Fuzzy Signal Controller for Critical Intersections in Istanbul

A. Akbas[a,1] , V. Topuz[a,1], H.H. Celik[b,2] and M. Ergun[c,3]

[a] University of Marmara,
Vocational High School of Technical Sciences, 81040 Istanbul, Turkey

[b] University of Marmara
Faculty of Technical Education, 81040 Istanbul, Turkey

[c] Istanbul Technical University
Faculty of Civil Engineering, 34469 Istanbul, Turkey

Abstract: The Fuzzy Logic Signal Controller for 4-leg intersection, representing the urban road network is designed for this study. The input information of Fuzzy Signal Controller for each approaches in the intersection are the average saturation degree of flow that evaluated from microscopic flow data of the through. The microscopic flow data are measured by detectors located on the middle of the lines. These data are the information of green times for each signal plan. This controller evaluates the average saturation degree of each flow on the legs then calculates and decides the next green times after the previous green times for each cycle. After that signal times become more familiar with the dynamic of intersection flows. Finally, the performance developments by new Fuzzy Signal Controller are tested with VISSIM simulation space at the 4-leg intersection. Test results shows that there is an improvement about capacity usage and average delay times, when it is compared with the fixed time signal control systems.

Keywords: Urban traffic control; fuzzy signal control.

---

[1]E-mail: ahmetakbas@marmara.edu.tr, vtopuz@marmara.edu.tr
[2]E-mail: hcelik@marmara.edu.tr
[3]Corresponding author. E-mail: mergun@ins.itu.edu.tr,
URL: atlas.cc.itu.edu.tr/~ergunmur

1 Introduction

Some intersections in the urban road network have an influence on the general performance of urban traffic characteristics. For this reason, these intersections have a critical importance from the traffic signal control point of view. The flows in the different approach on these intersections, after that it can be called as critical intersections, are not regular along the day. These demand sometimes pass over the normal limit of each approach, sometimes not. To create control mechanisms for the signal plan, it can be generally used real time approach instead of fixed time approach, because of getting better performance at intersection [1].

Some traditional fixed time approaches such as TOD and MULTIPLAN may relatively give better performance increase at the intersections for present days. MULTIPLAN approach related with the change of signal plan due to the changing in traffic information, but TOD uses different signal plan for different time interval. The approaches are more similar with the modern signal approaches [2]. However, these approaches would be not suitable for every flow demand of the traffic at the intersection.

Today's traffic conditions that cause decrease in the performance of flow on urban road network can lead to development on the dynamic methods which are related with the real time signal planning and traffic actuated information. This necessity can be fulfilled with some real time signal controllers which are under developing or developed. These controllers mainly use some new artificial intelligence approaches.

The main aim of the artificial intelligence approaches is imitating of human brains with computer and the educating the skill of the brain partly. The artificial intelligence approaches try to model the thought skill, the working process, and the biologic evaluation of human brain. The main artificial intelligence approaches are Expert Systems, Fuzzy Logic, Neural Networks, and Genetic Algorithms [3,4,5].

Expert Systems can be qualified shortly as a rule based systems. The created rules are the experience or opinion the expert. These rules, the deduction can be drawn from the logical operations. Fuzzy logic can be thought as rule based system, but the deductions is not concrete as in expert systems. Fuzzy Logic makes the creation of the uncertain words of the rule based system used in daily life with this way.

The Fuzzy Logic Signal Controller is designed for applying on the critical intersection of the urban road network of Istanbul in this study. The 4-leg intersection geometry and 4 phases signal plan are chosen for modelling. The development gained by the Fuzzy Logic Signal Controller are tested with VISSIM simulation space at the 4-leg intersection. Test results shows that there are the improvement about capacity usage and average delay times, when it is compared with the fixed time signal control systems.

In the following sections; the basic considerations and the developed fuzzy controller have been introduced first. Then, the simulation based test studies which are realised in VISSIM simulation environment and their results have been introduced.

2 Basic considerations

The 4-leg intersection model and 4 phases signal plan are shown in Figure 1 as explained above. The left-turning, right-turning, and straight flow component of each flow at each approaches get the right the way at the same phase (along the green time). The demand of trough flow at each approaches is assumed bigger than the left-turning and right-turning flow. For this reason, the phases are calculated from the saturation rate of the straight flow. The traffic flow detectors are located at middle lane and stop line as shown in Figure 1.

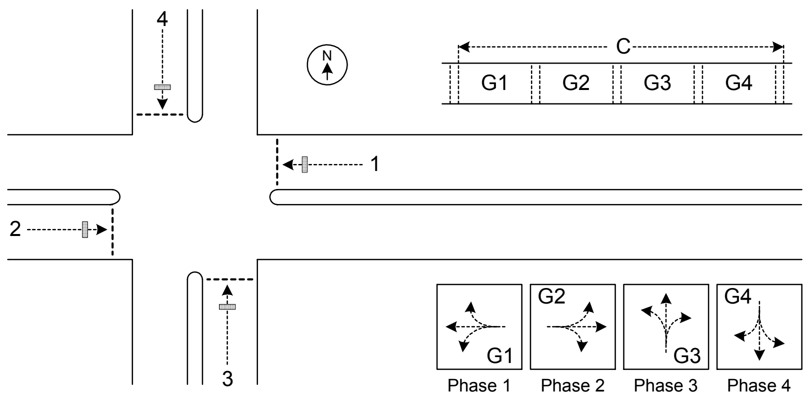


Figure 1. 4-leg 4-phase intersection model with its signal plan and phase plan representation.

The input of the Fuzzy Signal Controller is the average degree of saturation for each approaches that are calculated from microscopic flow data via these detectors. The output of the Fuzzy Signal Controller is the green time of 4 different signal group.

The macroscopic degree of saturation of the through flows are determined by using the microscopic flow parameters (vehicle occupancy time, number of vehicles) [2] obtained from the traffic detectors, due to the following equation at the end of every cycle time index (k):

$$DS_i(k) = \frac{\sum_{j=1}^{N_i(k)} o_j}{G_i(k)} \quad , \quad i = 1,2,3,4; \quad DS_i(k) \leq 1 \tag{1}$$

Here, i represents the phase (or signal group) number; $G_i(k)$ represents the phase duration for cycle time index k; $N_i(k)$ represents the vehicle count passed through the traffic detector along the green time duration; j represents the vehicle number and o_j is its occupancy time obtained from the traffic detector; $DS_i(k)$ is the average degree of saturation of the through flow for phase i at the time index k.

As shown in equation (1), the average degree of saturation are calculated by using cumulative occupancy times obtained through the green time period. So, the average degree of saturation obtained in this way can reflect the real traffic conditions in precision [6,7].

The new signal plan for each cycle is prepared from the green time calculated by Fuzzy Signal Controller and the phases diagram as shown in Figure 1. Then, signal timing is working with the harmony of the intersection dynamic. In the preparing processes of new signal plan, the total cycle tine, C, is founded from the addition of the green times (GT) and intergreen times (IGT). The intergreen times ,s chosen as a 2 second in this study. Consequently, the green times for each cycle is obtained from below equation.

$$C = 4 * \mathrm{IGT} + \sum_{i=1}^{4} G_i(k+1) \quad , \quad G_i(k+1) = \begin{cases} G_i(k+1) & \text{, if } G \quad \leq G \quad k+1 \leq G \\ G & \text{, if } G \quad k+1 > G \\ G & \text{if } G \quad k+1 < G \end{cases} \tag{2}$$

3 Fuzzy Signal Controller

Fuzzy Signal Controller decide the green times of the signal groups for the next signal cycle from the evaluation of the degree of saturation at the end of the each signal cycle measured by real time condition. The block diagram of the Fuzzy Signal Controller is shown in Figure 2.

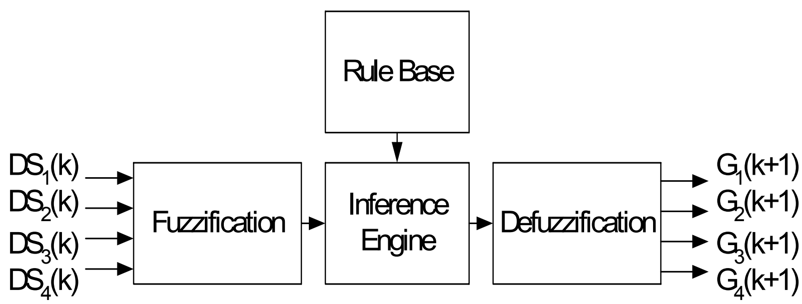


Figure 2. The block diagram of the fuzzy signal controller.

Here, $DS_1(k)$, $DS_2(k)$, $DS_3(k)$ ve $DS_4(k)$, represent the average degree of saturation of arm flows for actual cycle index k; $G_1(k+1)$, $G_2(k+1)$, $G_3(k+1)$ and $G_4(k+1)$ represent the phase (or signal group) green time for the next cycle time index. The inference engine of the Fuzzy Signal Controller is constructed from the Mamdani method. For the defuzzification of the Fuzzy Signal Controller, Centroid method is used.

For each input variable of Fuzzy Controller (*DS1,DS2,DS3 ve DS4*) is defined as 2 Fuzzy sets as shown in Figure 3. The membership function of these sets are chosen as a trapezoidal shape element.

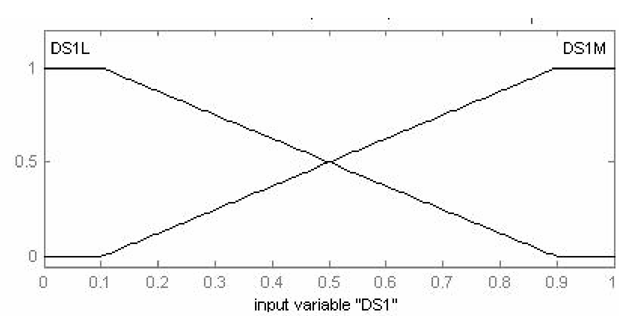


Figure 3. Fuzzy controller input membership functions for DS1.

For each output variable of Fuzzy Controller *(G1,G2,G3 and G4)* is defined as 3 Fuzzy sets as shown in Figure 4. The membership function of these sets are assigned from the minimum and maximum green times (G_{min}=5, G_{max}=40 sn) of the each signal group.

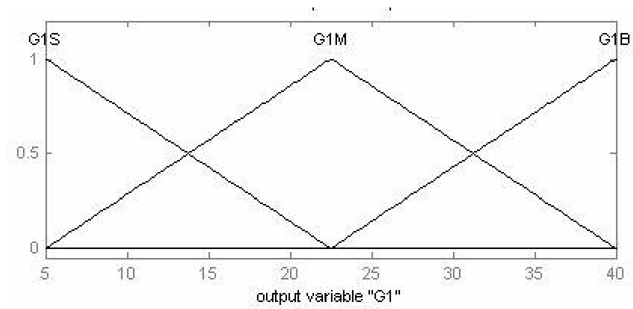


Figure 4. Fuzzy controller output membership functions for G1.

The 16 rules as shown in Table 1 is prepared by using Mamdani method. The view of created controller is shown in Figure 5 (using MATLAB and Simulink Package Program).

Table 1. Fuzzy controller rule base.

Rule	input variable				output variable			
	DS4	DS3	DS2	DS1	G1	G2	G3	G4
1	DS4L	DS3L	DS2L	DS1L	G1M	G2M	G3M	G4M
2	DS4L	DS3L	DS2L	DS1M	G1B	G2S	G3M	G4M
3	DS4L	DS3L	DS2M	DS1L	G1S	G2B	G3M	G4M
4	DS4L	DS3L	DS2M	DS1M	G1B	G2B	G3S	G4S
5	DS4L	DS3M	DS2L	DS1L	G1M	G2M	G3B	G4S
6	DS4L	DS3M	DS2L	DS1M	G1M	G2S	G3M	G4S
7	DS4L	DS3M	DS2M	DS1L	G1S	G2M	G3M	G4S
8	DS4L	DS3M	DS2M	DS1M	G1M	G2M	G3B	G4S
9	DS4M	DS3L	DS2L	DS1L	G1M	G2M	G3S	G4B
10	DS4M	DS3L	DS2L	DS1M	G1B	G2S	G3S	G4B
11	DS4M	DS3L	DS2M	DS1L	G1S	G2B	G3S	G4B
12	DS4M	DS3L	DS2M	DS1M	G1M	G2M	G3S	G4B
13	DS4M	DS3M	DS2L	DS1L	G1S	G2S	G3B	G4B
14	DS4M	DS3M	DS2L	DS1M	G1B	G2S	G3M	G4M
15	DS4M	DS3M	DS2M	DS1L	G1S	G2B	G3M	G4M
16	DS4M	DS3M	DS2M	DS1M	G1M	G2M	G3M	G4M

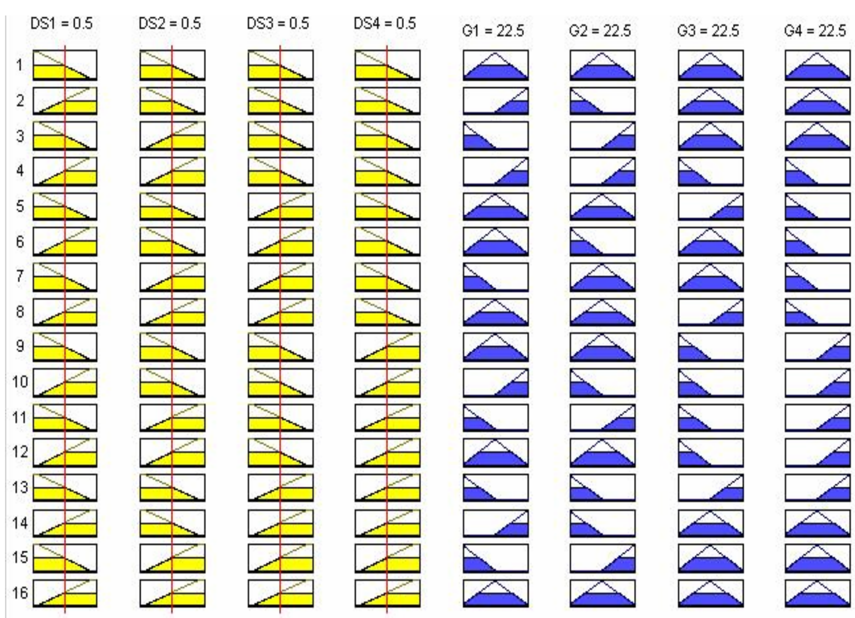


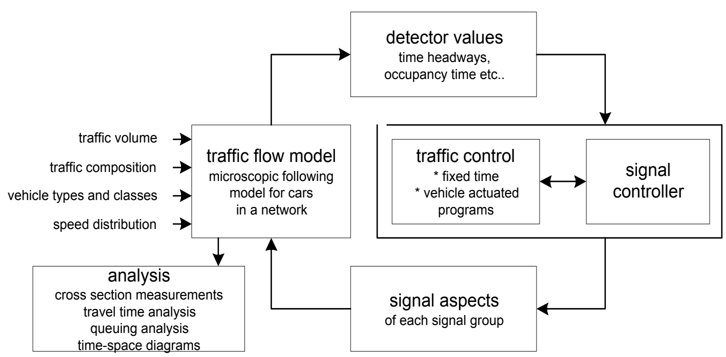
Figure 5. Fuzzy controller Rule Viewer screen in Simulink.

4 Simulation based Test Studies

Simulation based test studies have been realised in VISSIM simulation environment to compare the effectiveness of the fuzzy signal control, with respect to the fixed time signal control conditions. VISSIM (Verkehr in Stadten-Simulation; Traffic in Towns-Simulation) is a microscopic, time step and behaviour based simulation model developed to model urban traffic and public transit operations [8]. The program can analyse traffic and transit operations under the constraints such as lane configuration, traffic composition, traffic signals, transit stops, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness. VISSIM can be applied as a useful tool in a variety of transportation problem settings (Vissim, 2000).

The simulation package VISSIM consist internally of two different programs: traffic simulator and signal state generator. The traffic simulator is a microscopic traffic simulation program based on Weidemann statistical model including the car following and lane change logic. The signal state generator is a signal control software polling detector which processes information from the traffic simulator on a second by second basis. It then determines the actual signal status for the following second and gives this information back to the traffic simulator. The result of the simulation on-line is the animation of traffic operations and off-line the generation of output files gathering statistical data such as travel time, delay and number of stops (Vissim, 2000).

The block diagram, which shows the communication between traffic simulator and signal



state generator and interaction between the internal and external traffic data at VISSIM, has been shown in Figure 6.

Figure 6. Communication between traffic simulator and signal state generator at VISSIM.

Traffic control program can be transferred to the VISSIM test environment by using an additional program module VAP (vehicle activated programme). For this aim, control model is written as a text file by using the functions and commands of VAP. The fuzzy signal controller has been programmed in this way.

To evaluate the performance developments by using the fuzzy signal controller, first the geometric plan of the virtual 4-leg intersection model shown in Figure 1 has been created in VISSIM. Due to this apply, each the through flows, right turning flows and left turning flows are controlled by using 4-discrete signal groups. All the other approaching ways have 3 lanes.

The traffic scenario for 3 hours of simulations has been chosen as in Table 2. They are shown in this table, the vehicle inputs from all approaches and their distributions to the right turning flows, through flows and left turning flows.

Test1 has been completed for fixed time signal control; Test2 has been completed for fuzzy signal control case. Simulation processes have been repeated under the same traffic conditions for both test1 and Test2. Free flow speed have been accepted as 50 km/h; vehicle lengths have been accepted between 6 to 12 meters; traffic composition has been accepted as % 20 of heavy good vehicles for VISSIM simulations. For the Test1, the green times of the fixed time signal plan are chosen as G_1=20 s., G_2=20 s., G_3=20 s., G_4=20 sec and all the IGT=2 s.

Table 2. The traffic scenario used in the simulation based tests:
L, the left turning; R, the right turning; T, through flow.

simulation time (sec.)	0-3600	3601-7200	7201-10800
vehicle input 2 (W)	950	950	950
rel.flow (%R-%T-%L)	8 - 69 - 23	8 - 69 - 23	8 - 69 - 23
vehicle input 4 (N)	570	570	570
rel.flow (%R-%T-%L)	6 - 74 - 20	6 - 74 - 20	6 - 74 - 20
vehicle input 1 (E)	1000	1000	1000
rel.flow (%R-%T-%L)	5 - 81- 14	5 - 81- 14	5 - 81- 14
vehicle input 3 (S)	1200	1200	1200
rel.flow (%R-%T-%L)	7 - 77- 16	7 - 77- 16	7 - 77- 16
total demand (veh/hour)	3720	3720	3720

Through the simulations average delays and average number of stops has been established from VISSIM off-line analysis results in 10 minutes basis and arranged different graphics to show the performance developments.

5 Results

For the aim of performance analysis, delays and the number of stops have been measured from 4 different way segments each have 580 meters length on the through flow direction of each approach. So, obtained average delays and average number of stops must be evaluated for average length of 580 meters. For this length, the results obtained about the total delay and the total number of stops through the 3 hours of simulations have been shown in Figure 7 and Figure 8, respectively for the average delay and the number of stops.

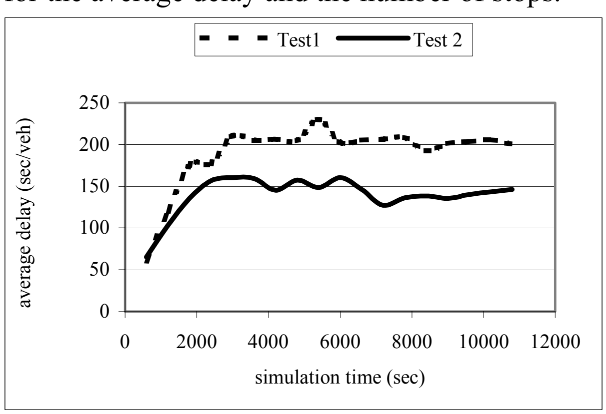


Figure 7. Test results for the total delay through the 3 hours of simulations.

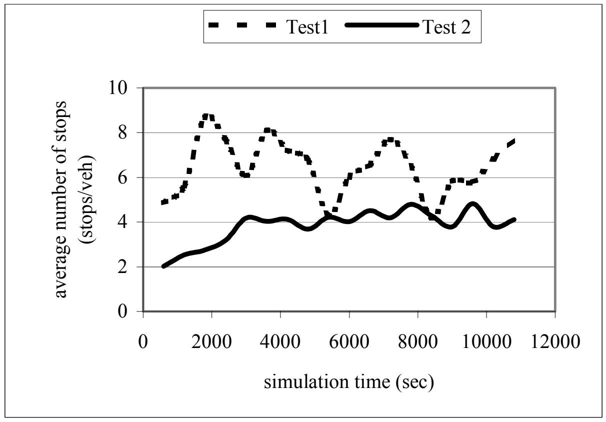


Figure 8. Test results for the total number of stops through the 3 hours of simulations.

According to the obtained results, average delays are 189.7, 139.2 sec./veh for the Test1 and Test2, respectively. Also, average number of stops are 6.46, 3.83 stops/veh for the Test1 and Test2, respectively.

Due to these results, the average delay is decreased %26.6 by the Fuzzy Controller, with respect to fixed-time control conditions. The average number of stops is decreased %40.7 by the Fuzzy Controller, with respect to fixed-time control conditions.

6 Conclusion

The test result shows that the Fuzzy Signal Controller is decreased the average delay and the average number of stop satisfactorily. The performance development gained from Fuzzy Signal Controller via simulation based test may be used for the solution of the Istanbul Urban Traffic Control Problem. It is expected the better performance of the intersection if these intersection is controlled by Fuzzy Signal Controller.

References

[1] Akbas, A., 2001, "*Optimal Control of Urban Traffic Signal System (Optimisation of Urban Traffic)*", Ph. D. Thesis University of Marmara , Istanbul-Turkey.

[2] Akcelik R., 1995, "*Traffic Signals Capacity and Timing Analysis, ARR123 Sept. 1995*", Australia.

[3] Lee J.H., and Kwang H.L., 1999, "*Distributed and Cooperative Fuzzy Cont. for Traffic Intersction Group*", Trans. on System, Man and Cyb. -Part C: App. and Rew., Vol.29, No 2, May, 1999.

[4] May, Adolph D., 1990, *Traffic Flow Fundamentals*, Prentice-Hall Publication, New Jersey.

[5] Mizar Automazione SpA, Torino, 1996, *Utopıa Urban Traffic Control Tech. Reference Manual*.

[6] Takashi, H., Hiroshi, I., 1975, *Road Traffic Control*, University of Tokyo Press, Tokyo.

[7] Teodorovic D., (1998). *Traffic Control and Transport Planning: A Fuzzy Sets and Neural Networks Approach.* Kluwer Academic Publishers, London, 1998.

[8] VISSIM- User Manual, (2000). PTV system Software and Consulting GmbH, Stumpfstraße 1 D-76131 Karlsruhe, Germany.