An Application of Fuzzy Logic Model in Solving Road Traffic Congestion

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***Abstract*-- The chaotic traffic situation at most of the major road junctions in Nigerian cities, especially when the traffic wardens are off duty, has become source of major distress to road users. Vehicles have to wait endlessly in a traffic deadlock. This paper gives a brief discussion of the procedures we adopted to develop an intelligent fuzzy logic model control system for dealing with the road traffic congestion problem. The system was developed using fuzzy logic technology which is capable of accommodating inherent uncertainty and vagueness in traffic control and implementation was done with Java programming language. The resulting intelligent fuzzy logic control system for traffic control was tested using the YKC(Young Kennedy Centre) junction, at Worji in Port Harcourt, Rivers State of Nigeria; the situation which is typical at most of the busy junctions in Nigerian cities. Analysis carried out shows that this system eliminated 80% of the problems identified in the current traffic monitoring and control systems and will solve traffic congestion problems in other junctions with similar structure as YKC.**

Keywords: Congestion, Fuzzification, Fuzzy rules, Defuzzification, Traffic controller, Fuzzy sets, Fuzzy Logic, Soft Computing.

I. INTRODUCTION

Human nature involves movement from one place to another which increases traffic on the route of the movement, the increased traffic eventually leads to congestion [4]. Road traffic congestion has been one of the major problems encountered in large cities such as Port Harcourt in Nigeria. In Nigeria, the Federal Road Safety Commission of Nigeria is the institution charged with the responsibility of maintaining safety on the roads. The commission affirmed that the high traffic density was caused by the influx of vehicles as a result of breakdown in other transport sectors and is most prevalent in the 4-way intersection '+' road junctions. In an effort to solving this problem, several traffic laws and regulations have been put in place by government and its agencies. The recent is the traffic law in Lagos State Nigeria which spelt out jail terms for defaulters. In Rivers State, Nigeria, Tima-Riv is charged with the responsibility of monitoring road traffic and defaulters are charged with high fees plus mental test. These measures have, however, failed to meet the target of freeing major 4-way intersections '+', resulting in loss of resources, human lives and waste of valuable man hour during the working days. Scientists and researchers have also made their contributions by developing technique aimed at solving real life problems notable among which is the field of soft computing. The main goal of soft computing is to develop intelligent machines and to solve nonlinear and mathematically un-modelled problems [17][18][20][2][19]. This paper is aimed at solving identified problems of traffic congestion at 4-way intersections by developing an intelligent traffic congestion control system based on fuzzy logic model which mimics human reasoning. Fuzzy logic models are suitable for controlling intersections, especially those with heavy traffic, because it is able to emulate the control logic of traffic police officers who sometimes replaces traffic signal control when the intersection is congested [23][8].

II. RELATED LITERATURE

Fuzzy logic handles the concept of partial truth, that is, the truth with values between "completely true" and "completely false". It is a powerful technique for solving a wide range of industrial control and information processing applications [1]. Fuzzy models can be regarded as flexible mathematical structures, similar to neural networks or radial basis function networks that can approximate a large class of nonlinear systems to a desired degree of accuracy [15]. A generic fuzzy logic system is shown in fig 1.

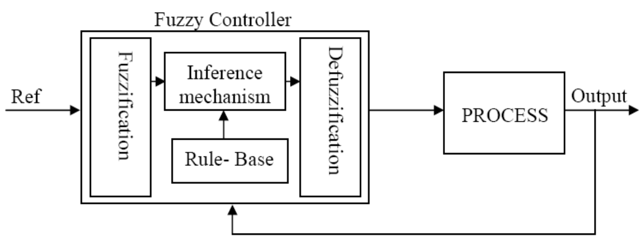

Fig. 1: Fuzzy Logic Process

The fuzzy logic model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. Since the first initiation of fuzzy logic by [22][21], fuzzy inference systems have been developed to improve performance in the control and decision-making scheme over the past decades in; non-linear system modelling [6] [7] [3] industrial plant control, robotics, system identification [15] [12] and so on.

The earliest known attempt to apply fuzzy logic in traffic control was made by [11]. They implemented a fuzzy logic controller in a single intersection of two one-way streets. Ever since, much similar research has been done and generally reported better performance of the fuzzy logic controllers compared to the pre-timed controllers [9][16].

Reference [5] believed that electro sensitive traffic lights had better efficiency than fixed preset traffic signal cycles because they were able to extend or shorten the signal cycle when the number of vehicles increases or decreases suddenly. Their work was centred on creating an optimal traffic signal using fuzzy control. Fuzzy membership function values between 0 and 1 were used to estimate the uncertain length of a vehicle, vehicle speed and width of a road and different kinds of conditions such as car type, speed, delay in starting time and the volume of cars in traffic were stored.

A paper by [13] described the design and implementation of an intelligent traffic lights controller based on fuzzy logic technology. The researchers developed software to simulate the situation of an isolated traffic junction based on this technology. Their system was highly graphical in nature, used the Windows system and allowed simulation of different traffic conditions at the junction. The system made comparisons between the fuzzy logic controller and a conventional fixed-time controller; and the simulation results showed that the fuzzy logic controller had better performance and was more cost effective.

Referenced [10] designed an intelligent traffic control system to monitor and control road traffic in a Nigerian city. A hybrid methodology obtained by the crossing of the Structured Systems Analysis and Design Methodology (SSADM) and the Fuzzy-Logic based Design Methodology was deployed to develop and implement the system. These system, however, do not appear to have the capability to handle the problems identified with the current traffic control system at the '+' junctions. This necessitated our design and implementation of a new system which is sensor based to solve the problems.

III. ANALYSIS OF FUZZY LOGIC MODEL CONTROL SYSTEM FOR TRAFFIC CONGESTION

As its name suggests, eight sensors were introduced in the four intersections to capture the vehicles in queue at any point in time, the fuzzy system takes decision on the necessary action based on the information from the sensors. Fig. 2 shows the position of eight incremental sensors that are put in specific positions. In fig 3, S represents the two electromagnetic sensors placed on the road for each lane as showed in fig. 2. The first sensor was placed behind each traffic lights and the second sensor was located behind the first sensor. A sensor network normally constitutes a wireless ad-hoc network meaning that each sensor supports a multi-hop routing algorithm [10]. While the first sensor is required to count the number of vehicles passing the traffic lights; the second is required to count the number of vehicles coming to intersection at distance D from the lights. To determine the number of vehicles between the traffic lights, the difference of the reading between the two sensors is evaluated. This differs from what is obtained in a conventional traffic control system where a proximity sensor is placed at the front of each traffic light and can only sense the presence of cars waiting at the junction and not the number of vehicles waiting in the traffic. The first sensor behind each traffic light counts the number vehicles coming to the intersection and the second counts the cars passing the traffic lights. The number of vehicles between the traffic lights is determined by the difference of the reading of the two sensors. For example, the number of cars behind traffic light North is S7-S8.

The distance D, chosen to be 200ft., is used to determine the maximum density of vehicles allowed to wait in a very crowded situation. This is done by adding the number of vehicles between the paths and dividing it by the total distance. For instance, the number of vehicles between the East and West is ((S1-S2) + (S5-S6)) /400. (1)

The fuzzy traffic controller receives data from the counter queue arrival and traffic lights interface as showed in fig. 3 and controls the light cycle. There is one state for each phase of the traffic light. There is one default state which takes place when no incoming traffic is detected. This default state corresponds to the green time for a specific approach, usually to the main approach. In the sequence of states, a state can be skipped if there is no vehicle queues for the corresponding approach.

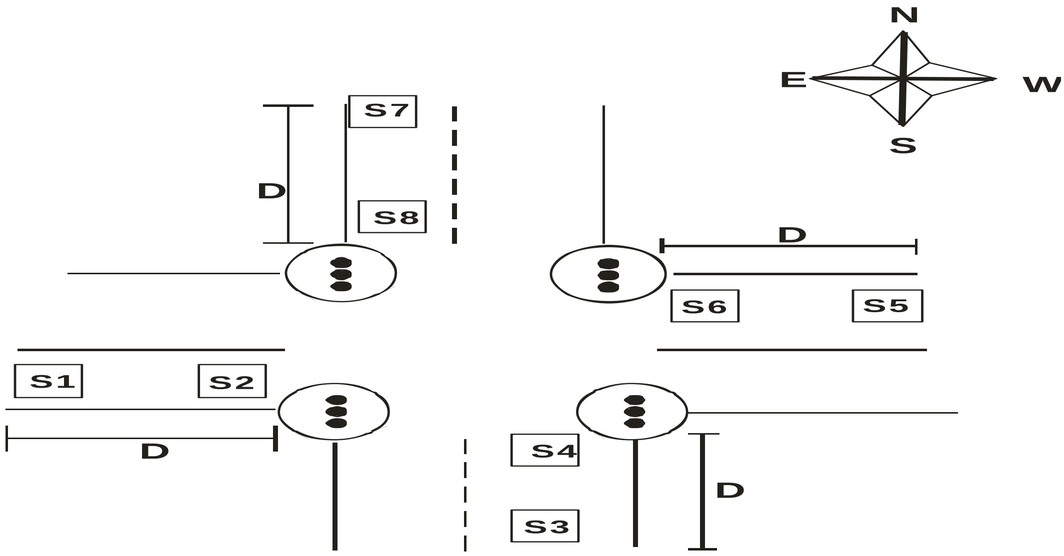

Fig. 2 Diagram showing the position of sensors

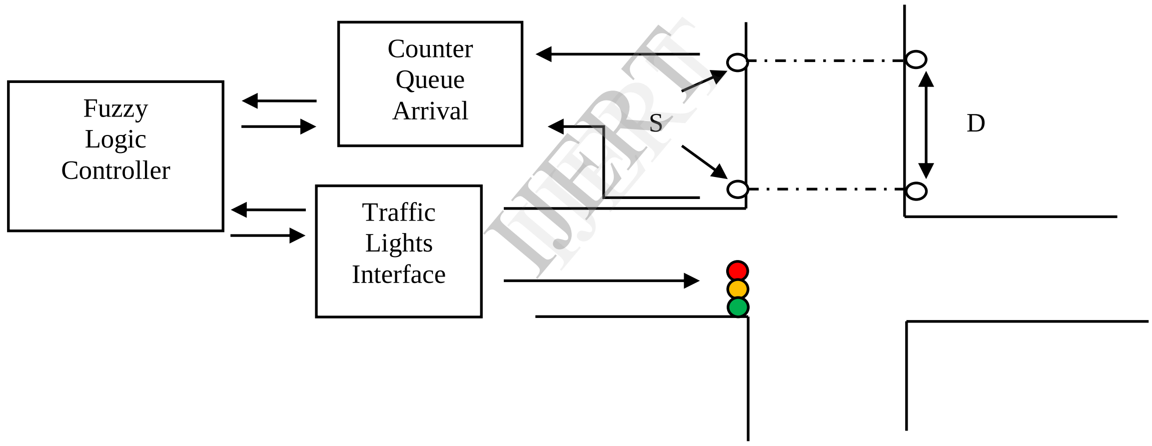

Fig. 3 Designed Model of Fuzzy Traffic light Control System

A. Fuzzy Input/Output Specifications

The Fuzzy input/output variable used here is a reflection of the traffic congestion situation as obtained at YKC junction over a period of time, the manual control method was assumed to be conventional traffic light system since there is none installed at the junction. The fuzzy I/O specification is presented in table 1.There are two input variables and one output. The output is the change in cycle time as a result of the input states.

Table 1: Fuzzy variables (I/O Specifications)

Input		**Output**
Red Light (Queue)	**Green Light (Motion)**	**Circle Time Change (Extension)**
Zero (Z) no waiting car	Very Short (VS) queuing cars leaving the traffic controller)	No (N) no change in cycle time)
Low (L)	Short (S)	Small (S)
Medium (M)	Medium (M)	Medium (M)
High (H)	Long (L)	Long (L)
Chaos (C)	Very Long (VL)	Very Long (VL)

B. *Fuzzification*

The fuzzification is the process of transforming a crisp value into a fuzzy set, so that it can be used and processed by fuzzy inference mechanism [14]. The inputs and output of the design as specified in table 1 are assigned linguistic variables and some degrees of membership. Assuming red light is shown to both North and South streets and distance D is constant, the inputs of the model consist of vehicles behind red light and cars behind green light. The cars behind the light are the maximum number of cars in the two directions. The corresponding output parameter is the probability of change of the current cycle time. Once this is done, the input and output parameters are divided into overlapping member functions, each function corresponding to different levels. For inputs one (vehicles behind red light) the level and corresponding range is zero(0,1), low(0,10), medium(7,21), high(16,36), and chaos(30,48). For input two (vehicles behind green light), the levels are very short (0, 14), short (0, 34), medium (14, 60), long (33, 88), very long (65,100). The levels of output are no(0.00), probably small(0.25), maybe(0.50), probably yes (0.75), and yes(1.00). Note: For the output, one value (singleton position) is associated to each level instead of a range of values.

C. *Fuzzy Rules*

The rules, are formulated using a series of if-then statements, combined with AND/OR operators. For instance, if cycle time is medium AND vehicles behind Red are low AND vehicles behind Green are medium, then change is Probably Not. With two inputs, each having 5 membership functions, we have 5 * 5 = 25 rules as showed in table 2. The fuzzy rules for this research were developed with the aid of four traffic wardens (domain experts) with a good level of experience in handling road traffic congestion control especially at 4 way intersections.

Table 2: The Fuzzy Rule Base

No	Queue	Motion	Extension
1	Z	VS	N
2	Z	S	S
3	Z	M	M
4	Z	L	L
5	Z	VL	VL
6	L	VS	N
7	L	S	N
8	L	M	S
9	L	L	M
10	L	VL	L
11	M	VS	N
12	M	S	N
13	M	M	M
14	M	L	M
15	M	VL	L
16	H	VS	N
17	H	S	N
18	H	M	S
19	H	L	L
20	H	VL	L
21	C	VS	N
22	C	S	N
23	C	M	M
24	C	L	L
25	C	VL	VL

Some of the rules obtained from table 2 are as follows:

R1: If vehicles on Red Light (Queue) is Zero and vehicles on Green Light (Motion) is Very Short then Cycle time is not changed

R9: If Vehicles on Queue is Low and Vehicles on Motion is Long then change Cycle time is Medium

R13: If Vehicles on Queue is Medium and Vehicles on Motion is Medium then change Cycle time is Medium

R19: If Vehicles on Queue is High and Vehicles on Motion is Long then change Cycle time is Long

R25: If Vehicles on Queue is Chaos and Vehicles on Motion is Very Long then change Cycle time is Very Long

Using the values for each of the linguistic variable we have No = 0.0, Small = 0.25, Medium =0.50, Long =0.75, Very

Long = 1.00

D. *Defuzzification*

The transformation from a fuzzy set to a crisp value is called defuzzification. The CoG is adopted in this study for defuzzification because its computational complexity is relativ ely high. It is depicted in Equation 2

$$COG(B^0) = \frac{\sum_{q=1}^{N_q} \mu_{B^0}(y_q) y_q}{\sum_{q=1}^{N_q} \mu_{B^0}(y_q)} \qquad (2)$$

Where N_q is the number of quantization used to discretize membership function $\mu_B{}^0(y)$ of the fuzzy output B^0. $\mu_B{}^0(y)$ is the degree of membership and y_q are elements of the set.

Crisp Output = {Sum (Membership Degree * Singleton Position)}/(Membership degree). For instance with the output output membership degree, Change Probability yes = 0, change probability Probably Yes=0.6, change probability maybe=0.9, change probability probablyNo= 0.3, change probability No = 0.1 then the crisp value will be

Crisp Output= 0.1*0.00)+(0.3*0.25)+(0.9*0.50)+(0.6*0.75)+(0*1.00)/0.1+0.3 +0.9+0.6+0) =0.51

The system takes the density of Vehicles on both North and South, when it is in waiting state and divides by distance D, the resulting value will determine if the cycle time will be extended or not. Assuming that S3-S4 = 50 and S7-S8 = 70 then the resulting value will be calculated as ((S3-S4) + (S7-S8))/D = (50+70)/200 = 0.6. Since the output is 0.6 cycle time should be extended Medium.

E. *High Level Model of the Proposed System*

Fig 4 shows the high level model of the intelligent system. Several classes and methods are created to handle the operations with a main class to control and create the interface using Java programming language. The routes controller handles number of vehicles for both straight routes (vehicles coming from north to south, vice versa, and east to west, vice versa) and Diversion (vehicles coming from west to south, north to west, east to north and south to east). Fuzzy Logic controller evaluate traffic situation based on traffic density and determine which route is giving green light time and for how long. The traffic light change toggles between the red and green light cycle time based on signal from the fuzzy logic controller.

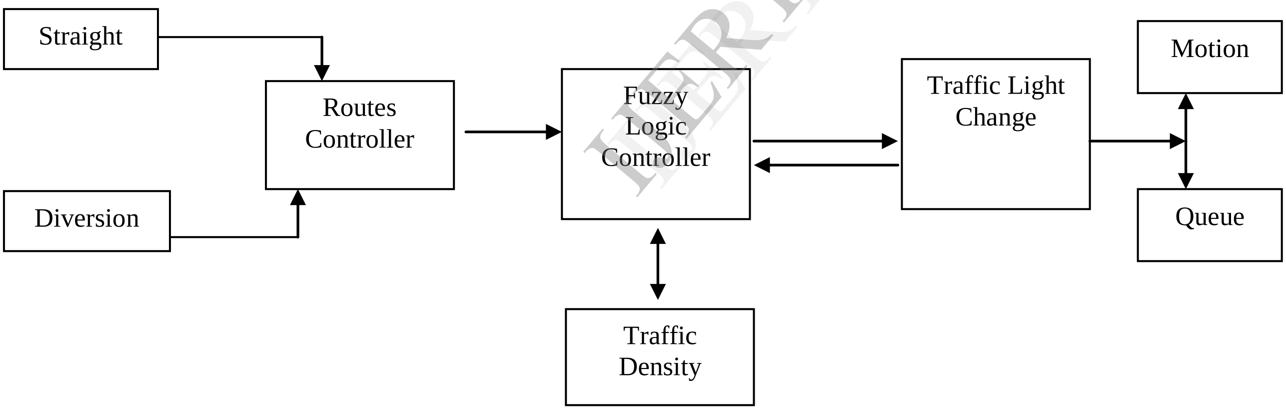

Fig 4. High level model of the intelligent traffic control system

IV. EXPERIMENTATIONS

Several input were collected from YKC junction as shown in table 3 and 4 at different time interval both pick and non-pick periods at YKC junction Worji, Port Harcourt, Rivers State of Nigeria representing the traffic situation of the junction and feed into the system. Table 5 shows the results of the fuzzy traffic control system when feed with the input data in tables 3 and 4.

Table 3: Input of vehicles on straight route collected from YKC Junction

	Direction of movement			
	North-South	South-North	East-West	West-East
Vehicles	23	5	23	6
Vehicles	20	19	20	18
Vehicles	20	21	25	18
Vehicles	5	1	0	0
Vehicles	40	35	23	15
Vehicles	0	13	14	21
Vehicles	8	5	0	3
Vehicles	0	0	15	16
Vehicles	27	26	28	22
Vehicles	6	5	7	4

Table 4: Input of vehicles on diversion route collected from YKC Junction

	Direction of movement			
	West-South	North-West	East-North	South-East
Vehicles	6	3	3	4
Vehicles	8	8	2	10
Vehicles	4	8	2	2
Vehicles	5	12	25	7
Vehicles	48	13	26	27
Vehicles	10	35	18	10
Vehicles	5	12	0	3

V. RESULTS AND DISCUSSION

Outputs obtained from different data sets are displayed in fig 5 to 13

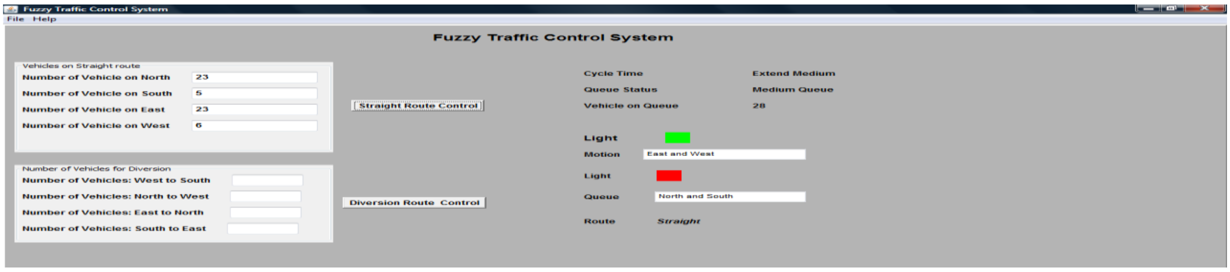

Fig. 5: FTCCS Straight Route showing cycle time extended to Medium

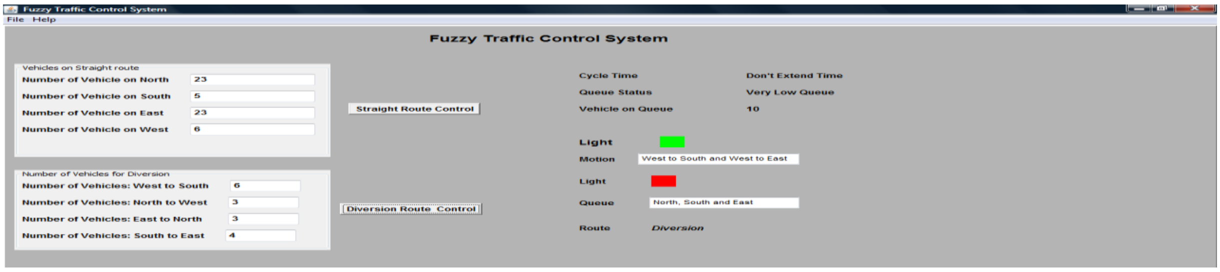

Fig. 6: FTCCS Diversion Route showing cycle time not extended

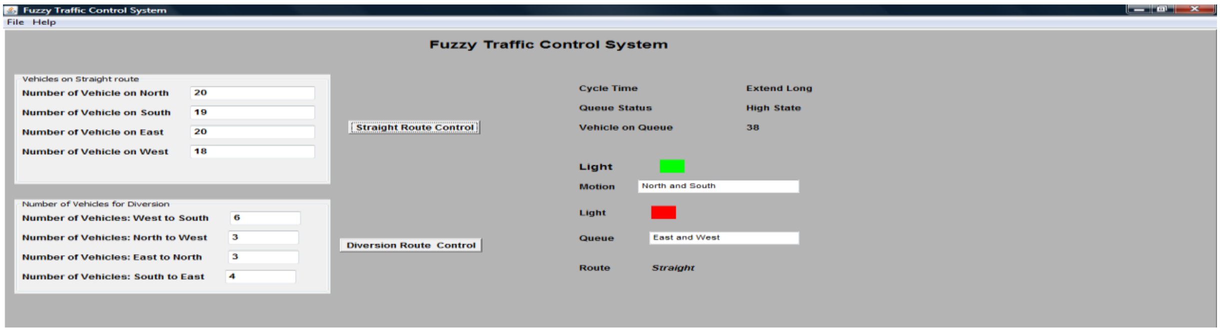

Fig. 7: FTCCS Straight Route with cycle extended long

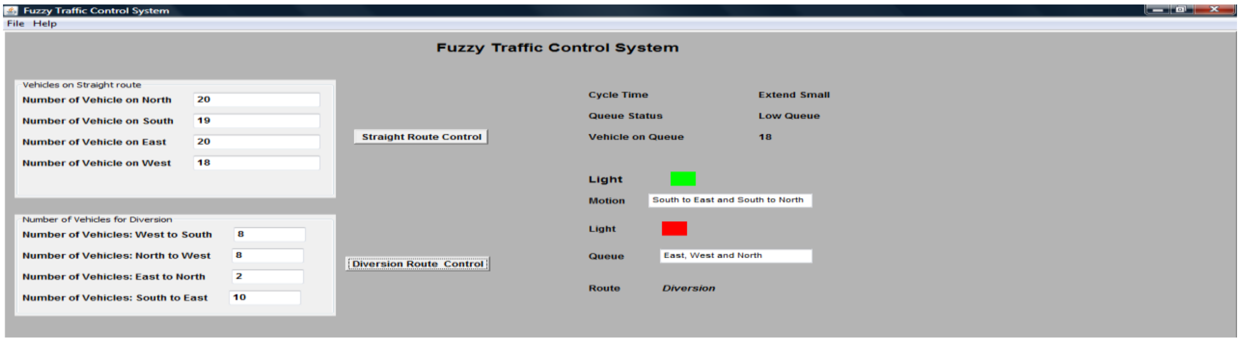

Fig. 8: FTCCS Diversion Route with cycle time extended small

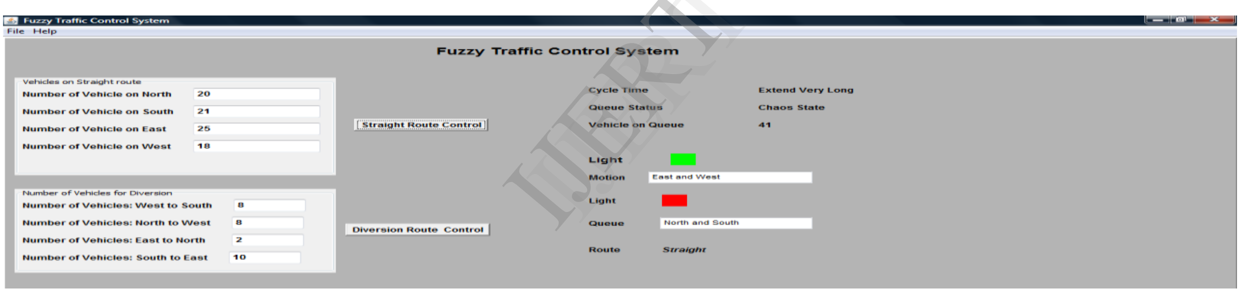

Fig. 9: FTCCS Straight Route with cycle time extension very long

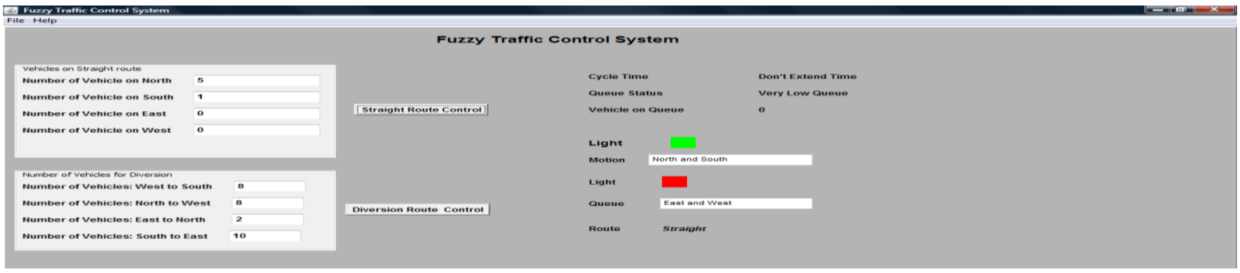

Fig. 10: FTCCS Straight Route with cycle time not extended

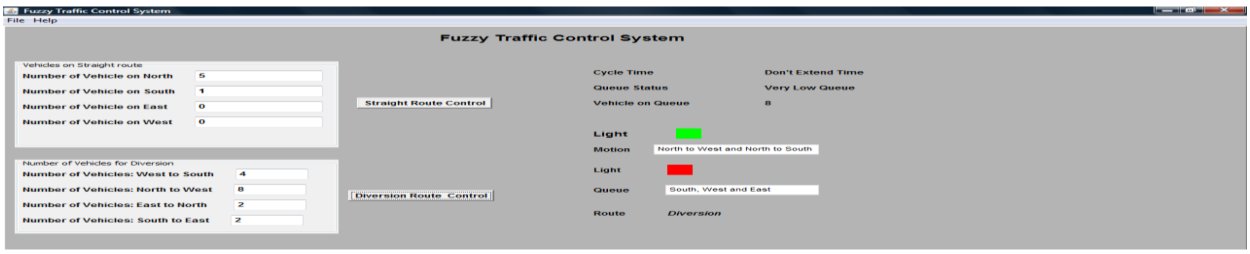

Fig. 11: FTCCS Diversion Route with very low queue

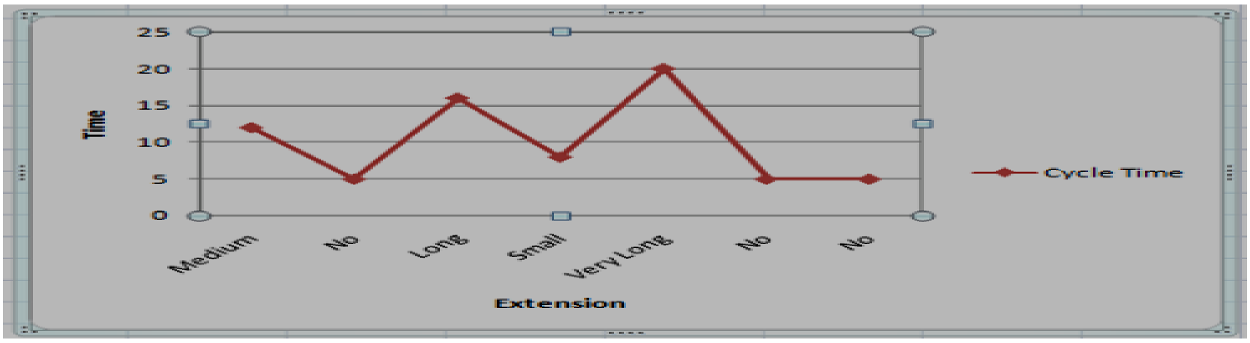

Fig. 12: Time interval against cycle time extension

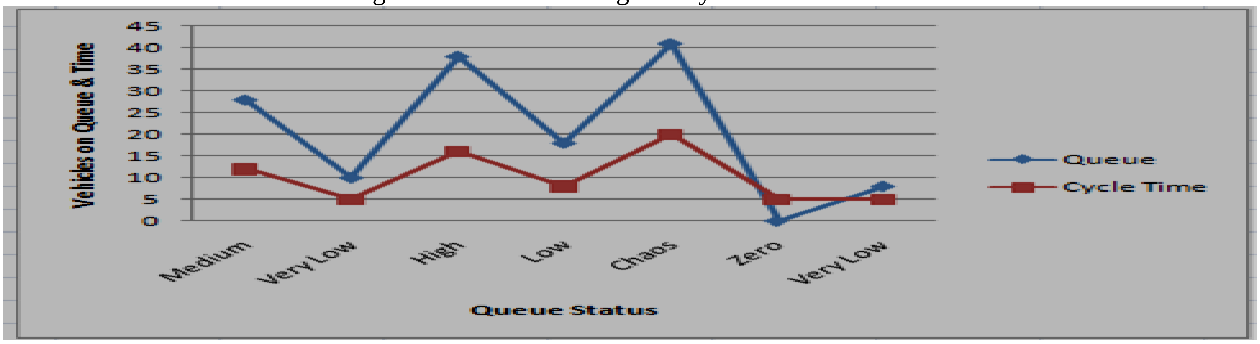

Fig. 13: Queue status against cycle time extension

Table 5 Summary of result from the intelligent system

S-No	Green light	Red light	Queue Status	Light Cycle Time
1	East-West	North-South	Medium	Medium
2	North-South	East-West	High	Long
3	East-West	North-South	Chaos	Very Long
4	North-South	East-West	Very Low	Normal
5	North-South	East-West	High	Long
6	East-West	North-South	Low	Medium
7	East-West	North-South	Very Low	Long
8	North-South	East-West	Very Low	Small
9	North-South	East-West	Chaos	Very Long
10	East-West	North-South	Low	Normal
11	West-South	North, South, East	Very Low	Normal
12	South-East	East, West, North	Low	Small
13	North-West	South, West, East	Very Low	Normal
14	East-North	South, West, North	Medium	Medium
15	West-South	North, South, East	Chaos	Very Long
16	North-West	South, West, East	High	Long
17	North-West	South, West, East	Very Low	Small

Fig. 5 is FTCCS interface at run time. Number of vehicles on north is 23, south is 5, east is 23 and west is 6 all on straight route. The FTCCS allows traffic on east and west to move while north and south stop because more vehicles are on east and west than north and south. Queue status is medium with 28 vehicles on queue thus cycle time is medium extension.

The number of vehicles on west to south is 6, north to west is 3, east to north is 3 and south to east is 4 all on diversion route as showed in fig. 6. The FTCCS allows traffic from west to south and west to east, to move while north, east and south stop because more vehicles are more on west to south than north-west, south-east and east-north. Queue status is very low with 10 vehicles on queue thus cycle time is no extension.

Fig. 7 shows the number of vehicles on north as 20, south as 19, and east as 20 and west as 18 all on straight route. The FTCCS allows traffic on north and south to move while east and west stop because more vehicles are on north and south than east and west. Queue status is high with 38 vehicles on queue thus cycle time is long extension.

The number of vehicles on west to south is 8, north to west is 8, east to north is 2 and south to east is 10 all on diversion route as displayed in fig. 8. The FTCCS allows traffic on south to east and south to north, to move while north, east and west stop because more vehicles are on south to east than north-west, west-south and east-north. Queue status is low with 18 vehicles on queue thus cycle time is small extension.

Fig. 9 display number of vehicles on north as 20, south as 21, and east as 25 and west as 18 all on straight route. The FTCCS allows traffic on east and west to move while north and south stop because more vehicles are on east and west than north and south. Queue status is chaos with 41 vehicles on queue thus cycle time is very long extension.

Fig. 11 presented very low queue situation with number of vehicles on west to south as 4, north to west as 8, east to north as 2 and south to east as 2 all on diversion route. The FTCCS allows traffic on north to west and north to south, to move while south, east and west stop because more vehicles are on north to west than south-east, west-south and east-north. Queue status is very low with 8 vehicles on queue thus cycle time remains normal.

The number of vehicles on north is 5, south is 1, east is 0 and west is 0 all on straight route as showed in fig. 10. The FTCCS allows traffic on north and south to move while east and west stops because there are more vehicles are on north and south while east and west are empty. Queue status is very low with 0 vehicles on queue thus cycle time is normal, not extended.

The graphical presentation of the above results is presented in fig. 12 and 13 which shows the relationship between the traffic situation and traffic light behaviour. The traffic light cycle time varies based on queue status, when the queue is very low the normal cycle time is maintained and when queue increases the cycle time also increases to allow for more traffic flow.

VI. CONCLUSION

The research has shown that a sensor based fuzzy logic model has the potential of eliminating the road traffic congestion to bearest minimum. This was achieved by its ability to take decisions whether to extend or terminate the current green light time based on a set of fuzzy rules and real-time traffic information. The results from experimentation shows that the system eliminated 80% of the problems observed in the manual and conventional traffic control system as the flow density was varied according to real life traffic situations. It was observed that the fuzzy logic control system provided better performance in terms of total waiting time as well as moving time. Since the efficiency of any service facility was measured in terms of how busy the facility is, we therefore deemed it imperative to say that the system under question is not only highly efficient, but also has curbed successfully the menace of traffic deadlock which has become a phenomenon at YKC junction as less waiting time will not only reduce the fuel consumption, but also reduce air and noise pollution which impact negatively on the inhabitants. This solution can be extended to other junctions with similar problem to that at YKC. Thus, it will support timeliness and efficiency in service delivery.

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