Smart Traffic Light Control Using Fuzzy Logic with Green Time Optimization

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ABSTRACT

In this research, the development of smart traffic light control based on multi stage fuzzy logic and ant colony optimization (ACO) algorithm has been carried out. Smart traffic light control is a traffic light control system that is able to adapt to the conditions of each road section at the intersection. In multi stage fuzzy logic, the output of the first stage of the fuzzy logic becomes the input to the next stage of the fuzzy logic. The output of the fuzzy system is to determine the priority scale for the next green phase. Furthermore, Ant Colony Optimization calculates the optimal green time in that phase. Based on the simulation result, it is found that by using smart traffic light control system compared to a fixed time traffic light control system, there is a reduction in queue length and waiting time.

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1. INTRODUCTION

The use of traffic lights is currently being applied more by using a static timing system or a traffic light system that does not consider the condition of the intersection where there are many or few vehicles. The application of a traffic light system like this does not answer the conditions that occur on the highway, so that it can cause congestion. Congestion can cause a lot of losses, including a lot of wasted time and wasted fuel. For this reason, it is better if there are only a few queues of vehicles in one road, the green light will be longer than if there are many vehicles on that road. So that the traffic light regulation pattern is more adaptive so it is hoped that it will not cause long queue. Therefore, it is necessary to build a smart traffic light control system, namely a system that is able to adapt to the conditions of each road section at the intersection. This system is referred to as a smart traffic light control system.

In general, the aim of smart traffic light control is to improve traffic safety at intersection, maximize intersection capacity, and minimize delay. Researches on smart traffic light control system have been carried out. Some of them are using Fuzzy Logic [1-5], using ANFIS [6,7], using Fuzzy Logic and Genetic Algorithm [8], using Deep Learning [9], using Fuzzy Logic and PI Controller [10], and using Max-Plus MPC [11]. Some of the studies above, especially those using Fuzzy Logic, have not taken into account the optimum green time. Therefore, in this study, a smart traffic light control system is offered using the Multi-Stage Fuzzy Logic algorithm by considering the initial green time that will be given in the active phase. Ant Colony Optimization algorithm is used to get the optimum green time. It is hoped that this system will be able to increase the capacity of the intersection, reduce queue length and reduce vehicle waiting time.

Fuzzy inference system is a mechanism process of mapping fuzzy sets in the set of universes contained in the reason (premise) part to the other fuzzy sets in the consequent part based on the rules. The mapping mechanism from a certain set of universes to another set of universes can be connected by interpreting the rules in the basic rules containing fuzzy rules as a fuzzy implication. There are many kinds of interpretation models, including the Takagi-Sugeno-Kang (TSK) system, the Mamdani fuzzy system and the Tsukamoto fuzzy system. In this research using Mamdani method. Some study use the Mamdani method as in [12,13].

The ant colony system is a model of ant behavior that is known to be able to find the shortest distance between the nest and their food source.Ants are social insects that live in colonies. Although each individual ant moves quasi-randomly, doing simple work, in a colony, ants can move in a certain pattern. Every movement, ants release chemicals called pheromones. This chemical is detected and used as an indirect communication tool by other ants.

2. METHOD

In this research, an integrated model between Fuzzy Logic and Ant Colony Optimization algorithm is proposed to obtain the optimum cycle time and green time according to the current situation. Data on traffic conditions on each side of the road will be obtained from surveillance cameras. The system model to be built can be seen in Figure 1.

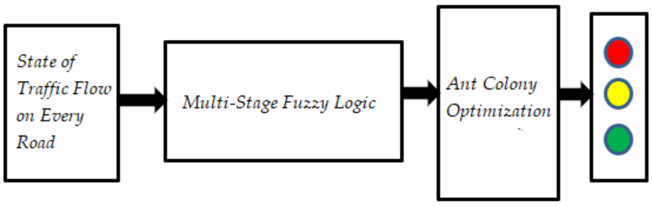

Figure 1.

The traffic condition at each intersection road becomes the input to the fuzzy logic system. In Multi Stage Fuzzy Logic, the output of the first stage of the fuzzy logic system becomes the input to the next stage of the fuzzy logic system. The output of the fuzzy system is to determine the priority scale for the next green phase. Furthermore, the Ant Colony Optimization (ACO) algorithm calculates the optimal green time for that phase. The multi-stage fuzzy logic system built is shown in Figure 2.

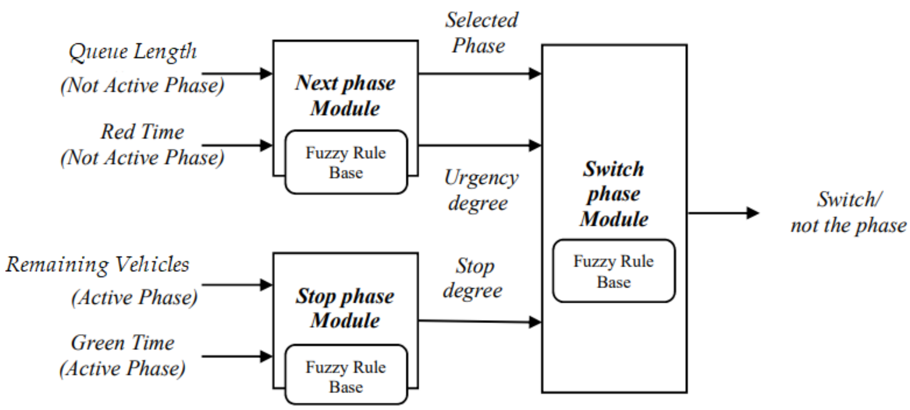

Figure 2. Multi-Stage Fuzzy Logic

There are two stages of fuzzy logic, the first stage consists of two fuzzy logics, namely **Next Phase Module** fuzzy logic and the **Stop Phase Module** fuzzy logic. **Next Phase Module** fuzzy logic is fuzzy logic whose input comes from roads that are experiencing a red phase. Meanwhile, the input of the **Stop Phase Module** fuzzy logic comes from roads that are experiencing a green phase. The second stage is **Decision** fuzzy logic.

This fuzzy logic serves to decide whether to switch to the green phase for other road or continue the green phase on the currently active road.

After building a multi-stage fuzzy logic system whose output is a priority scale of the green phase, the next step is to determine the optimal of green time. The purpose of determining the optimal of green time is to provide a maximum limit for the length of the green phase on the currently active road section. The optimal of green time is obtained based on the minimum total waiting time for vehicles in the queue. The total waiting time for vehicles in the queue is obtained based on the following equations.[14]

When all the vehicles in the initial queue will be released in the queue then $(t_2 - t_1) \geq (q-1)hw$, total expected waiting time of the movement vehicles during the green time (from t_1 to t_2) can be expressed in equation (1),

$$J_{green1}(t_1, t_2) = \frac{q(q-1)hw}{2} + \sum_{i=1}^{q}(t_1 - t_a^i) + \frac{\lambda((q-1)hw)^2}{2} + \frac{\lambda\big((q-1)hw\big)\big[\lambda\big((q-1)hw\big)-1\big]hw}{2} \quad (1)$$

When $(t_2 - t_1) \geq (q-1)hw$ then not all vehicles in the initial queue can released of the queue. The total waiting time for this case can be expressed in equation (2),

$$J_{green2}(t_1, t_2) = \frac{q_{out}(q_{out}-1)hw}{2} + \sum_{i=1}^{q}(t_1 - t_a^i) + (q - q_{out})(t_2 - t_1) + \frac{\lambda(t_2-t_1)^2}{2} \quad (2)$$

where,
t_1 is the initial time of the green light (seconds)
t_2 is the end time of the green light (seconds)
q is the number of vehicles in the queue at time t_1 (vehicles)
q_{out} is the number of vehicles that left the queue during the green phase (vehicles)
hw is headway (2 seconds)
t_a^i is the arrival time of vehicle i (seconds)
λ is traffic flow on the road to be activated (vehicles/second)

Ant Colony Optimization Algorithm is used to find the minimum total waiting time among several generated waiting times. Here is the Ant Colony Optimization algorithm to find the minimum value.

In the first cycle, the first step is that the ants (the number of ants are determined at random) are placed randomly at different points. Then until the end of the first cycle, the ants will move from point i to point j (which is allowed) by considering visibility,

$$\eta_j = \frac{1}{C_j} \quad (3)$$

where C_j is the cost of point j. Ants will go to the point with the greatest visibility value. In this case the value of Cj is the total waiting time value obtained from equations (1) and (2).

After each cycle, the ant will leave a trail, pheromone, at every point it visits. After completing one cycle, the ants will die and be replaced by new ants with the same number.

In the second cycle and so on, new ants are placed at one of the points that have been visited by the ants in the previous cycle, and will move from point i to point j (allowed) based on a probability function, called the state transition rule. transition rule), that is

$$p_j(t) = \begin{cases} \dfrac{[\tau_j(t)]^\alpha[\eta_j]^\beta}{\sum_{j \in allowed}[\tau_j(t)]^\alpha[\eta_j]^\beta}; & if\ j \in allowed \\ 0; & if\ not\ allowed \end{cases} \quad (4)$$

where $\tau_j(t)$ is the amount of ant pheromone at point j at time t. Parameters α and β are used to control the relative importance of pheromone and visibility.

Thus, after an ant completes its journey in one cycle, the amount of pheromone will be updated to:

$$\tau_j(t+N) = \rho\tau_j(t) + \Delta\tau_j(t, t+N) \quad (5)$$

where ρ is a coefficient ranging from 0 to 1, such that (1- ρ) indicates the evaporation of the pheromone, and

$$\Delta\tau_j(t, t+N) = \sum_{k=1}^{m}\Delta\tau_j^k(t, t+N), \quad (6)$$

where $\Delta\tau_j^k(t, t+N)$ is the pheromone left by ant k at point j, between t and $(t+N)$, which is determined as follows:

$$\Delta\tau_j^k(t, t+N) = \begin{cases} \frac{1}{L^k}; & if\ j \in trip\ k \\ 0; & otherwise \end{cases} \quad (7)$$

where L^k is the total cost of the trip made by k ant. N is the number of points visited by each ant in one cycle.

The number of pheromones at *t=0* for each point is $\tau_j(0)$, determined equal to the value of its visibility. The point that has the highest amount of pheromone is the minimum point.

3. RESULTS AND DISCUSSION

In this case, the traffic light phase applied is two-phase. There are two stages of fuzzy logic, the first stage consists of two fuzzy logics, namely **Next Phase Module** fuzzy logic and the **Stop Phase Module** fuzzy logic. **Next Phase Module** fuzzy logic is fuzzy logic whose input comes from roads that are experiencing a red phase. Meanwhile, the input of the **Stop Phase Module** fuzzy logic comes from roads that are experiencing a green phase. The second stage is **Decision** fuzzy logic. This fuzzy logic serves to decide whether to switch to the green phase for other road or continue the green phase on the currently active road. The universe of discourse of fuzzy sets and fuzzy membership functions were determined based on the analysis of the data obtained from the traffic volume survey. Following are the details of each fuzzy logic.

3.1. Next Phase Module

Next Phase Module consists of two inputs, namely **Queue Length** and **Red Time** which can be seen in Figure 3. The **Queue Length** membership function can be seen in Figure 4. and the membership function of **Red Time** can be seen in Figure 5., and the consequent membership function can be seen in Figure 6.

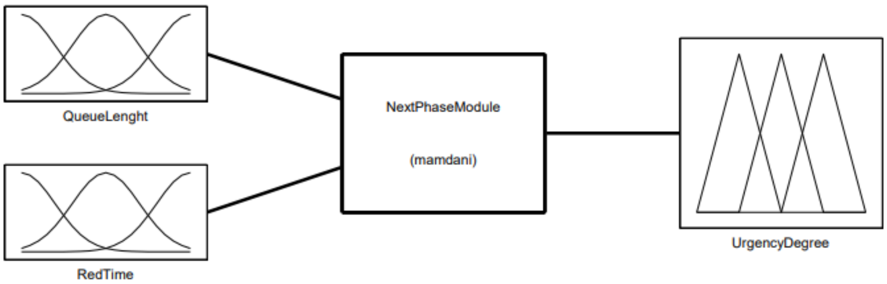

Figure 3. Next Phase Module fuzzy logic

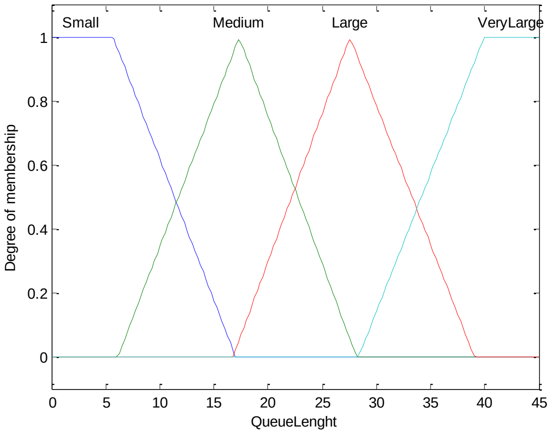

Figure 4. Queue Length membership function

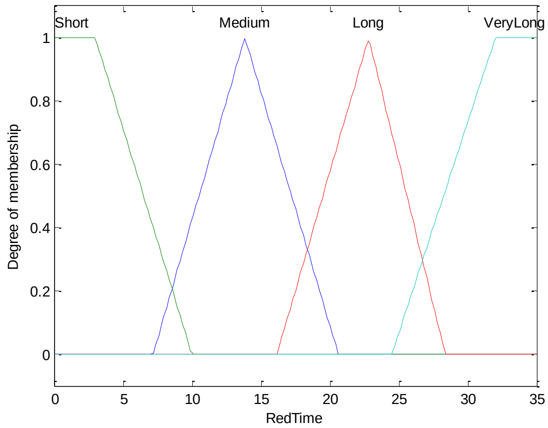

Figure 5. Red Time membership function

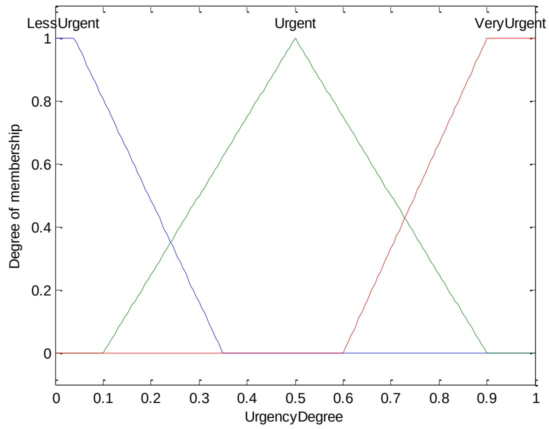

Figure 6. Consequent membership function of Next Phase Module

The rules base of **Next Phase Module** Fuzzy Logic can be seen in Table 1.

Table 1. The rules base of **Next Phase Module** Fuzzy Logic

		Red Time			
		Short	Medium	Long	Very Long
Queue Lenght	Small	Less Urgent	Less Urgent	Less Urgent	Less Urgent
	Medium	Less Urgent	Less Urgent	Less Urgent	Urgent
	Large	Urgent	Urgent	Urgent	Very Urgent
	Very Large	Urgent	Very Urgent	Very Urgent	Very Urgent

3.2. Stop Phase Module

Stop Phase Module consists of two inputs, namely **Remaining Vehicles** and **Green Time** which can be seen in Figure 7. The **Remaining Vehicles** membership function can be seen in Figure 8. and the membership function of **Green Time** can be seen in Figure 9., and the consequent membership function can be seen in Figure 10.

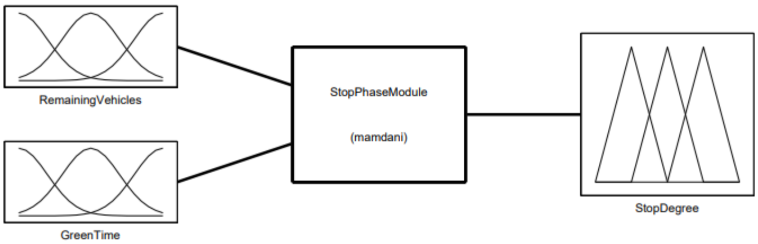

Figure 7. Stop Phase Module Fuzzy Logic

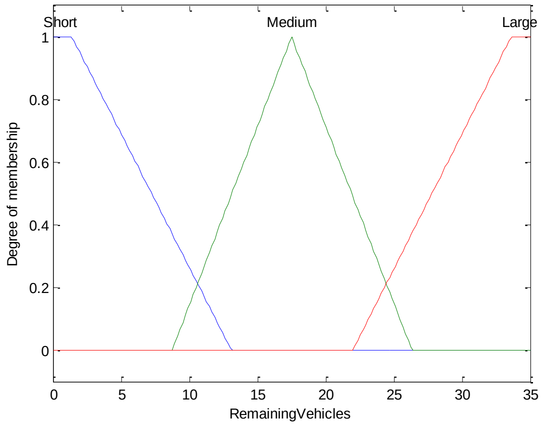

Figure 8. **Remaining Vehicles** membership function

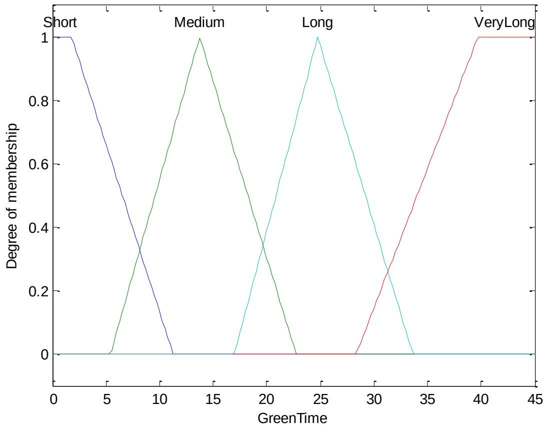

Figure 9. **Green Time** membership function

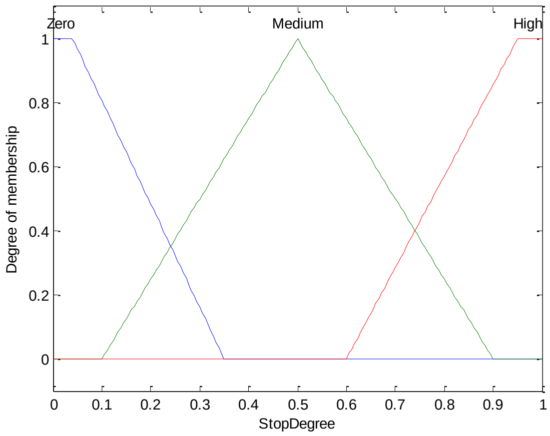

Figure 10. Consequent membership function of Stop Phase Module

The rules base of **Stop Phase Module** Fuzzy Logic can be seen in Table 2.

Table 2. The rules base of **Stop Phase Module** Fuzzy Logic

		Remaining Vehicles		
		Short	Medium	Large
Green Time	Short	Zero	Medium	High
	Medium	Zero	High	High
	Long	Zero	Medium	Medium
	Very Long	Zero	Medium	High

3.3. Decision Fuzzy Logic

Decision Fuzzy Logic consists of two inputs, namely **Urgency Degree** and **Stop Degree** which can be seen in Figure 11. The **Urgency Degree** membership function can be seen in Figure 12., and the membership function of **Stop Degree** can be seen in Figure 13., and the consequent membership function can be seen in Figure 14.

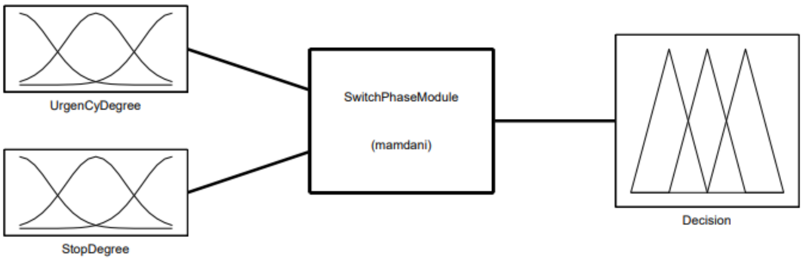

Figure 11. Decision Fuzzy Logic

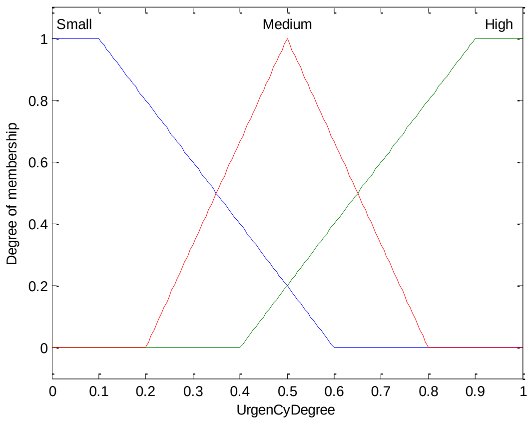

Figure 12. Urgency Degree membership function

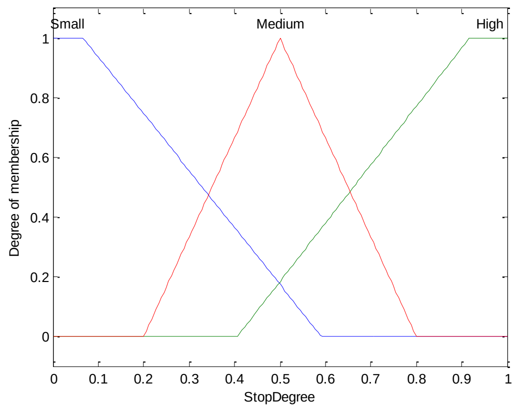

Figure 13. Stop Degree membership function

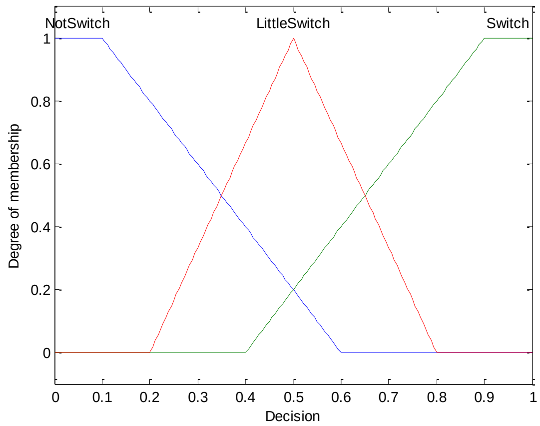

Figure 14. Consequent membership function of Decision Fuzzy Logic

The rules base of **Decision** Fuzzy Logic can be seen in Table 3.

Table 3. The rules base of Decision Fuzzy Logic

		Urgency Degree		
		Small	Medium	High
Stop Degree	Small	Not Switch	Not Switch	Switch
	Medium	Not Switch	Little Switch	Switch
	High	Not Switch	Little Switch	Switch

3.4. Simulation

The simulation is carried out by comparing the performance of the smart traffic light control system with the fixed time traffic light control system. In this simulation, a random Poisson distribution is generated with an average arrival of 1200 vehicles/hour for the West-East road and an average arrival of 800 vehicles/hour for the North-South road. In the fixed traffic light control, green time for the West-East road section is 40 seconds and green time for the North-South road section is 35 seconds. The following is a graph of the results of running the simulation.

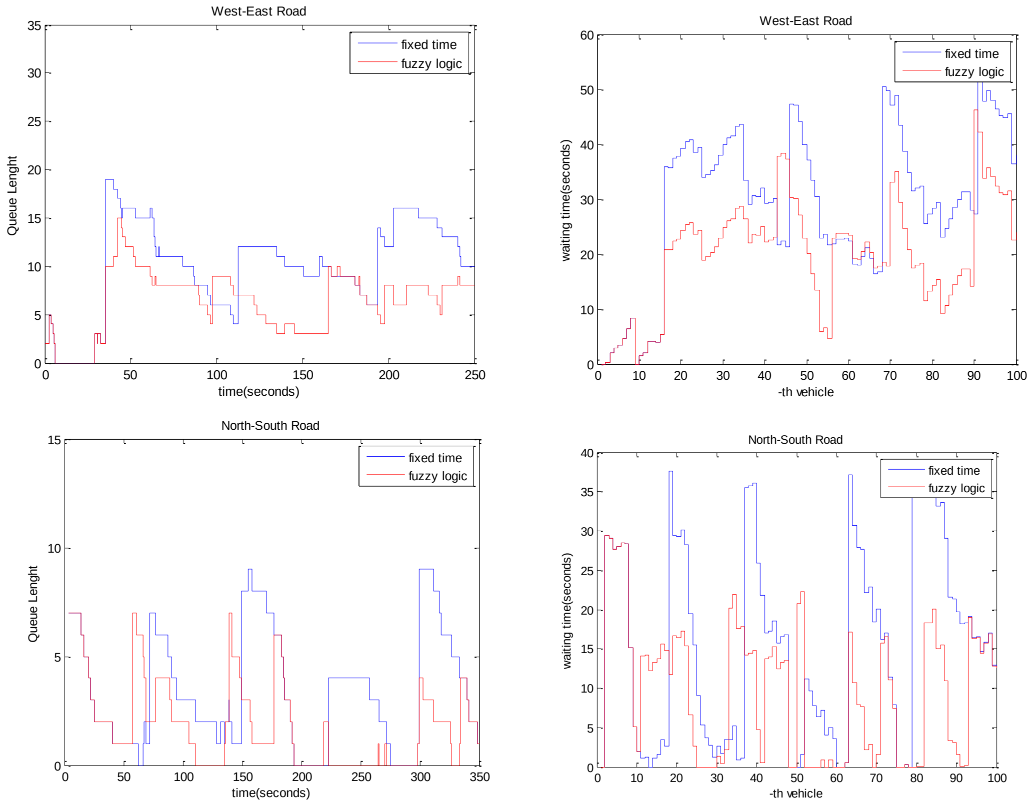

Figure 15. Comparison between the performance of fixed time traffic light and fuzzy logic traffic light

Table 4. shows the comparison of the average queue length and the average waiting time between the fixed time traffic light and the fuzzy logic traffic light

	Fixed Time Traffic Light		Fuzzy Logic Traffic Light		Decrease Percentage	
	W-E	N-S	W-E	N-S	W-E	N-S
Queue Lenght	9.36	4.11	6.13	2.73	34.50%	33.58%
Waiting Time	29.08	15.48	17.38	10.82	40.23%	30.10%

4. CONCLUSION

A smart traffic light control system has been developed based on multi-stage fuzzy logic and ant colony optimization algorithm. In Multi-stage Fuzzy Logic, the output of the first stage of the fuzzy logic system becomes the input to the next stage of the fuzzy logic system. The output of the fuzzy system is to determine the priority scale for the next green phase. Furthermore, Ant Colony Optimization algorithm calculates the optimal green time for that phase.

Based on the simulation results, it is found that by using smart traffic light control system compared to fixed time traffic light control system, there is a reduction in vehicle queue length and vehicle waiting time. In the case of the simulation, the average queue length was reduced by 34.04% and the average waiting time was 35.17%.

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