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Adaptive Neuro-fuzzy Controller for Double Lane Traffic Intersections

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ABSTRACT

Traffic Control System plays a key role in overall safety of traffic and pedestrians. These prompt idea of Adaptive Traffic Light Controller based on Neuro-fuzzy techniques which were used in controlling traffic so as to design and simulate a hypothetical T-junction intersection traffic scenario to achieve congestion free and smooth traffic condition with special consideration of traffic length, presence and absent of emergency on traffic using priority. The developed system considered five input variables one output variable, All the input, were obtained by detectors/sensors lock, which process and converts the crisp value of inputs into the fuzzy value and they were mapped with three linguistic variables (Low, Average, High), Gaussian membership function was used to fuzzify all the variables, the objectives of the work were design an adaptive neuro-fuzzy based model to control vehicle movement in a double lane traffic intersections, which were simulated using MATLAB integrated development environment and performance evaluation of the system shows highly perfect in achieving the desire objectives.

Key words: Traffic Control System, Gaussian membership function, congestion, Congestion Estimation, Fuzzy Inference, Fuzzy Logic Controller, Traffic Light Duration.

1. INTRODUCTION

Traffic Control System plays a key role in overall safety of traffic and pedestrians. A traffic light control system is mainly situated at road junctions, intersections and pedestrian crossings. It is an intensive method that allows efficient use of existing road in order to promote movement of human and goods in a safe, effective, convenient and efficient manner [1]. Controlling congestion, detection of incidents and control of traffic light are the sub areas of traffic light control. Traffic light and controller unit as highlighted by [2] are the two parts of traffic light control systems.

Traffic signal usually have different three indicator lights: a red signal implies ” stop”, a green signal implies “go” and a yellow sometime called amber signal implies “ready to go”; which are used to control traffic movement at busy road intersections. Designing of traffic signals was conceived to ensure safe as well as well-ordered flow of traffic, protection of pedestrians and vehicles and reduction of casualties and several accidents between pedestrians and vehicles alike entering major intersections.

Organized movement on traffic, improved capacity of the major intersection and required only uncomplicated geometric design are merits of traffic control [3]. However, inadequate traffic control may lead to adverse effects of long queues and delay, collision, noise and air pollution as well as complexity in the design and implementation.
There are two notable classes of traffic light control, which are Fixed-Time (FT) traffic signal which simply based on mechanism control and Real-time (RT) traffic signal which based on algorithm control.

Most literature refers to the latter as Traffic-Responsive control, Dynamic traffic light control, automated traffic control system. For the essence of this research work, traffic responsive control will be used throughout this research work.

2. RELATED WORKS

Traffic congestion had been identified as the major problem requiring intelligent traffic control system. A number of works on traffic light controller are presented. [4] presents a fuzzy logic control system that will control the traffic movement approaching the major intersection sets.

Resulting from number of traffic approaching the junctures, an adaptive Fuzzy Logic Traffic Controller (FLTC), designed using hybrid Fuzzy and Genetic algorithm, are used in regulate the "ready to go" phase which is (green indicator) to divide north-south from east-west approaching traffic indicator lights.

The research study is however inadequate as the vehicles that can be identified by the traffic sensors cannot exceed twenty, because it was presumed that individual vehicle in length is about four metres. Distance in one metre between individual vehicle when on motionless, and waiting on queue for green light to turn on.

An adaptive neuro-fuzzy inference system which was developed by [5] was examined in traffic indicator lights controlling. Given a set of input traffic signal dataset, the developed Adaptive Neuro-Fuzzy Inference System (ANFIS) drew up its own corresponding rules and membership functions. Therefore, achieving its own model design, process easily and dependable in comparison with fuzzy logic standard controllers.

Usually utilized as meaningful inputs to fuzzy indicator signal systems are distance between two different vehicles, hold on queue at intersections, flow of vehicle and its density determined by traffic and length of each vehicle. Taking into account the real fuzzy applicability, the average delay of each vehicle influx rate of traffic lane was taken in this study as inputs to the adaptive neuro-fuzzy model signal controller while green light time of one traffic lane is taken as the system's output.

Results show better performance of low average retard of vehicles on stop light which is red indicator light and better synchronicity of "ready to go" phases which is green indicator light. Comparison with the fixed light system, the nuero-fuzzy system minimizes delays at both junctions. When the traffic conditions are changed abruptly at one junction, the green light time periods of both intersection changes accordingly, adapting to the current vehicle movement conditions. [6] identified the needs in addressing the difficulty in controlling intersections and managing available traffic flow indicator.

The goals of this research are to develop an understanding fuzzy logic system for traffic administration in controlling of traffic indicator at major intersection which aimed at minimizing the delay time. The research work provides a solution for controlling intersections by prioritizing the paths, but the research work was not implemented. [7] stated that traffic indicator in controlling of fuzzy which can be seen as major likely solutions to incoming generation on traffic indicator control glitches.

The objective of this paper is to present an adaptive three-phases of fuzzy logic traffic controller signals. Based on the rolling horizon approach, a GA-based heuristic integrated with the golden ratio searching is developed to learn the optimal parameters of fuzzy controllers. The limitations of this work is that it is difficult to extend this method to control multiple intersections of an urban network, this is because parameters of the fuzzy controller are updated by using genetic algorithm to search in the efficient solution set.

For the need to tackle the growth of population traffic congestions that facing cities and metropolitans, [8] developed an adaptive traffic indicator light in order to deal with the difficulty of congestions on traffic. The research work used the dataset that was compiled from Amman works. This dataset contained several intersections. Individual intersection had various cycle and all these individual cycle are to designate unchanged particular cycle time in accordance to cycle subordinate to attribute to get a large dataset. WEKA, a data miming software was used to minimize the dataset that will achieve rules which will contains post and pre-condition, and constrains to choose associative measures in accordance to input sets to achieve precise cycle time. However, development model did not support an enhanced livability, workability and sustainability. [9] developed a vehicle speed restriction control system in a fastidious zones using global positioning system. The motivation behind the research work are to restrains the occurrence of accidents due to high speed by the drivers. The aim of this research work is to solve the difficulty of high speed by drivers by having a speed limiting control system that would act upon drivers' carelessness especially in critcal zones. The research work made use of phone's built-in GPS sensors, to send signal to user by the mobile application alerting the user once a critical zone has been approached.

3. METHODOLOGY

The research describes the design of a traffic control strategy using an ANFIS model technique. The approach first formulates a 4-way intersection of double lane road network problem. Given a hypothetical double lane multi-connected (4-way intersection) road network, where four cardinal points are used, which are S, E, N and W, represented as South, East, North and West respectively, these represent the four intersections shown numbered in clockwise direction as shown in Figure 1.

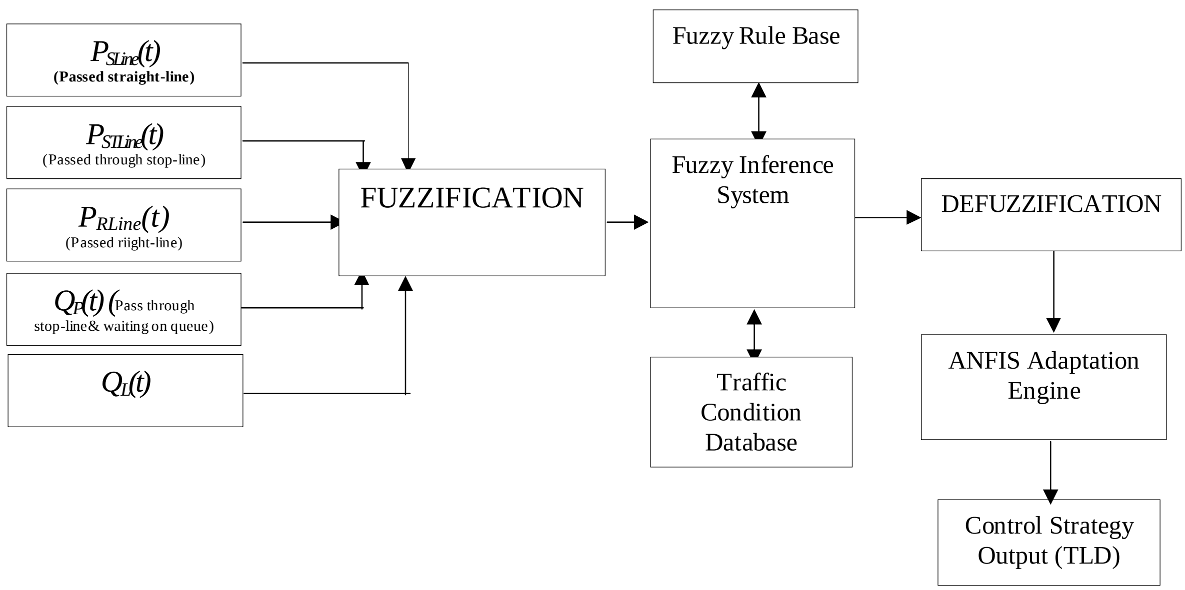


Figure 1: System Architecture

In this architecture, which shows the Fuzzy Logic Controller, there are four major blocks. The first block, which is the input variables, it will be obtained by detectors/sensors as shown in Figure 2.

The variables to be considered for traffic in a proposed intersection are as follow:

i. the vehicles $P_{SLine}(t)$ passed straight-line within the space of time [t - Δt, t];
ii. the vehicles $P_{STLine}(t)$ moved through stop-line (not referaring to right hand side-lane vehicles) within the space of time [t - Δt, t];
iii. the vehicles $P_{RLine}(t)$ movedright hand side-lane within the space of time [t - Δt, t];
iv. the vehicles $Q_P(t)$ which to move toward stop-lane, but did not goes right, as well remain on queue within space of time *t; and*
v. the vehicles Q_L *{t)*holding by red light and still on queue within space of time on left hand side lane.

All this inputs were applied to the fuzzification block, which process and converts the crisp value of inputs into the fuzzy value. After the fuzzification, fuzzy inference system block performs the necessary action based on the rule base and mapped with three linguistic variables (Low, Average, High), Gaussian membership function and traffic condition database are used to fuzzify all the variables are fuzzified. The fuzzy inference system evaluates the control rules stored in the fuzzy rule base and traffic condition database.

Defuzzification block process and change the fuzzy output values of a fuzzy inference crisp to real crisp values. The Adaptive Neuro Fuzzy Inference System (ANFIS) adaptation model engine will continually update the architectural parameters as traffic conditions changes, by taken the output real crisp values and train dataset, with its decision centered around the condition of traffic

The output of the system is the traffic light duration (TLD). The control strategy output variable will be mapped to three linguistic variables (Low, Average, High), using Gaussian membership function.

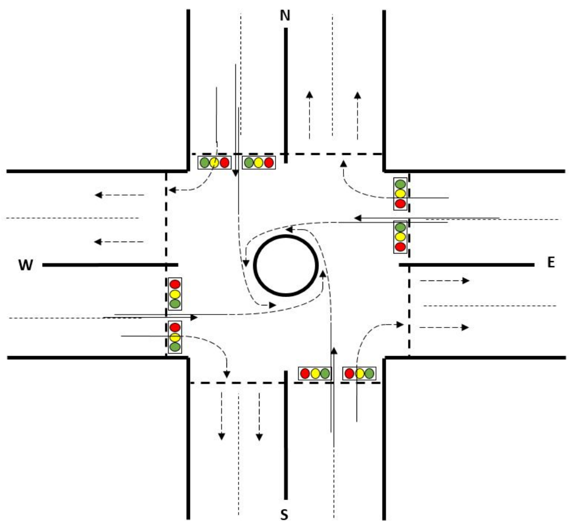


Figure 2: General Structure of the 4-way intersection of double lane road network

The following assumptions are considered in the design of the control strategy for an interconnected double lane, four junction intersections with traffic coming from junction S, E, N and W which denoted as South, East, North and West, respectively in the Figure 2.

A. No turnaround at any intersection.

B. All oncoming traffic can move in any of the three directions as shown in Figure 3.1. For instance, traffic coming from south towards intersection A can move SE, SN or SW (representing South-East, South-North, South-West) and not otherwise.

C. Sensors/detectors for vehicle detection will be installed and configured on stop-lines behind each traffic light, upstream-lines behind the first sensor at distance *S*, and corners of every right hand side-lane. Sensors will count the vehicles moving through straight-lanes, stop-line and corner-lanes which are right/left within a given interval of time [t - Δt, t].

For left-turning vehicles to be detected, ultrasonic detectors will be placed on left-turning sides. These sensors will be used to identify the vehicle shapes and calculate vehicles that are driven towards left-lanes sides. Two traffic light contains three sets of green, red and amber lights at each quadrant of the intersections controls the movement of oncoming traffic along each lane to any of the allowable three directions.

D. The time duration of the green light is the output of the adaptive fuzzy logic control strategy which is a function of nature of traffic. Nature of oncoming queue describes presence or absence of emergencies like accident, ambulance movement, fire truck, government convoy, security/bullion van movement.

E. Priority will be given to each of the routes and emergencies. Routes SN and NS has priority 1, routes WE and EW has priority 2, while routes SW, WN, NE and ES has priorities 3, 4,5 and 6 respectively. Routes SE, WS, NW and EN will not be considered in the design because their movements are not affected by any traffic combination (i.e. their traffic lights are always GREEN). However, priority 0 is given to any route having presence of emergency.

Four ways signalized intersection will be studied with three approaches and each lane sensors. Figure 3.3 shows an intersection which represented as four cardinal points with lanes and vehicle sensors configuration. Each approach are represented as left hand side-lane, straight through and right hand side-lane movements i.e SE, SN or SW representing (South-East, South-North, South-West) and not otherwise.

Vehicle detection were installed on stop-lines i.e located behind each traffic light, upstream-lines i.e placed at the back of first sensor at distant of *S*, and corner-lines for right-turning. Sensors will count vehicles passing through straight-line, right hand-lane and left-land at interval time *t*. To discover vehicles on left hand-side lane, sensors called ultrasonic were placed on left hand side lane corner.

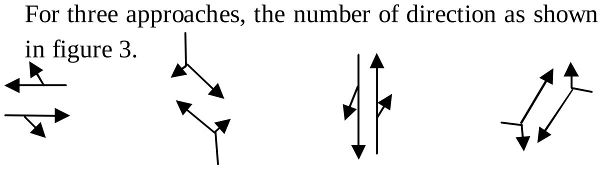
These sensors are capable to identify appearance of each vehicle and it will count vehicles driven towards left hand side lane. A three-phase sign consisting of straight lane, left hand lanes, and right hand lanes are shown in Figure 3.

In each process, every approach were assigned with two different measures, the "ready to go" light which is green indicator signalized vehicles on each approach can pass through the intersection, while "stop light" which is red indicator signalized vehicles on each approach cannot move.

E denoted East, S denoted South, W denoted West, and N denoted North respectively, are four cardinal points which each three approaches have to cut across, the vehicles passed straight-lane within the space of time [t - Δt, t] respectively.
$P_{EAST,SLANE}(t)$, $P_{SOUTH,SLANE}(t)$, $P_{WEST,SLANE}(t)$, and $P_{NORTH,SLANE}(t)$. Likewise, the vehicles goes through stop-line (not referring to right hand side-lane vehicles) within the space of time [t - Δt, t] is represented as,
$P_{EAST,STLINE}(t)$, $P_{SOUTH,STLINE}(t)$, $P_{WEST,STLINE}(t)$, and $P_{NORTH,STLINE}(t)$.

Vehicles turning right hand lane (E to N, S to E, W to S, and N to W), the vehicles moving through right hand-lane within the interval of time [t - Δt, t] is represented as, $P_{EAST,RLANE}(t)$, $P_{SOUTH,RLANE}(t)$, $P_{WEST,RLANE}(t)$, and $P_{NORTH,RLANE}(t)$.

For three approaches, the number of direction as shown in figure 3.



(a) (b) (c) (d)

Figure 3: Direction for four signalize

Vehicle which turn left side within the interval of time [t - Δt, t] is represented as, $P_{EAST,SIDE}(t)$, $P_{SOUTH,SIDE}(t)$, $P_{WEST,SIDE}(t)$, and $P_{NORTH,SIDE}(t)$.At every interval of time t, the vehicles on queuing is represented as, $Q_{EAST,SIDE}(t)$, $Q_{SOUTH,SIDE}(t)$, $Q_{WEST,SIDE}(t)$, and $Q_{NORTH,SIDE}(t)$.

Likewise, vehicles moving through stop-line on each approach, but did not move right, and hold on a queue at given interval of time t are represented as, $Q_{PEAST}(t)$, $Q_{PSOUTH}(t)$, $Q_{PWEST}(t)$, and $Q_{PNORTH}(t)$.
Probably, for vehicle turning right, the vehicles are defined as $Q_{REAST}(t)$, $Q_{RSOUTH}(t)$, $Q_{RWEST}(t)$, and $Q_{RNORTH}(t)$.
Similarly, the vehicles hold on queue at time t on the left hand-side turning lanes are noted as $Q_{LEAST}(t)$, $Q_{LSOUTH}(t)$, $Q_{LWEST}(t)$, and $Q_{LNORTH}(t)$.
The total vehicles $Q_T(t)$ hold on queue at time t comprised the previous three parts, for illustration, moving toward east $Q_T(t)$ are expressed as

$$Q_{TEAST}(t) = Q_{PEAST}(t) + Q_{REAST}(t) + Q_{LEAST}(t).\ Q_T(t) \quad (1)$$

$$\text{if } \{\{P_{East,Sline}(t) \text{ is } high\} \text{ and } \{\{P_{East,Rline}(t) \text{ is average}\} \text{ and } \{P_{East,STline}(t) \text{ is small}\}\} \text{ or } \{Q_{PEast}(t) \text{ is high}\}, \text{ then } \{U(a)\_{East} \text{ is high}\}$$

$$\text{if } \{\{P_{West,Uline}(t) \text{ is high}\} \text{ and } \{\{P_{West,Cline}(t) \text{ is average}\} \text{ and } \{P_{West,Sline}(t) \text{ is small}\}\} \text{ or } \{Q_{West}(t) \text{ is high}\}, \text{ then } \{U(t)\_{West} \text{ is high}\}$$

$$\text{if } \{\{U(t)\_\text{East is high}\} \text{ or } \{U(t)\_West \text{ is high}\}\}, \text{ then } \{S(t) \text{ is high}\}$$

The Fuzzification of the Model variables are expressed in the equations below

$$f_{tri}(x_1;a_i,b_i,c_i) = \begin{cases} Low----if\_x_1 \le 1.8 \\ Average--1.2 \le x_1 \le 2.8 \\ High--2.2 \le x_1 \le 3.8 \end{cases} \quad (2)$$

$$f_{tri}(x_2;a_i,b_i,c_i) == \begin{cases} Low----if\_x_1 \le 1.8 \\ Average--1.2 \le x_1 \le 2.8 \\ High--2.2 \le x_1 \le 3.8 \end{cases} \quad (3)$$

$$f_{tri}(x_3;a_i,b_i,c_i) == \begin{cases} Low----if\_x_1 \le 1.8 \\ Average--1.2 \le x_1 \le 2.8 \\ High--2.2 \le x_1 \le 3.8 \end{cases} \quad (4)$$

$$f_{tri}(x_4;a_i,b_i,c_i) == \begin{cases} Low,----if\_x_1 \le 1.8 \\ Average,--1.2 \le x_1 \le 2.8 \\ High,--2.2 \le x_1 \le 3.8 \end{cases} \quad (5)$$

$$f_{tri}(x_5;a_i,b_i,c_i) == \begin{cases} Low,----if\_x_1 \le 1.8 \\ Average,--1.2 \le x_1 \le 2.8 \\ High,--2.2 \le x_1 \le 3.8 \end{cases} \quad (6)$$

$$f_{tri}(y;a_i,b_i,c_i) = \begin{cases} STOP\ ,--if\_y \le 0 \\ READY\ ,---y = 0.5 \\ GO\ ---y = 1 \end{cases} \quad (7)$$

The linguistic expression for the variables and their membership functions which are (low, average and high) are properly examined from the aforementioned triangular membership functions and it is denoted by lower limit **a**, an upper limit **b**, and **m** value, where **a** < **m**< **b**. The actual membership functions of these linguistic values.

The ANFIS model will be experimented with 1, 2, 3, 4 and 5 hidden layers structure. In figure 4 below, a circle symbol indicates a fixed node, while a square symbol indicates an adaptive node. These seven-layer structure, individual layer are elaborate in specify as follows. The first layer is the input layer consisting of z-number of neurons.

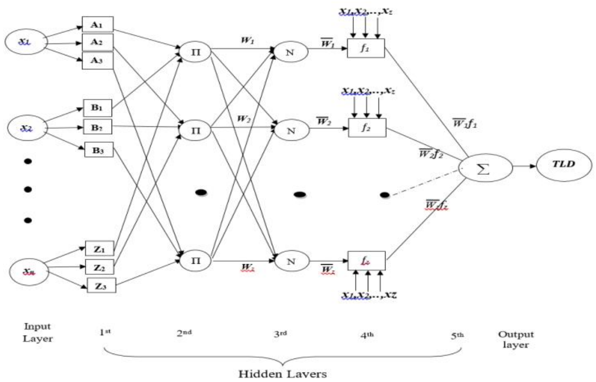


Figure 4: The architecture of ANFIS model for traffic control strategy

The first hidden layer comprise of adaptive nodes. The products of this layer are fuzzy membership rate of the inputs, which are expressed as.

$$O_i^1 = \mu_{A_i}(x_1), \quad i = 1,\ldots,3 \qquad (8)$$

A is the linguistic variable, x_1 is the first input and $\mu_{A_i}(x_1)$ is the fuzzy membership function. In this research, Gaussian, will be used during the ANFIS modelling. The Gaussian membership function is given by;

$$\mu_{A_i}(x_1) = f(x;\sigma,c) = \ell^{\frac{-(x-c)^2}{2\sigma^2}} \qquad (9)$$

where μ_{A_i} represent membership function of linguistic variable (A_i) while σ, c determines the skewness and center of the Gaussian curve.

The second hidden layer, which consists of rule nodes. The output of this layer is a result of multiplier effect (w_i) with the fuzzy inputs as shown. Each node in second layer corresponds to fuzzy rule. A rule neuron receives inputs from the input nodes and calculates the firing strength it represents. It is labelled as "Π" in Figure 3.4.

$$O_i^2 = \mu_{A_i}(x_1) * \mu_{B_i}(x_2), \quad i = 1,\ldots,3 \qquad (10)$$

The third hidden layer carries out a normalization function. The output of this layer outputs respective normalized firing strength or weights. The nodes are also fixed and labelled as "N" in Figure 3.4, to show that they handle a normalization part to the firing strengths from the second hidden layer. The product of the layer is known as normalized firing strengths and given as;

$$O_i^3 = \mu_{A_i}(x_1) \oplus \mu_{B_i}(x_2), \quad i = 1,\ldots,3 \qquad (11)$$

The fourth hidden layer comprise of adaptive nodes. They adapt to changes in the output of normalized firing strength and nth order polynomial. This nodes are also fixed and labelled as "*f*" in Figure 3.4, The output of this layer is known as adaptive of firing strengths and given as;

$$O_i^4 = \overline{w}_i = \frac{w_i}{w_1 + w_2 + w_3 + \ldots + w_z}, \quad i = 1,\ldots,z \qquad (12)$$

The fifth hidden layer results to an adaptive node. The product of these individual node in this layer is subsequent output of the normalized firing strength and a first order polynomial. These resulted to ($\overline{w}_i f_i$). It consists of one single fixed node which labelled as "$\sum$." is expressed by;

$$O_i^5 = \overline{w}_i f_i = \overline{w}_i (p_1 x + ,\ldots, + q_1 x_z + r_1), \quad i = 1,\ldots,z \qquad (13)$$

where the consequent parameters are p, q and r.

The last layer which is the output layer performs a summation of all subsequent node outputs. These node performs the summarization of all succeeding signals. All-encompassing products of the model is adapt to changes and labelled as "*f*" in Figure 3.4, given by;

$$O_i^6 = \sum_i \overline{w}_i f_i = \frac{\sum_i \overline{w}_i f_i}{\sum_i \overline{w}_i} \qquad (14)$$

The fuzzy rules for the ANFIS is given by;

Rule(1):

$IF(x_1\_is\_A_1) AND, \ldots, AND(x_5\ is\ E_1), THEN\_ f_1 = 1 = 1 =$

$$IF(x_1\_is\_A_1) AND, \ldots, AND(x_5\_is\_E_1), THEN\_ f_1 = p_1 x + ,\ldots, + q_1 x_5 + r_1 \qquad (15)$$

Rule(n):

$$IF(x_1\_is\_A_n) AND, \ldots, AND(x_5\_is\_E_n), THEN\_ f_n = p_n x + ,\ldots, + q_n x_5 + r_n \qquad (16)$$

Where x, A, E are input variable, first input fuzzy set, nth input fuzzy set and *f* is the fuzzy output respectively. The design functions to be tuned at the process of training the ANFIS are represented by p, q and r respectively. The ANFIS architecture consisting of seven layers is shown in Figure 4.

The selection of hidden layer structure and tuning of parameters will ensure optimum accomplishment of ANFIS model strucure. The development and simulation of the ANFIS model is carried out in MATLAB Integrated Development Environment (IDE).

4. RESULTS AND ANALYSIS

This section describes the analysis and implementation results of the Fuzzy-based for Adaptive neuro-fuzzy traffic controller for double lane intersections. The implementation of the Fuzzy-based model simulation was done and tested on three (3) different MATLAB applications, which are: MATLAB 8.4 (R2014b), MATLAB 8.5 (R2015b) and MATLAB 9.4 (R2018b) versions respectively with high performance computing language for simulation of the traffic models.

Simulation output shown in figure 5, analysis the flow of vehicles on Routes SE, WS, NW and EN.

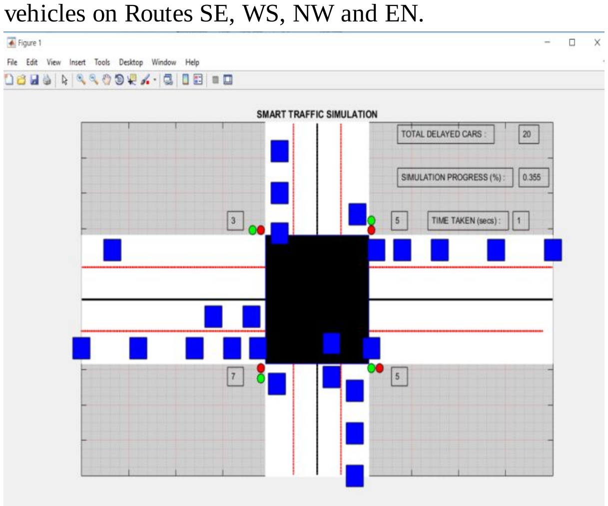


Figure 5: Screen shot of Traffic Simulation of Minimum Traffic Light ON.

Average delay of each vehicle on red light against time is shown in figure 6.

Figure 6: Delay Plot against Time plot

Average waiting time of each vehicle on green light against time is shown in figure 7.

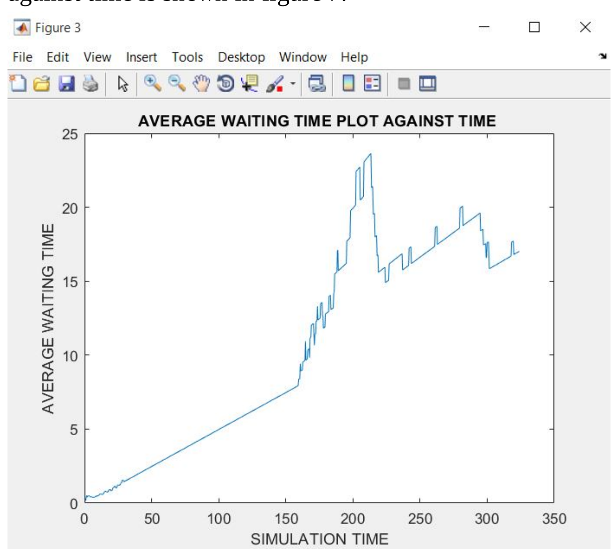


Figure 7: Average Waiting Time against Time plot

Performance evaluation metrics of the system which make it unique and more reliable to conventional system of traffic light management is shown in figure 8. It calculated total simulated cars, total time taken, average waiting time, and average flow rate of each routes per minute.

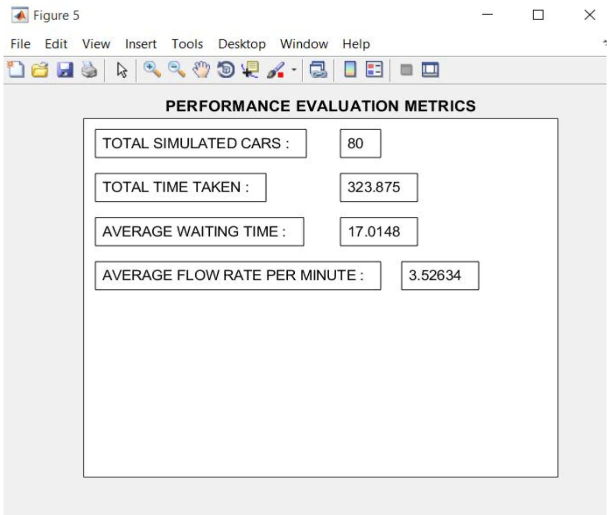


Figure 8: Performance Evaluation

The proposed research controller resulted minimum vehicle movement delays and percentage of stopped vehicles are lesser than the traditional fixed time system.

5. CONCLUSION

This research explores the various factors that enhanced high performance of fuzzy-based simulation model for adaptive neuro-fuzzy traffic controller for double lane intersections for four approaches with through, left-turning, straight-turning and right-turning movements, considering the traffic conditions like presence and absent of emergencies on the road.

This work equally demonstrates the feasibility of using triangular and Gaussian membership function (MF) which are considered for queue lengths in fuzzy controllers. The results of the experiments for the simulation scenarios show the better performance of the ANFIS to identify optimal parameters in controlling of fuzzy system with amount of conceivable conflicting accomplished measures.

This work establishes a priority dependent adaptive neuro-fuzzy based traffic control strategy which reduced the level of congestion and long queues experienced in multi-networked roads. The output of this work will served as a veritable framework and report for urban town planners and transport management personnel in the transportation industry.

6. FURTHER RESEARCH

It is believed that when a system is this kind developed and implemented; the problems of traffic congestion will be solved, hence furthering the positive uptake of agent technology of using neuro-fuzzy inference system, linguistic and its membership function should be able to solve numerous problem of traffic congestion, air pollution, noise on traffic/road network and some kinds of starvation on our road network in the country.

Likewise, conventional traffic system can be as well placed with regards to factors that were reflects the type that control its traffic system, or to utilize an intelligent controller system/expert system for making most decision urgent traffic light indicator on which phase should be open.

Furthermore, researchers needs thorough research to uncover the genetic algorithm optimality of solving traffic issues or any kind of related problems, like determine the value and to be more robust and sequence. Also, to prove the effect of traffic control algorithm in a real life situation.

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