conventional controller.

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