Modeling of vehicle delays at signalized intersection with an adaptive neuro-fuzzy (ANFIS)

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An adaptive neuro-fuzzy inference based delay estimation system is proposed. The system is compared with other delay estimation models, and tested through simulation and observation values. Rules, fuzzification and inference are modeled by neuro-fuzzy. Hybrid algorithm has been used for training and tests. The rule base of the delay estimation system is constructed either following a mathematical model or from real-time traffic operational data. This study has shown that adaptive neuro-fuzzy technique, a method to predict vehicle delays at signalized junctions, can be successfully applied to modeling of traffic systems.

Keywords: Delay estimation, Hybrid algorithm, Neuro fuzzy, Signalized junction

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Introduction
In order to minimize vehicle delays on roads and evaluate alternative junction construction projects, the amount of delays should be estimated with high accuracy. There are numerous works¹-³ that employ fuzzy logic and artificial neural networks on signal control and vehicle delay estimation at signalized junctions. Neuro-fuzzy systems profit from both the linguistic, human-like reasoning of fuzzy systems and the powerful computing ability of neural networks⁴-¹³. This study develops a neuro-fuzzy logic based system using a mathematical model in a simulation study for estimating vehicle delay at a junction.

Adaptive Neuro Fuzzy Inference System (ANFIS)
In this study, sub-clustering in ANFIS structure and hybrid algorithm in training stage are used (Fig.1)¹⁴. The values for this model in the training for sub-cluster parameter training stages are determined as: range of influence, 0.53; squash factor, 1.28; accept ration, 0.52; reject ration, 0.16; and epoch, 55. Hybrid learning has following parameter: nodes, 46; linear parameters, 20; nonlinear parameters, 30; total number of parameters, 50; fuzzy rules, 5; training error, 0.2160; and testing error, 0.5921 (Fig. 2).

Delay Models
Delay is the most frequently used measure of effectiveness for junction operations. The most frequently used forms are: i) stopped delay; ii) approach delay; and iii) control delay¹⁵.

Stopped delay is the time a vehicle is stopped at a junction. Average stopped delay is the total stopped delay

Fig. 1—ANFIS structure for delay
experienced by all vehicles arriving during a designated period divided by the total vehicle volume. The stopped-vehicle count technique is the most common approach to measure stopped delay, highway capacity manual (HCM)\textsuperscript{16}. Stopped delay is easier to measure in the field than other delays. Therefore, it has been the traditional performance measure used to determine the level of service at signalized junctions.

Approach delay is the difference between the time used by any vehicle to travel a fixed distance from a prespecified point upstream of a junction to the junction stop bar, and the free-flow time associated with that distance\textsuperscript{17}. Approach delay is often obtained from stopped delay.

Control delay is total delay at signalized junction. It includes deceleration, stopped and acceleration delays. Collection of such delay information is labor-intensive, time-consuming, and expensive\textsuperscript{18}.

**Webster’s Delay Formula**

Probabilistic delay equation, developed by Webster\textsuperscript{19}, gives average delays as follow:

\[
d = \frac{C(1 - \lambda)^2}{2(1 - \lambda x)} + \frac{x^2}{2q(1 - x)} - 0.65 \left( \frac{C}{q} \right)^{1/3} x^{2.5} \lambda \quad ...(1)
\]

where, \(d\) = average delay per vehicle, sec/veh; \(C\) = cycle length; \(g\) = effective green time for each lane; \(q\) = vehicle arrival rate; \(\lambda\) = proportion of the cycle that is effectively green for the phase under consideration (that is, effective green/ cycle time), g/C; \(x\) = saturation degree ((volume-to-capacity ratio \((x=q/\lambda, s))\)); and \(s\) = saturation flow, veh/sec. Increase in the delay is a function of saturation degree and the lane capacity. Average delay per vehicle become infinite for \(x=1\) in Webster equation, that is, the equation is applicable for values of \(x\) not greater than 1.0 (\(x<1\)).

**High Capacity Manual (HCM) Delay Formula**

HCM delay formulation is

\[
d = d_1 + d_2 \quad ...(2)
\]

\[
d_1 = \left[ \frac{0.38 C \left( \frac{(1 - g / C)^2}{1 - (g / C) x} \right)}{1 - (g / C) x} \right] \quad ...(3)
\]

\[
d_2 = 173 x^2 \left( x - 1 \right) + \sqrt{(x - 1)^2 + 16(x / c)} \quad ...(4)
\]

where, \(d_1\) = average uniform delay, \(d_2\) = average incremental delay due to random and over-saturated queues, and \(c\) = lane capacity in vehicles per hour. This formula\textsuperscript{20} gives reliable results for \(x\) smaller than 1.2.

**Doherty Delay Formula (DDF)**

DDF is applicable for the cases when junction is loaded under its capacity, otherwise it cannot be used. However, there can be above capacity incoming flows with short time periods, resulting in an overloaded system. This situation cannot last for long periods, otherwise queue length and hence delays go to infinity and system breaks down. In this respect, a system overloaded for a short period first eliminates excessive load in the following period with under capacity flow and then continues its normal operation. This situation is encountered in city junctions especially at rush hours (morning, noon, evening).

DDF to handle this situation is,

\[
D(x, t) = A + N - M / 4. Q \quad ...(5)
\]
M = 2c + t.Q (1-x) ...........................................(6)
N = ( M2 + 8c.Q.t.x)1/2 .............................................(7)
A = C/2(1 - λ)2 .........................................................(8)

where, t= vehicle arrival time, x= saturation degree, c= a constant dependent on the vehicle arrival and service time (0.5), Q (APP)= approaching way capacity (λs), C= time period, and A= a constant that represents the average vehicle delay for very small flows. DDF gives average delay time\(^2\) of vehicles arriving at time \(t\) with saturation degree \(x\) under the assumption that the initial queue length is 0 at time \(t\).

**Simulated Model**

**Operation Rules**

In the simulation model\(^{22}\), although the real system is tried to be transformed into the model, for the sake of simplicity irrelevant parameters are not taken into account. In the simulation model developed, some logical assumptions were made with this aim.

The operation rules of simulated model are: i) The simulation starts with the red light turning on and at that time it is supposed that there isn’t any vehicle in the lane of junction; ii) It is supposed that the traffic flow is random and the period of the coming vehicle is driven by a negative exponential distribution; iii) When a vehicle is formed, it follows the harmony of the light [if green light is on, this vehicle will pass on without waiting and if the red light is on, it will stop behind the stop line and it will be delayed. Therefore the number of the vehicles at the queue increases (added one)]; iv) It is assumed that the vehicles waiting at the red light disperse equally to the lines of the approaching lane; v) The vehicle queue or queues subjected to delaying during the red light discharge when the green light turns on (The delaying will continue until every vehicle arrives at the stop line. When the green light turns off, if there are any vehicles at the queue their delay will continue); vi) The simulation assumes only one kind of vehicle as passenger car; vii) The accidents, which can happen in junction and the effect of pedestrians on the vehicle traffic, are not taken into consideration; viii) The simulation time unit is second and time progress method was used; ix) Double exponential headway distribution function has been used for vehicle arrival internal (If \(S\)=1, the flow will be a dependent function or if it is \(S\)=0 it will be an independent one. The form at the equation will be negative exponential and double exponential respectively. The dependent and independent flow percentages in the function are calculated by Salter equations\(^1\)); x) For one way and double line roads, \(S=0.00158Q – 1.04222\) where; \(S\) is the rate of dependent vehicle, \(Q\) is the traffic volume that is between 660 veh/h and 1295 veh/h; xi) In this simulation program, all the vehicle delays are one to one calculated and then are summed up after individual calculations (Average delay per vehicle has been found by dividing this total amount by vehicle number); xii) Input data required for simulation models are, the average traffic flow at the approaching lane (veh/h), the number of lines at the approaching lane, the simulation period, the minimum gap between vehicles, the periods of red, yellow and green light; xiii) The output data from the simulation model are the list of the input data, the period since the beginning of the simulation, traffic flow (the number of vehicle arrivals at the junction leg), queue (the number of vehicles in the queue), cumulative total of vehicle headway and delaying.

**Simulations and Comparison**

Traffic flow and vehicle delays at signalized junction of “50th year avenue in Erzurum-Turkey” are determined by observation. Vehicle delays are calculated by getting the difference between the time vehicle enters the queue and the time it passes the stop line. Then total delay is found by summing individual delays and average delay per vehicle is calculated by dividing the total delay by the number of vehicles. In simulations, vehicle delay values are calculated using the equations and Signal Simulation Model (SSM). ANFIS is trained using half of the values obtained from SSM and other half is tested with ANFIS.

Composing prediction delay values for a period of 1600 sec, 165 vehicles, average vehicle delay is: observation, 11.55; Webster, 21.16; HCM, 15.59; DDF, 18.55; SSM, 12.354; and ANFIS, 12.10 sec. SSM and ANFIS values are close to the observation values (Table 1, Fig. 3). Webster, HCM and DDF values are not so successful. Standard deviations (\(S_{\text{webster}} = 91.00, S_{\text{HCM}} = 15.09, S_{\text{Doherty}} = 30.80, S_{\text{SM}} = 0.79, S_{\text{ANFIS}} = 1.55\)) calculated as per Eq. (9) are used as a very simple statistic to compare method performances. Lower standard deviation means a better modeling approach, thus a better estimation capability.

\[
S_{\text{SSM}} = \sqrt{\frac{\sum(\text{observed} - \text{SSM estimated})^2}{n - 1}} \quad \cdots (9)
\]

SSM and Observation of the neuro-fuzzy system have shown that neuro-fuzzy logic based modeling is a
promising approach for improving junction delay estimation (Fig. 3).

Conclusions

An adaptive neuro-fuzzy inference system based delay estimation system is proposed, compared with other delay estimation models, and tested through simulation and observation values. Neuro-fuzzy has three input variables representing simulation of the time (TIME), number of approaching vehicles in the green direction (APP) and number of queuing vehicles in the red direction (QUE). The test results of ANFIS are compared with Observation, Webster, HCM, Doherty, and SSM (Fig. 3). It is observed that neuro-fuzzy technique can be successfully applied to modeling of traffic systems.

References