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**Adaptive Traffic Signalization Model using Neuro-Fuzzy Controllers**

**Devesh Batra\*, Pragya Verma**

\* Student, Stanford University, USA , Member, IEEE

[\\*deveshb@stanford.edu](mailto:*deveshb@stanford.edu)

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**Abstract**

Current traffic lights are pre-programmed and use daily signal timing schedules, which contribute to traffic congestion and delay. Thus, with the increase in the number of vehicles on road, need for adaptive signal technology arises which has the potential to adjust the timing of red, yellow and green lights in order to accommodate changing traffic patterns and ease traffic congestion. In this paper, we present a model for adaptive traffic signalization, which uses fuzzy neural network for designing traffic signal controller. The controllers use vehicle detectors in order to detect the number of incoming vehicles. Based on the number of approaching vehicles, the current signal phase is either extended or terminated. The traffic volume at one particular region in an intersection is compared with that in the competing regions of the same intersection. The decision made is thus robust and results in less congestion and delays.

**Keywords:** Adaptive Traffic Management, Adaptive Traffic Controllers, Fuzzy Logic.

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**Introduction**

Current Traffic Signal Control systems coordinate individual traffic signals to achieve network wide traffic operations objectives. These systems generally consist of intersection traffic signals, a communications network to tie them together and a central computer or network of computers to manage the system [1]. Coordination is generally implemented either through the use of time-based method or hardwired interconnection method.

The objective of the traffic signal control is to provide favorable signal timings to people on road. In order, to fulfill this objective, a system, which is responsive to real-time fluctuations in the congestion on road, is needed. Such a system consists of controllers, which can detect the number of approaching vehicles through an intersection and adjust the signal timings in order to minimize the waiting time on road. Thus, for those intersections, which consist of higher number of approaching vehicles, the duration of green signal is extended. On the other hand, for intersections with fewer number of approaching vehicles the green signal is either terminated or its duration shortened.

Design of such systems focuses on the implementation of various Artificial Intelligence techniques such as Neuro-fuzzy control, Bayesian control, Genetic control, etc. This paper focuses on design and assessment of Neuro-fuzzy Controllers for

detection and/or prediction of real-time traffic flow.

The paper is presented as follows: Some previous works on adaptive traffic signal control are presented in section II. The theoretical background to the proposed approach is presented in Section III. The methodology of the experiment is presented in Section IV, followed by the results and discussions in Section V. Finally; Section VI presents the conclusions of the findings in this paper.

**Related work**

There is a lot of research going on in order to make the traffic lights adaptive to real traffic demands and various models have been discussed in the literature for the same.

In [2] (2003), Q-learning, a simple yet powerful reinforcement-learning algorithm is introduced. The ability of a control agent to learn relationships between control actions and their effect on the environment while pursuing a goal is a distinct improvement over pre-specified models of the environment. The objective of this research involves optimal control of heavily congested traffic across a two-dimensional road network—a challenging task for conventional traffic signal control methodologies.

In [3], the two objectives- distributed learning and of agents and cooperation among agents correspond to localized reinforcement learning and global combinatorial optimization. The paper proposes the

method in which each agent performs reinforcement learning and reports its cumulative performance evaluation, and combinatorial optimization is simultaneously carried out to find appropriate parameters for long-term learning that maximize the total profit of the signals (agents).

[4] uses a fully distributed architecture in which there is effectively one only one (low) level of control. Such systems are aimed at increasing the response time of the controller, and incorporate computational intelligence techniques. A classifier system with fuzzy rule representation to determine useful junction control rules within the dynamic environment is implemented.

In [5], two modules - a Gate network (GN) and an Expert network (EN) are presented. The GN classifies the input data into a number of clusters using fuzzy approach, and the EN specifies the input-output relationship as in conventional neural network approach.

[6] investigates the applicability of autonomous intelligent agents in Urban Traffic Control (UTC). The UTC model is based on several Intelligent Traffic Signaling Agents (ITSA) and some authority agents.

**Theoretical Background**

**Types of Traffic Signal Control**

Traffic Signal Control can be broadly classified into three categories – Basic (Free) Operation, Coordinated (Time-of-Day) Operation and Adaptive Operation [7].

Basic (Free) Operation does not involve any kind of pedestrian or vehicle detection. They are commonly used for isolated intersections and the Green times are programmed on the basis of demand anticipation.

The Coordinated (Time-of-Day) Operation is used in corridors or downtown grid signal systems. Cycle, Offset and Splits are the key parameters that are typically programmed for anticipated demand at different time periods.

Adaptive Operation requires vehicle detection. Most systems dynamically adjust Cycle, Offset, and splits on the basis of current and historical demands.

**Phase Split, Offset and Cycle**

Each signalized intersection movement is known as a phase [7]. Thus, a four-way intersection with left-turn arrows has 8 phases.

Split time is defined as the summation of duration of green, yellow and all red.

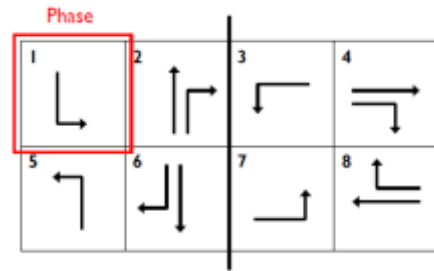


Figure 1: Phase

Phase split times are programmed to account for demand. Duration can also be shortened with vehicle detection.



Figure 2: Phase Split

Cycle is defined as the total time it takes to serve all phase splits. It can be expressed as shown in figure 3.

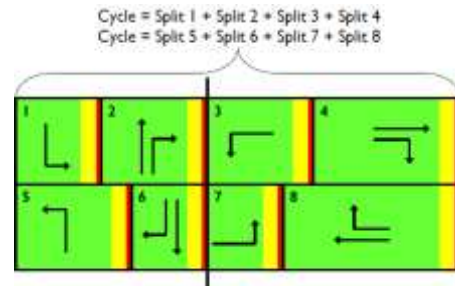


Figure 3: Cycle

**Fuzzy Logic**

Fuzzy logic is an approach to computing based on "degrees of truth" rather than the usual "true or false" (1 or 0) Boolean logic on which the modern computer is based that is, Fuzzy logic includes 0 and 1 as extreme cases of truth (or "the state of matters" or "fact") but also includes the various states of truth in between [8].

A Fuzzy set can be defined mathematically by assigning to each possible individual in the universe of discourse a value representing its grade of membership in the fuzzy set. Mathematically, it can be represented as following

$$\mu_A: X \rightarrow [0, 1]$$

Where  $[0, 1]$  means real numbers between 0 and 1 (including 0 and 1).

Certain properties are given to fuzzy sets like increasing, decreasing or convex, according to properties of a membership function that characterizes the fuzzy set.

Figure 4 shows the graphical representation of a fuzzy set.

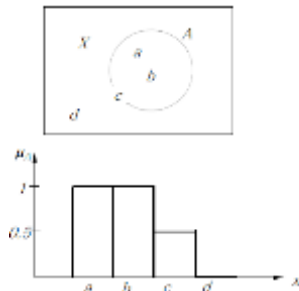


Figure 4: Graphical Representation of a fuzzy set

The value of membership degree might include uncertainty. If the value of the membership function is given by a fuzzy set, it is a type-2 fuzzy set. This can be extended up to Type-n fuzzy set [9].

The basic set operations such as union, intersection and complement can be applied to fuzzy sets.

### Methodology

This section presents the methodology used for simulating the real traffic conditions at an isolated signalized intersection. A typical isolated intersection consists of four approaches.

The detectors used at these intersections count the number of approaching vehicles from each approach direction. The approach directions are North, South, East and West. These are represented by the notations  $O_{north}(t)$ ,  $O_{south}(t)$ ,  $O_{east}(t)$  and  $O_{west}(t)$  respectively during the time interval  $dt$ . In order, to detect the number of turning vehicles, a detector is needed at the turning points. These detectors can only detect the presence of vehicles but not count the number of vehicles present.

No. of vehicles waiting in a queue

Let  $Q_{north}(t)$ ,  $Q_{south}(t)$ ,  $Q_{east}(t)$  and  $Q_{west}(t)$  represent the number of vehicles waiting in a queue at any time  $t$ .

The maximum detectable queue length by the system for each lane is given by the following equation,

$$Q_{limit} = D/l,$$

where  $D$  is the distance between the detectors and the stop line and  $l$  is the average length occupied by each vehicle waiting in the queue.

Queue Length during a through phase

The queue length on a through approach is a function of the detected approach flow  $O_a(t)$  during the last time interval  $dt$  and previous time interval  $t-dt$ , and the phase of the signal.

During red signal, the queue length can be mathematically represented by the following,

$$Q_a(t) = Q_a(t-dt) + O_a(t)$$

$$Q_{lta}(t) = \min \{ Q_{lta}(t-dt) + O_{lta}(t), Q_{bay} \}$$

Similarly, during green signal the queue length is represented as follows,

$$Q_a(t) = \max \{ \min \{ Q_a(t-dt) + O_a(t) - nOS(t), nQ_{limit} \}, 0 \},$$

$$Q_{lta}(t) = \min \{ Q_{lta}(t-dt) + O_{lta}(t), Q_{bay} \}$$

Where  $OS(t)$  is the discharge flow within time step  $dt$ , which is defined as:

$OS(t) = 0$  during the lost time (i.e., the first  $T_{lost}$  seconds at the start of the green interval),

$OS(t) = S$  otherwise.

$S$  is the saturation flow rate, i.e., the maximum discharge flow rate.

First Stage: Neuro-fuzzy Controller

The Neuro-fuzzy controller is used to determine whether to extend or terminate the green phase. The decision is based on dynamic traffic conditions. The controller is activated after a fixed time period which can be represented by  $T_{min}$ . Also, the length of any green phase cannot exceed a maximum time limit. Let this maximum time period be denoted by  $T_{max}$ .

The fuzziness of a signal control can be divided into three levels: input, control, and output level [10]. The input level consists of the prevailing traffic situation. Since, the cause-consequence relationship of a signal cannot be explained; the best or the right possibility cannot be selected at the control level.

Thus, the first stage consists of fuzzy interpretation of the flows and queues on all approaches to obtain a fuzzy description of traffic intensities.

Second Stage

The second stage of the fuzzy controller is used to determine whether the current green phase is to be extended by some time period or terminated immediately. The inputs to this stage are the traffic intensities during the green and red phase respectively. The output can be either to extend (E) or terminate (T) the current green phase.

The rules for switching traffic signals are as shown in Table 1.

Table 1: Fuzzy Rules for switching traffic signals

Traffic Intensity (Red)	Traffic Intensity (Green)			
	Zero	Small	Medium	Big
Zero	T	E	E	E
Small	T	E	E	E
Medium	T	T	E	E
Big	T	T	E	E

**Results and discussion**

According to the report, *Transport demand forecast study & Development of an integrated road cum multi-modal Public Transport Network for NCT of Delhi* prepared by RITES, the volume capacity ratio of key areas is as shown in figure 5 [11].

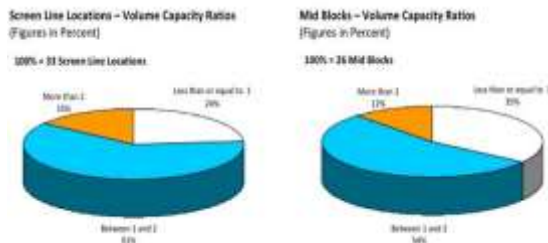


Figure 5: Volume Capacity Ratio of roads at key locations in Delhi.

Also, the number of registered vehicles in Delhi is more than 6.0 million [12]. It has been observed, that the number of vehicles on road is constantly increasing. This increase in the number of vehicles can be represented by the graph shown in figure 6.

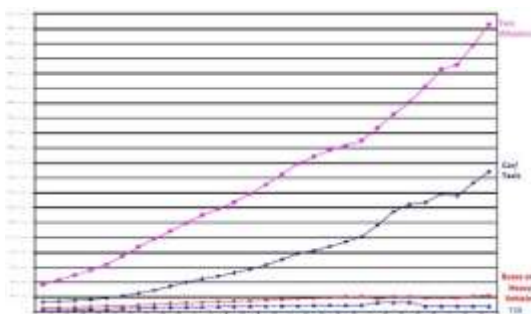


Figure 6: Increase in number of vehicles on road

Coordinated (Time-of-Day) Operation and Adaptive Operation are compared on the basis of Cycle, Offset and Phase split.

Cycle length, observed during Coordinated Operation is fixed. Whereas, that observed during Adaptive Operation is longer for congested periods and shorter for off-peak hours.

For conventional traffic signal control methods, the offset is pre-programmed on the basis of anticipated traffic flow. On the other hand, for adaptive traffic signalizations the offset is adjustable and accommodates inbound vs. outbound traffic. It also accounts for change in traffic speeds due to severe weather.

Phase Splits are also pre-programmed on the basis of anticipated traffic flow in the case of coordinated (Time-of-Day) Operation. For, Adaptive Operation, more/less time is given for turning movements and side streets depending on the dynamic traffic flow.

Adjustable cycle length, phase split and offset is obtained with the help of Neuro-fuzzy controllers, which can detect the approaching vehicles. Fuzzy sets are used to determine the degree of saturation and the offset between adjacent signals to minimize stops in the dominant approach.

**Conclusion**

In this paper, a model for implementation of Neuro-fuzzy controllers was suggested in order to make the traffic signal operations adaptive to real-time approaching traffic. Neuro-fuzzy controllers were used to adjust the cycle length, offset and phase split. Fuzzy sets were used to determine the degree of saturation on the basis of which the three parameters were made adjustable to dynamic approaching traffic flow. Results obtained from the deployment of Neuro-fuzzy controllers shows reduction in vehicle delays as compared to that observed for Coordinated (Time-of-Day) operation while the number of stopped vehicles was proportionate in both cases. The Neuro-fuzzy controller regularly investigates the traffic condition in order to make a decision either in the favor of extending or terminating the current green phase. Adaptive traffic Signalization is found to be more effective in scenarios where the traffic is non-recurring and cannot be estimated beforehand. Adaptive Operation is also found to be superior to Basic (Free) or Coordinated (Time-of-Day) operation in terms of average vehicle delay. Last but not the least; cost of installation of the discussed Neuro-fuzzy controllers is also comparable to the cost of coordinated (pre-timed) controllers.

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