

# Using Fuzzy Logic to Control Traffic Signals at Multi-phase Intersections

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**Abstract** Theoretically, fuzzy control has been shown to be superior in complex problems with multi-objective decisions. Traffic signal control is a typical process, where traffic flows compete from the same time and space, and different objectives can be reached in different traffic situations. Based on recent research work, fuzzy control technology appears particularly well suited to traffic signal control situations involving multiple approaches and vehicle movements. Based on the results of our paper, we can say that the fuzzy control principles are very competitive in isolated multi-phase traffic signal control. The experiences and results of the field test and the calibration of membership functions with neural networks have been extremely promising.

## 1 Introduction

The control of traffic signals is one of a class of problems where a limited resource is required by a number of potential users, and the quantity of that resource is not always sufficient to meet demand. The users are competing against each other for a share of the resource and thus the control problem could be termed competitive. In the case of traffic signal control, the resource in question is green time, and the problem is made more complex by its temporal aspects and the ever-changing and stochastic nature of the demand. This means that the allocation of green time must be constantly reviewed as time passes and the traffic situation changes, in order to distribute it in the desired manner [4].

In general, traffic signal control is used to maximize the efficiency of existing traffic systems without new road construction, maintain safe traffic flows, minimize delays and hold-ups, and reduce air and noise pollution. Current traffic signal control is based on tailor-made solutions, and is poor at handling approaching traffic and cause and effect relationships. Fuzzy logic offers a number of opportunities in the field of adaptive traffic signal control. Fuzzy control has been successfully applied to a wide range of automatic control tasks, such as traffic signal control. Based on recent research work, fuzzy control technology appears particularly well suited to traffic signal control situations involving multiple approaches and vehicle movements [3]. The aim of this paper is to discuss the fuzzy traffic signal control process in general and to present the new results of fuzzy multi-phase control. The results are based on FUSICO-research project at Helsinki University of Technology in Finland.

## 2 Advantages of Fuzzy Control

Human decision-making and reasoning in general and in traffic and transportation in particular, are characterized by a generally good performance. Even if the decision-makers have incomplete information, and key decision attributes are imprecisely or ambiguously specified, or not specified at all, and the decision-making objectives are unclear, the efficiency of human decision making is unprecedented [2]. The benefits of fuzzy logic lie in its ability to handle linguistic information by representing it as a fuzzy set. Fuzzy logic simultaneously tests this information against a variety of linguistic rules and makes a compromise decision.

For example, a police officer controlling traffic at an intersection may outperform advanced intersection controllers, even though he does not exactly know how many vehicles have been waiting for how long, or what the exact magnitude of the capacity of the intersection is. In general, fuzzy control has proved an effective way and a systematic way of solving problems with multi-objective decisions, like traffic signal control with many conflict objectives (minimizing delays, maximizing traffic safety, and minimizing fuel consumption / CO<sub>2</sub>)

Fuzzy control also offers the benefits of a simple process structure and low maintenance cost, control adaptivity, fast evaluation time, and savings in material costs. Fuzzy signal control algorithms are also at least as good or even better in terms of effectiveness than traditional vehicle-actuated control.

## 3 Structure of Fuzzy Signal Controller

The design of an adaptive intersection controller naturally requires more than a suitable strategy of control. The physical and environmental design requirements have to be taken into account in the planning phase. Our fuzzy signal control process consists of seven parts (Figure 1); current traffic situation with signal status, detection and measuring part, traffic situation modeling, fuzzification interface, fuzzy inference (fuzzy decision making), defuzzification, and signal control actions. Basically, the fuzzy controller operates on a normal PC.

As much as possible the intelligence is left to the real controller, especially all safety functions. The fuzzy phase selector decides the next signal groups. Then the fuzzy green extender makes the decisions about exact timing and the length of the green phase (Figure 2). So, the main function of the fuzzy controller is to give correct orders for the signal groups. All physical and environmental design requirements are taken into account in the planning phase. One application is the use of neural networks for updating the parameters of the fuzzy membership functions.

The fuzzy controller has to collect data for the updating of the traffic situation model, which is the base of determination of signal sequence and timings. The traffic situation model contains the following elements; approaches, lanes, vehicles (size, driving characteristics), detectors, phase pictures and signal groups. The basic idea is that vehicles move along the lane according the driving dynamics and traffic models of HUTSIM-simulation program. Vehicles are generated based on detection. The

additional detectors give possibilities to match vehicle movement with detector pulses. The exact traffic situation data and the good traffic model also provide an opportunity to predict the changes in the traffic flow, for example during the next 10 seconds. The fuzzy decision algorithms, which are presented later, can use the outputs of traffic situation model as input. The fuzzy timing and selection algorithms make decisions based on this data and send the decisions to the controller unit and to the signal groups.

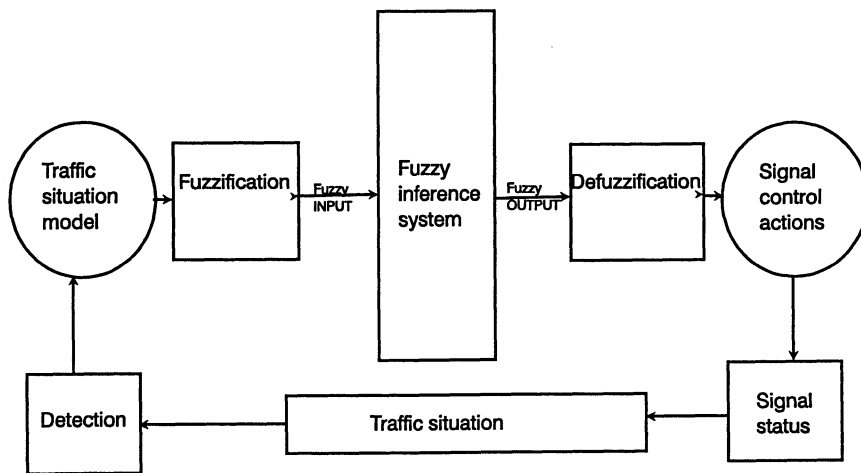


Fig.1. Fuzzy traffic signal processing.

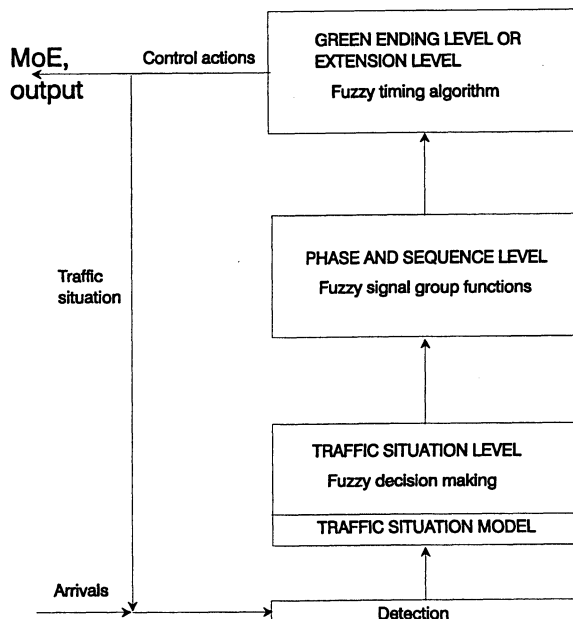


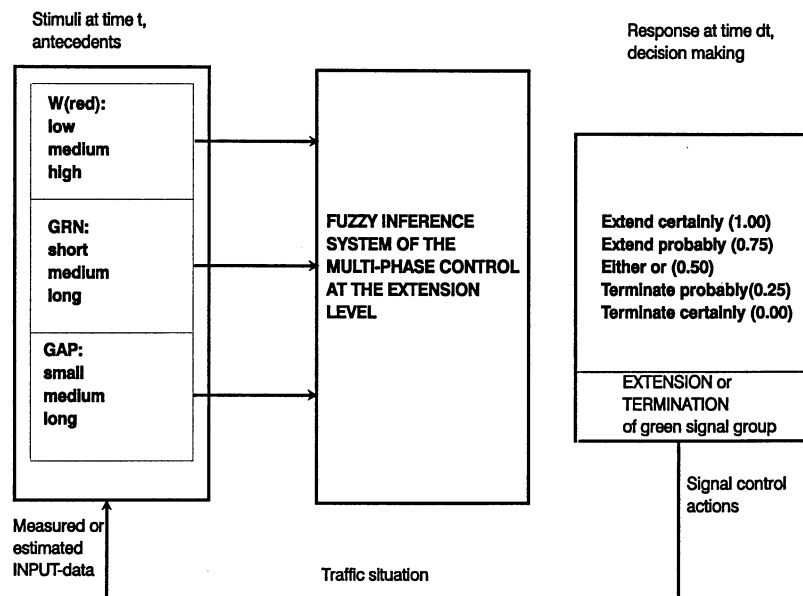
Fig.2. Structure of multi-level control algorithm.

## 4 Fuzzy Multi-Phase Control Algorithm

Based on Figure 2, the fuzzy rule base works at three levels:

1. *Traffic situation level*; the traffic situation is divided into three different levels (low demand, normal, oversaturated)
2. *Phase and sequence level*; the main goal of this level is to maximize the capacity by minimizing intergreen times.
3. *Green ending level or extension level*; the main goal of this level is to determine the first moment to terminate a signal group.

The fuzzy control system of the third level at the multi-phase control is shown in Figure 3.



**Fig.3.** The fuzzy control system of the extension level.

The fuzzy rules are

*If W(red) is low and GRN is short and GAP is long then extend probably (1)  
 ...  
 or if W(red) is high and GRN is long and GAP is small then terminate certainly (27) .*

*W(red) = weight of red signal group, number of queuing vehicles,  
 GRN = running green time of signal group,  
 GAP = last gap between two approaching vehicles at the detector 80-100 meters before stop line.*

W(red) is low	GRN			
	GAP	Short	medium	long
Small	1.00	1.00	0.75	
Medium	1.00	0.75	0.50	
Long	0.75	0.50	0.25	

W(red) is medium	GRN			
	GAP	Short	medium	long
Small	0.75	0.50	0.25	
Medium	0.50	0.50	0.25	
Long	0.25	0.25	0.00	

W(red) is high	GRN			
	GAP	short	medium	long
Small	0.50	0.25	0.00	
Medium	0.25	0.00	0.00	
Long	0.00	0.00	0.00	

**Fig.4.** Decision tables for multi-phase traffic signal control.

In the defuzzification part, the rules are located in five groups, and the maximum value of membership function of each group will be selected. The COG-method (center of gravity) calculates our extension ratio, which will be compared with the extension criteria (for instance 0.50).

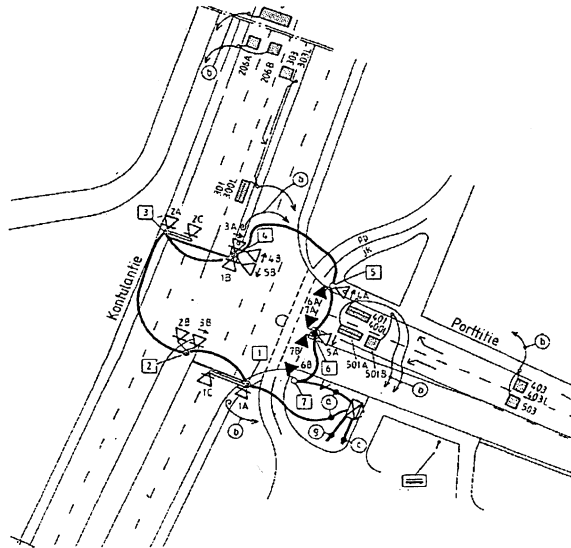
## 5 Testing and Compared Results of Multi-Phase Control

The testing of a new control scheme such as the problem at hand requires not only the algorithm for control but also a microscopic simulation model, which allows testing of many control schemes under a realistic setting. In this respect, a sophisticated simulation model is indispensable for development and testing of an advanced signal control algorithm. Our simulation package HUTSIM gives versatile possibilities to test different traffic signal control algorithms with each other.

HUTSIM is a simulation package that has been developed at the Helsinki University of Technology. In the original design, the simulation of adaptive signal control is done by connecting a real controller to the microcomputer (PC) based simulation system. For the development of new control methods, an internal controller system has been

included into HUTSIM. This system, called as HUTSIG, works so that the controller object has some measurement functions that are used to collect and analyze incoming detector data. The calculated indicators of the traffic situation are then transmitted to the control logic for timing decisions which are put into force by the group oriented signal control.

The comparison between fuzzy (FU) and vehicle-actuated (VA) control was made in real intersection in Helsinki, which was modeled for HUTSIM.



**Fig.5.** Layout of test intersection in Helsinki.

The simulation results proved that fuzzy control was competitive compared to traditional control methods. The compared measures of effectiveness (MoE) were average delay and percentage of stops. Totally, 18 different cases were tested :

**Table 1.** Simulation plan.

Major Traffic Flow	Minor/Major-ratio
200 veh/h	
400 veh/h	1:2
600 veh/h	1:5
800 veh/h	1:10
1000 veh/h	
1200 veh/h	

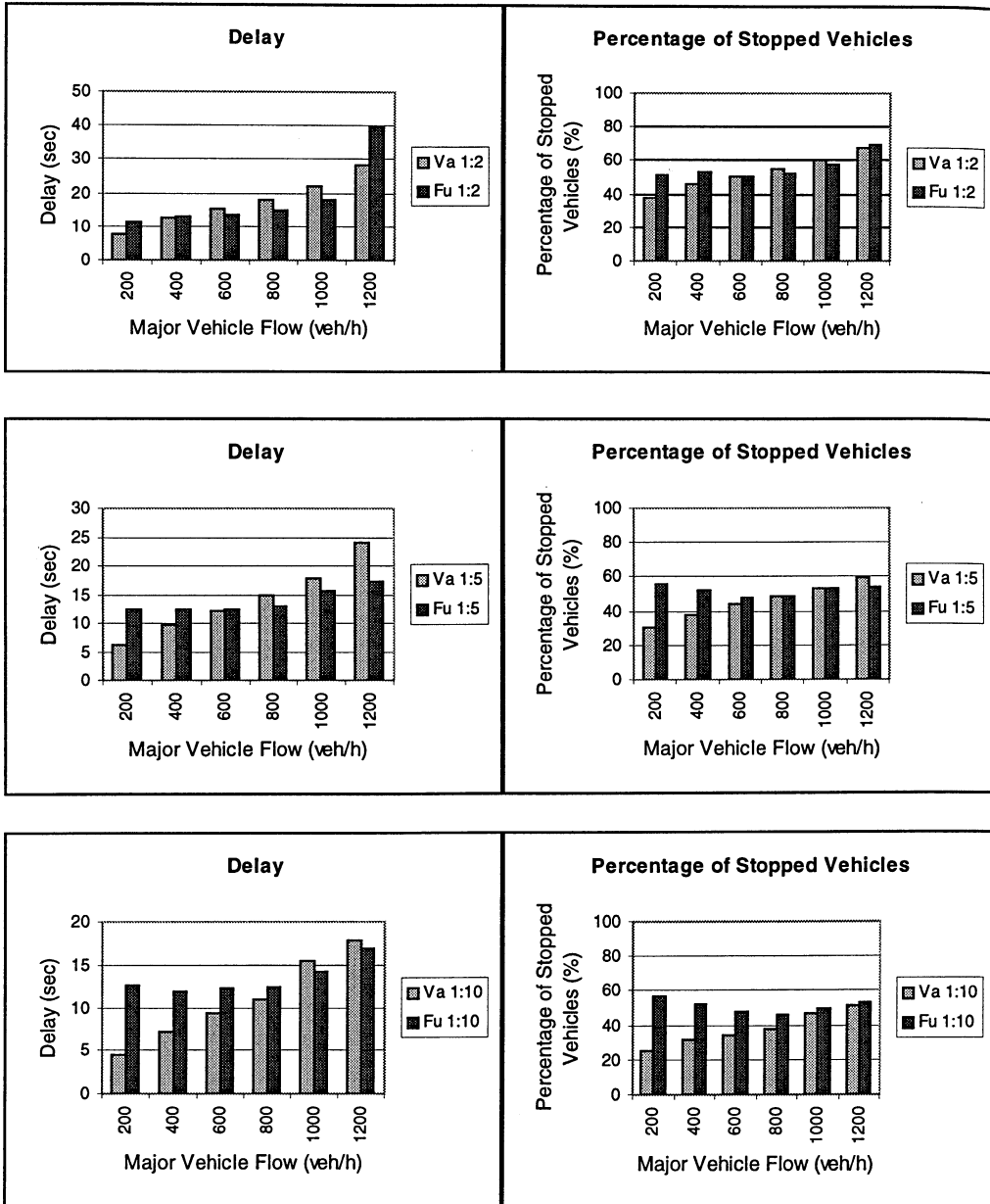


Fig.6. Compared results of VA- and Fuzzy-control.

## 6 Discussion of Results and Algorithm Development

The efficiency of our fuzzy algorithm was compared with the traditional vehicle-actuated control, called extension principle. The aim was that algorithm for comparison was as good as possible that is actually used in the reality. The simulation time of each case was 3600 s, and the simulated traffic situation was exactly the same in the

compared cases. The results prove that the extension principle is better traffic signal control mode in the area of very low traffic volumes. However, the results indicate that the application area of fuzzy control is available. If the major traffic flow is more than 500 veh/h, the results of fuzzy control were at least as good as the results of traditional control. According to the field measurements of test intersection, the real traffic volume of major flow varies between 600 – 900 veh/h and the minor/major-ratio is approx. 1:5. Based on this, we can say that fuzzy control principles are competitive in isolated multi-phase traffic signal control.

The better results of low traffic volumes can be achieved by using the second level fuzzy decision making with the fuzzy phase selector. Our simulations are based on only the decision making of the signal group extension. The main goal of the fuzzy phase selector is to maximize the capacity by minimizing intergreen times. The basic principle is that "signal group can be kept in green while no disadvantages to other flows occur". This is also called "the method to use extra green". The main decision of this level will be the right termination moment of the green.

The second goal of this level is to determine the right phase order. The basic principle is that the phase can be skipped if there is no request or if the weight ( $W(p)$ ) of this phase is low. This means that if the normal phase order is A-B-C-A the fuzzy phasing can, for example, give the orders A-B-A-C-A or A-C-A-B-C. The rules are a little bit complicated, when there are four phases, but the principle is the same as in the rules of three phases. The general principles of the rules are

- if  $W(p)$  is very high then phase p will be the next one,
- if  $W(p_i)$  is high and  $W(p_j)$  is zero then (i) will be the next one,
- the maximum waiting time of vehicle can not be too long.

For example, the rules of three-phase control can be

If Phase A is terminated then

- if  $W(B)$  is high then next phase is B or*
- if  $W(B)$  is medium and  $W(C)$  is  $mt(\text{high})$  then next phase is  $W(C)$  or*
- if  $W(B)$  is low and  $W(C)$  is  $mt(\text{medium})$  then next phase is C or ( $mt=\text{more than}$ )*
- if  $W(B)$  is  $lt(\text{low})$  then next phase is C. *( $lt=\text{less than}$ )**

The fuzzy factor  $W(X)$  is the fuzzy factor for the importance of the next phase, for example the number of queuing or arriving vehicles of each phase. The exact specification will be done later.

Bingham [1] studied a way to tune our fuzzy controller by updating the parameters of the membership functions. The objective was to construct a neural learning algorithm, which modifies parameters. The results were quite good, but the learning algorithm was not found successful at stochastic traffic situations. However, we believe that neural learning or/and genetic algorithms give us some new opportunities to handle the problems of traffic signal control. Especially, the fine-tuning of membership functions as a function of detector location can be solved systematically using neural learning.



## 7 Conclusions

A new control method, fuzzy logic, has been presented in this paper as a possibility for the traffic signal control of future. The results of our fuzzy traffic signal applications before (signalized pedestrian crossing and two-phase control) and now (multi-phase control) have indicated that the fuzzy control offers at least equal or better performance than the traditional vehicle-actuated control. We believe that fuzzy methods are well suited to almost all kinds of control, and the biggest benefits can be achieved in complicated intersections with multi-objectives. Theoretically, fuzzy control has been shown to be superior in complex problems with multi-objective decisions. Traffic signal control is a typical process, where traffic flows compete from the same time and space, and different objectives can be reached in different traffic situations. One basic advantage of fuzzy control is that it fires many soft rules simultaneously and makes a decision, which offers the compromise. Our first real fuzzy controlled intersection was installed in June 1998. The experiences of this field test have been extremely good, and we have plans to install three fuzzy controlled intersections more in 1999.

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