Division of Green Time for Adaptive Traffic Signal Control Method based on Fuzzy Logic

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Abstract: - Congestion at isolated intersection is a problem encountered in many developed countries because of ineffective traffic control signal. Hence it is imperative to optimize the traffic control to better adapt to the increasing demand. Traffic signal fuzzy control is regarded as the solutions to traffic signal control problems. In this paper we propose control system that manage both the phase selection and green time of an intersection with the objective of minimizing delay and reducing queue length. Based on queue length, the proposed system uses fuzzy rules according to the real-time traffic information received from the wide area radar to select the red light phase with longest queue as the next phase and also determine the green time. The performance of the system was evaluated by comparing it with fixed signal control. The result shows that the traffic controller using fuzzy logic ameliorate the traffic condition at isolated intersection.

Keywords: - Traffic controller, fuzzy logic, isolated intersection, phase selector, phase time allocator

1 Introduction

In urban regions, traffic signals are the basic mechanism for controlling movement to guarantee the protected crossing of surges of vehicles and pedestrians. With the increment in traffic demand, signal operations string up to be more essential. Functional and Efficient signal controls will alleviate congestion and increase smooth operation while poor signal controls could result in outrageous blockage or even a system gridlock. Traffic demand is fundamentally dependent on time, day, season, climate, and erratic circumstances, for example, accident, special occasions, or construction works.

Presently, cities in various countries have been actualizing traffic signal that can steadily optimize the signal control plan based on historical data but are no more effective to traffic intersections due to erratic traffic volumes. Signal controllers that can think strategically similar to human reasoning are developed utilizing Artificial Intelligence (AI) systems. Human cognitive processes in rush hour gridlock and transportation are exemplified by a great execution. Despite the fact that the decision making aims might not be known, the adequacy of human fundamental initiative is exceptional. Traffic intersections that are regulated by human administrators are more adequate compared to conventional techniques and traffic development responsive control [1]. Based on the exercises of proficient policeman, the control principles for regulating the traffic flow was modelled. This is due to the fact that the human administrator has the ability to deal with various flow patterns at the intersection [2]. Fuzzy logic allows the execution of rules corresponding to human mental processes of understanding. However, fuzzy controller can take decision with insufficient data. Fuzzy Control is a control methodology that utilizes the information of fussy arithmetic to mimic the idea of human's thought. It can perceive and arbitrate the fuzzy circumstance and control the framework successfully [3]. An ever increasing number of advanced controllers are designed for movement control at intersections. These controllers are persistently enhancing safety by alleviating the congestion of vehicles and pedestrians on signals.

There are range of literatures making use of set hypothesis within the traffic sign control. Pappis and Mamdani [4] constructed a traffic intersection of two-way where each approach encompasses flow of vehicle from a single lane. They utilized detectors installed at upstream of each approach of the intersections. At regular interval, the extension or termination of signal phase were based on the date from the loop detectors. Teodorovic [5] broadly worked on the implementation of fuzzy logic in transportation strategies and concluded that fuzzy logic present a mathematical technique to model complicated transportation system. Murat [6] simulated a cross isolated intersection utilizing fuzzy logic which includes green duration and phase selection model. Trabia et al. [7] designed and simulated a fuzzy logic signal controller that can adapt to various traffic conditions and demands at a four-approach intersection. The controller alleviated vehicle delays at intersection when compare to traffic actuated controller with different traffic volume and conditions.

The current method of optimizing the traffic signal controller depends on detectors to provide traffic demand information. When there is increase in vehicular queueing, the queue at the intersection becomes very long and extends beyond the detector. The arrival of vehicle approaching the intersection would not be determined and signal controller would receive inaccurate information.

The goal of this paper is to critically review the traffic signal system of isolated intersection and design an adaptive controller based on human-like decision making strategy to optimize the traffic light using fuzzy logic. The system relies on a wide radar installed at the intersection to provide traffic information for the optimization process.

2 Design of Adaptive Fuzzy Traffic Controller

Controlling the traffic at isolated intersections is the focus of attention in developing countries due to traffic randomness. It is imperative to develop a Traffic light control system in order to proffer solution to issues related to controlling traffic at intersections. Traffic light controller can be classified into conventional controller and adaptive controller. The fixed time controller uses the past knowledge of traffic condition where the controller is positioned to determine the preset cycle time. The preset green time is always fixed but during peak period more green time is allocated. Despite the additional green time during peak periods, fixed time controller still does not adapt to changes in the traffic conditions. Vehicle actuated method is an approach that can adopt to any change in traffic. The survey conducted by road managers indicates that the 78% of signal controlled intersection has actuated control. This approach considers the actual traffic demands and the presence of vehicle to determine the changes of the traffic signals [8]. In this approach, detectors are located at a specific distance from the stopline. When an approaching vehicle is detected, a minimal green time is allocated for safe passage of the vehicle at intersection but this time is limited to the maximum green time. In contrast to fixed signal control, the actuated signal control is more functioning. Both approaches do not regard the traffic situation at the red phase.

Consequently, it is advantageous to design an approach that can dynamically adapt to changing traffic situations. Y. Li. et al [9] use queue length, vehicle arrival, exiting vehicle and extra green time as parameter to actualize the fuzzy role for fuzzy logic controller. This controller adapts to the changing traffic conditions by determining the extension and termination of green phase at an intersection. Fuzzy logic provides the platform to implement and actualize human-like decision making strategy which is not possible in fixed time or vehicle actuated controller.

The signal control system in this paper was designed by considering the queue length on red light at the intersection. It assigns separate time interval for passing vehicle from all the approach that leads to the isolated intersection. We developed the controller using IF-AND-THEN statements. For example, “IF QUEUE LENGTH is LONG, then GREEN TIME is LONG. IF QUEUE LENGTH is SHORT, then GREEN TIME is SHORT”.

2.1 Fuzzy Phase Selector

Fuzzy phase selector is a rule based function that determines and select the felicitous phase order for all red phases to receive right of way when the green phase is terminated. The rules are composed to consider the phase with longest queue demand for green time. The traffic conditions are regularly checked and updated by the controller to make decision of the next phase. The input variable for the Fuzzy phase selector is the queuing vehicle. The number of queuing vehicles waiting for the green signal in each red phase are counted.

The geometry and phase order of the simulated intersection are depicted in fig.1 and fig.2. If the current green phase of an approach to an intersection is to be terminated, the phase selector decides which red phase of the other approach is to be launched.

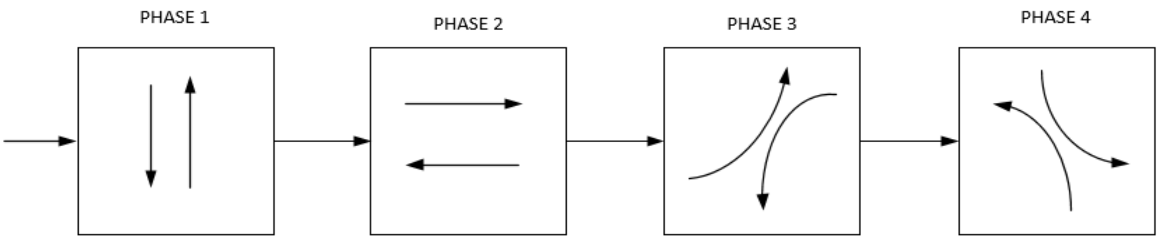

Fig. 1: Phase sequence of Signal control

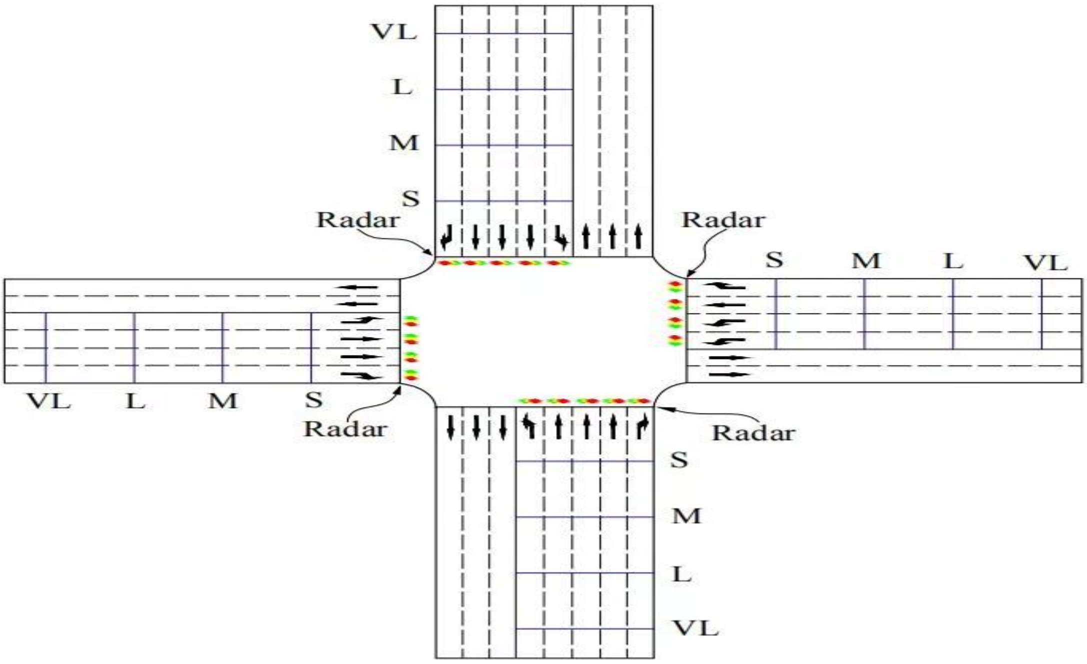

Fig. 2: Geometry of the simulated intersection

The fuzzy system contains rules that takes the vehicles queue length at red phase as input parameter. These fuzzy rules consist of a total of 64 possible rules which are developed for the effective implementation of traffic controller and it will perform the phase selection from these rules.

In this paper we assume that phase 1 is on green at the beginning of the cycle time and the phase selector decides the next green phase.

Table 1: Fuzzy Rules

RULES	**PHASE 2 (QNA2)**		**PHASE 3 (QNA3)**		**PHASE 4 (QNA4)**		**PHASE SELECTED**
		AND		AND		THEN	
IF	short	AND	short	AND	short	THEN	QNA2
IF	medium	AND	short	AND	short	THEN	QNA2
IF	long	AND	short	AND	short	THEN	QNA2
IF	very long	AND	short	AND	short	THEN	QNA2
IF	short	AND	medium	AND	short	THEN	QNA3
IF	medium	AND	medium	AND	short	THEN	QNA2
IF	long	AND	medium	AND	short	THEN	QNA2
IF	very long	AND	medium	AND	short	THEN	QNA2
IF	short	AND	long	AND	short	THEN	QNA3
IF	medium	AND	long	AND	short	THEN	QNA3
IF	long	AND	long	AND	short	THEN	QNA2
IF	Very long	AND	long	AND	short	THEN	QNA2
IF	short	AND	very long	AND	short	THEN	QNA3
IF	medium	AND	very long	AND	short	THEN	QNA3
IF	long	AND	very long	AND	short	THEN	QNA3
IF	Very long	AND	very long	AND	short	THEN	QNA2
IF	short	AND	short	AND	medium	THEN	QNA4
IF	medium	AND	short	AND	medium	THEN	QNA2
IF	long	AND	short	AND	medium	THEN	QNA2
IF	Very long	AND	short	AND	medium	THEN	QNA2
IF	short	AND	medium	AND	medium	THEN	QNA3
IF	medium	AND	medium	AND	medium	THEN	QNA2
IF	long	AND	medium	AND	medium	THEN	QNA2
IF	Very long	AND	medium	AND	medium	THEN	QNA2
IF	short	AND	long	AND	medium	THEN	QNA3
IF	medium	AND	long	AND	medium	THEN	QNA3
IF	long	AND	long	AND	medium	THEN	QNA2
IF	Very long	AND	long	AND	medium	THEN	QNA2
IF	short	AND	very long	AND	medium	THEN	QNA3
IF	medium	AND	very long	AND	medium	THEN	QNA3
IF	long	AND	very long	AND	medium	THEN	QNA3
IF	Very long	AND	very long	AND	medium	THEN	QNA2
IF	short	AND	short	AND	long	THEN	QNA4
IF	medium	AND	short	AND	long	THEN	QNA4
IF	long	AND	short	AND	long	THEN	QNA2
IF	Very long	AND	short	AND	long	THEN	QNA2
IF	short	AND	medium	AND	long	THEN	QNA4
IF	medium	AND	medium	AND	long	THEN	QNA4
IF	long	AND	medium	AND	long	THEN	QNA2
IF	Very long	AND	medium	AND	long	THEN	QNA2
IF	short	AND	long	AND	long	THEN	QNA3

RULES	PHASE 2 (QNA2)		PHASE 3 (QNA3)		PHASE 4 (QNA4)		PHASE SELECTED
IF	medium	AND	long	AND	long	THEN	QNA3
IF	long	AND	long	AND	long	THEN	QNA2
IF	Very long	AND	long	AND	long	THEN	QNA2
IF	short	AND	very long	AND	long	THEN	QNA3
IF	medium	AND	very long	AND	long	THEN	QNA3
IF	long	AND	very long	AND	long	THEN	QNA3
IF	Very long	AND	very long	AND	long	THEN	QNA2
IF	short	AND	short	AND	very long	THEN	QNA4
IF	medium	AND	short	AND	very long	THEN	QNA4
IF	long	AND	short	AND	very long	THEN	QNA4
IF	Very long	AND	short	AND	very long	THEN	QNA2
IF	short	AND	medium	AND	very long	THEN	QNA4
IF	medium	AND	medium	AND	very long	THEN	QNA4
IF	long	AND	medium	AND	very long	THEN	QNA4
IF	Very long	AND	medium	AND	very long	THEN	QNA2
IF	short	AND	long	AND	very long	THEN	QNA4
IF	medium	AND	long	AND	very long	THEN	QNA4
IF	long	AND	long	AND	very long	THEN	QNA4
IF	Very long	AND	long	AND	very long	THEN	QNA2
IF	short	AND	very long	AND	very long	THEN	QNA3
IF	medium	AND	very long	AND	very long	THEN	QNA3
IF	long	AND	very long	AND	very long	THEN	QNA3
IF	Very long	AND	very long	AND	very long	THEN	QNA2

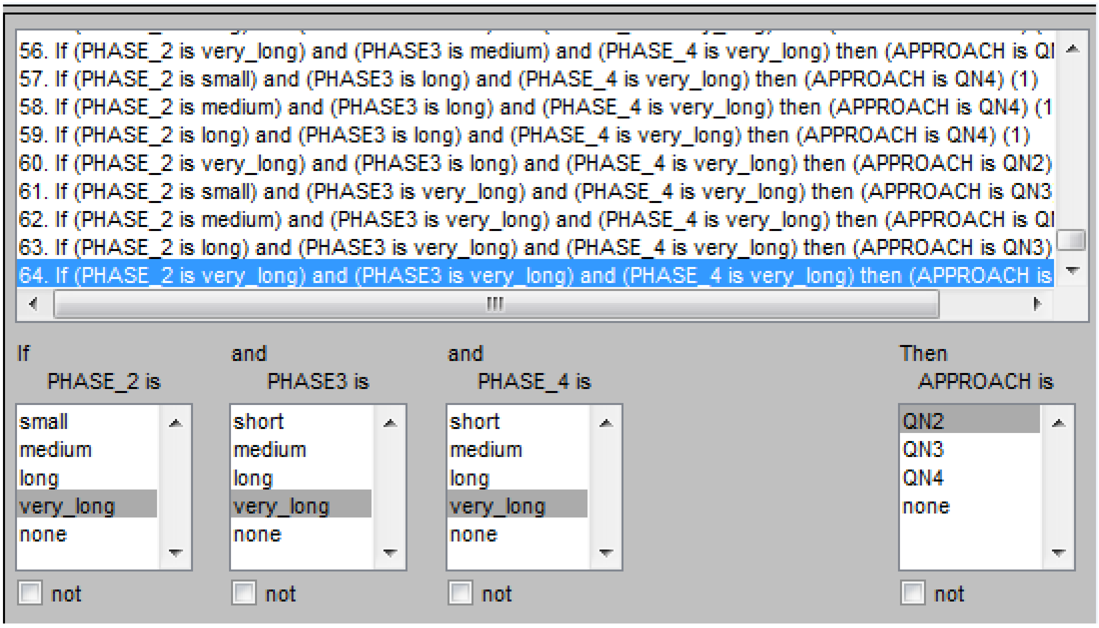

Fig. 3: Fuzzy rules for Phase selector

2.2 Fuzzy Green Time Duration

The primary purpose of traffic signal control is the allocation of green time among all the approaching movement at a signalized intersection by means of time separation. The proposed fuzzy green time duration rules compare traffic situation of the approach in the same phase to determine the sufficient green time to dissipate the queued vehicle at the back of red light. The input in the system consist of the two variables which are the number of queued vehicle from opposite approach in the same phase. For example, queued vehicle on West outbound is one variable and queued vehicle on the East outbound is the second variable. The output is green time duration. If the queued vehicle at East approach is longer than west approach since they are both on the same phase, fuzzy traffic controller will allocate longer green time to the East approach. Likewise, If the queue vehicle at South approach is longer than North approach since they are both on the same phase, fuzzy traffic controller will allocate longer green time to the South approach. The Input variables are divided into six membership functions very short (VS), short (S), medium (M), long (L), and very long (VL). Vehicle queue length is assumed at 0-50 vehicle on each lane of the approach. The range of the membership are 0 vehicle, 10 vehicles, 20 vehicles, 30 vehicles, and 40 vehicles.

The decision process is based on a set of fuzzy rules in Table 2,3

Table 2: Fuzzy Rules for West-East

RULES	**WEST Q**		**EAST Q**		**GREEN TIME**
IF	Short	AND	Short	THEN	Short
IF	Medium	AND	Short	THEN	Medium
IF	Long	AND	Short	THEN	Long
IF	Very long	AND	Short	THEN	Very long
IF	Short	AND	Medium	THEN	Medium
IF	Medium	AND	Medium	THEN	Medium
IF	Long	AND	Medium	THEN	Long
IF	Very long	AND	Medium	THEN	Very long
IF	Short	AND	Long	THEN	Long
IF	Medium	AND	Long	THEN	Long
IF	Long	AND	Long	THEN	Long
IF	Very long	AND	Long	THEN	Very long
IF	Short	AND	Very long	THEN	Very long
IF	Medium	AND	Very long	THEN	Very long
IF	Long	AND	Very long	THEN	Very long
IF	Very long	AND	Very long	THEN	Very long

Table 3: Fuzzy Rules for North-South

RULES	NORTH Q		SOUTH Q		GREEN TIME
IF	Short	AND	Short	THEN	Short
IF	Medium	AND	Short	THEN	Medium
IF	Long	AND	Short	THEN	Long
IF	Very long	AND	Short	THEN	Very long
IF	Short	AND	Medium	THEN	Medium
IF	Medium	AND	Medium	THEN	Medium
IF	Long	AND	Medium	THEN	Long
IF	Very long	AND	Medium	THEN	Very long
IF	Short	AND	Long	THEN	Long
IF	Medium	AND	Long	THEN	Long
IF	Long	AND	Long	THEN	Long
IF	Very long	AND	Long	THEN	Very long
IF	Short	AND	Very long	THEN	Very long
IF	Medium	AND	Very long	THEN	Very long
IF	Long	AND	Very long	THEN	Very long
IF	Very long	AND	Very long	THEN	Very long

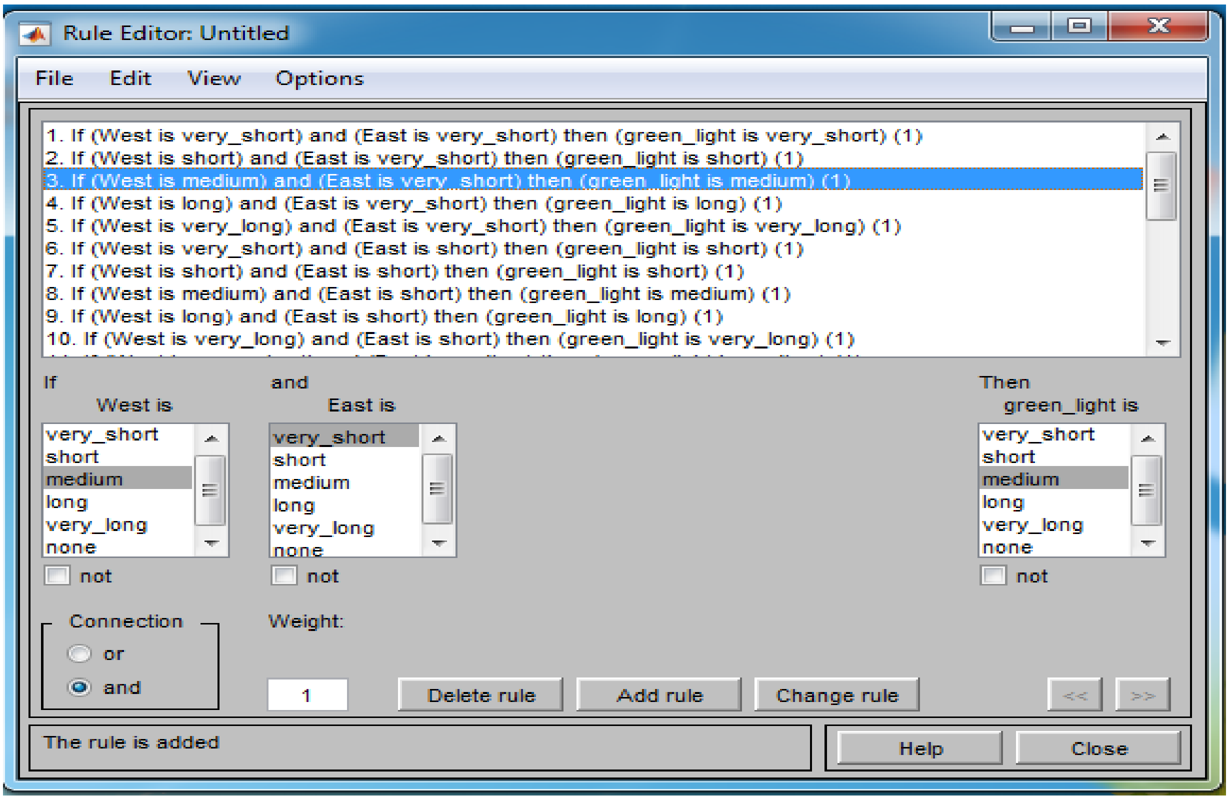

Fig. 4: Fuzzy rules for green time allocation on west-east

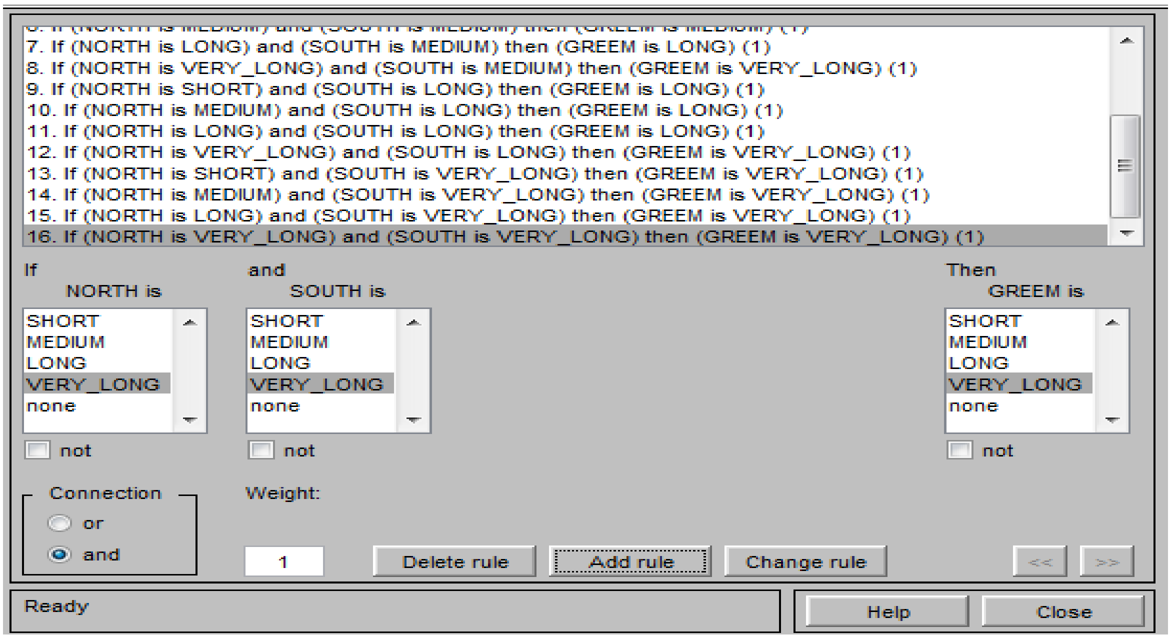

Fig. 5: Fuzzy rules for green time allocation on North-South

3 Simulation Result

The performance of the proposed adaptive signal controller for this study was evaluated by comparing it with fixed time control system in terms of queue length, waiting time and total vehicle departure. Queue length is the measure of vehicles at back of red light at the intersection while waiting for the green light. Waiting time is the measure of the difference between the duration of time the vehicles on the different approach have to wait at the intersection before receiving right of way to proceed through intersection. Total vehicle departure is the total number of vehicles that are allowed to pass through the intersection over a period of time.

Result in Table (4) indicates that signalized intersection that utilizes the fuzzy control can manage the green time allotted for safe passage and queue length. Comparing the total number of departed vehicles at each of the approaches at the isolated intersection is another way to have knowledge of the performance of the controller.

The number of vehicles and traffic flow in each lane were determined by wide radar which are depicted in figure (4). The signal in the opposite direction are arranged in the same signal group. The simulation result indicates that the proposed fuzzy controller operates better compared to fixed timed controller in relation to queue length, vehicles delay and departed volume. During red phase on any approach, there was a drastic reduction of queue length by 26% and vehicle waiting time by 31% compared to the fixed timed controller. When traffic volumes for each approach that are on the same phase are different from each other, fuzzy logic controller can perform better than fixed timed controller by managing the disparity in queue length when density of each approach are significantly different from each other. The system was able to assign a longer green time to the approaches that has a longer vehicle queue length over the approaches that has a shorter queue length on the same phase.

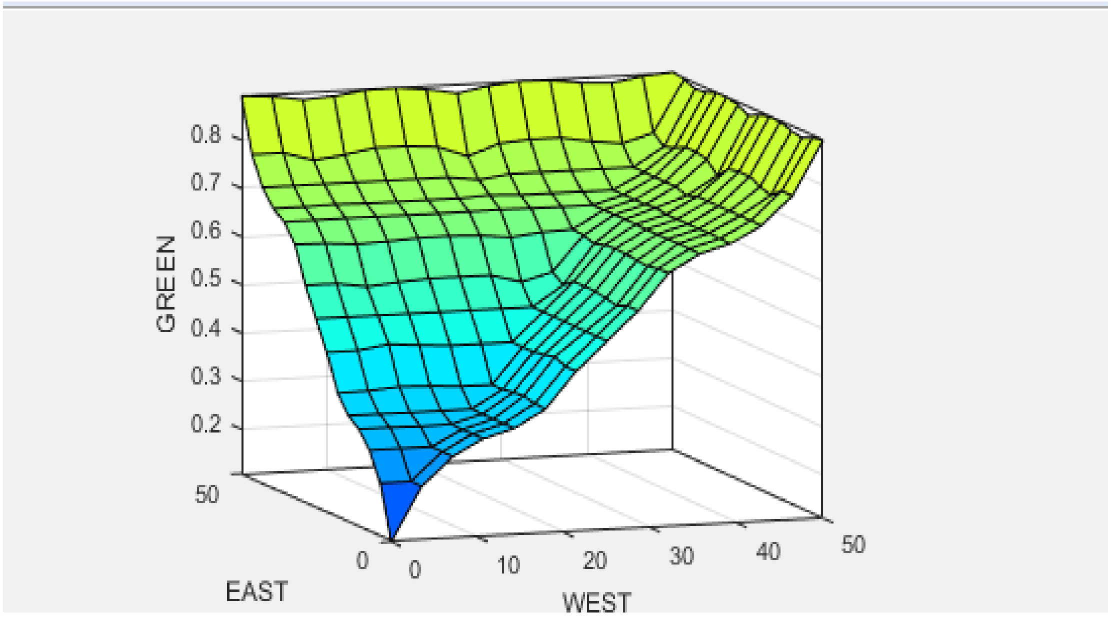

Fig. 6: Input Variables Queue (East and West), Vs Output Variable Green time

As shown in Figure (6), the Green time is small when the value of Queue EAST and Queue WEST have a small value. The Green time increase slowly and have a longer time when the queue become longer on either side since they are on the same signal group.

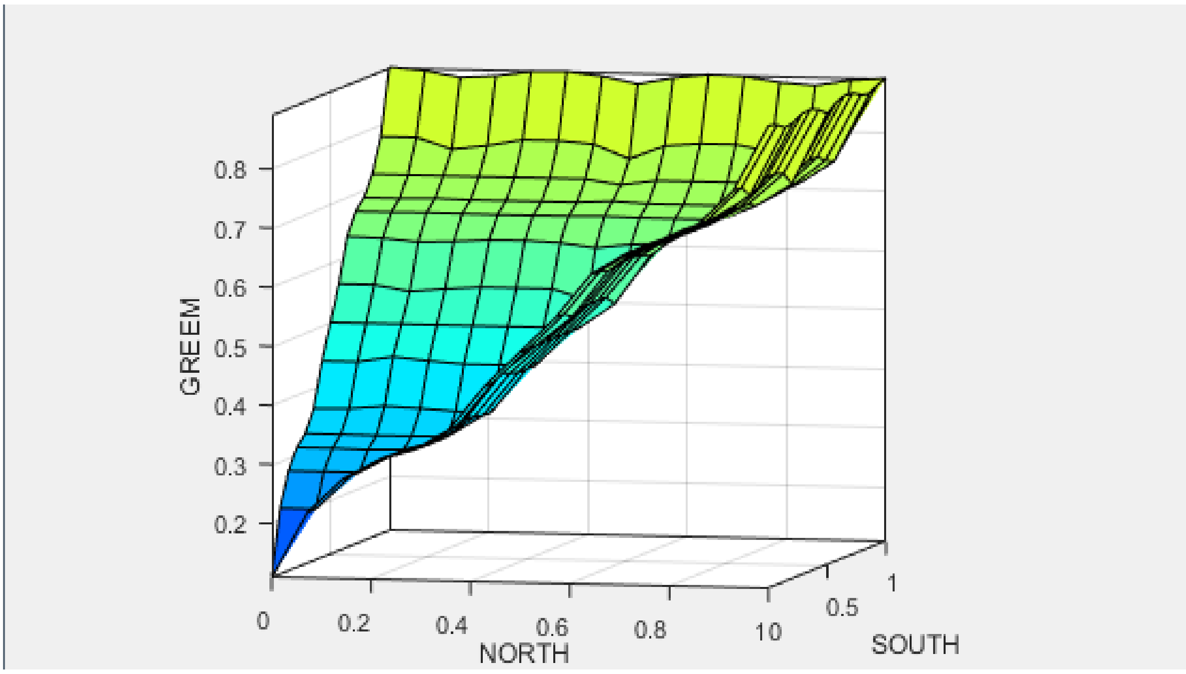

Fig. 7: Input Variables Queue (North and South), Vs Output Variable Green time

As shown in Figure (7), the Green time is small when the value of Queue NORTH and Queue SOUTH have a small value. The Green time increase slowly and have a longer time when the queue become longer on either side since they are on the same signal group.

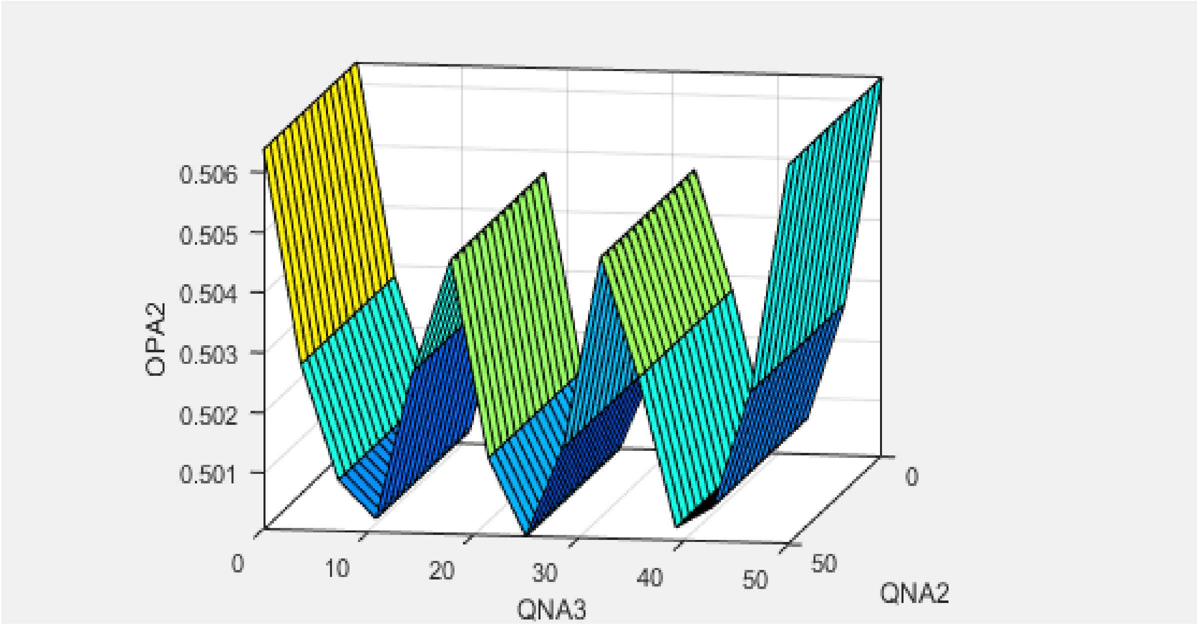

Fig. 8: Input Variables Queue (Phase 2 and Phase 3), Vs Output Variable Phase with time duration

As shown in Figure (8), the three colours determine the output value based on the rules. Determining the traffic signal phase selector, each colour represent a phase and the number of the queued vehicle at the back of the red line.

The traffic light worked on the basis of timer which is control by the queue length, the approach with the longest queue gets green, later switch to the approach with the longer queue and switch to the approach with shortest queue. However, when all the approach has the same queue length, priority was given to through movements (straight).

Table 4: Comparison of Waiting Time, Queue Length and Number of Departure of Fuzzy Traffic Contoller and Fixed Timed Controller

Performance Measure	Phase	Fuzzy	Fixed	Comparison %
Average queue length (vehicles)	North	13.66	18.62	26.63
	South	10.74	13.22	18.75
	West	6.02	10.66	43.52
	East	8.54	10.73	20.41
Average Waiting time (Seconds)	North	33.75	48.67	30.65
	South	30.25	42.08	28.11
	West	22.36	36.41	38.58
	East	27.55	38.17	27.82
Number of Departure (vehicles)	North	1185	1151	2.8
	South	1488	1435	3.5
	West	1409	1361	3.4
	East	1724	1721	0.17

4 Conclusion

The Adaptive signal based on Fuzzy rule is effective for actualizing the objectives of this project. The fuzzy control system used for this project contained phase selector and green time allocator. The results indicate that the application of the controller proposed in term of fuzzy phase selector and green time allocator performed better by increasing the number of vehicles that proceed through the intersection and adapted to the traffic condition. In the fuzzy logic controller, the allotting of green time depends on the number of queued vehicles discovered by the wide radar and the green time allocator determines the specific seconds needed to dissipate the queued vehicles at the back of red light based on the fuzzy rules.

Fixed timed signal control does not consider the traffic condition of different approach on the same phase. The proposed fuzzy controller was able to monitor the traffic flow, reduce the number of queue and vehicle delay than fixed timed control.

This fuzzy logic controller will be further extended in our ongoing research with the ability of detecting pedestrian and cyclist at isolated intersection.

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