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DYNAMIC BEHAVIOUR OF A MODELED TRANSPORTATION NETWORKED CONTROL SYSTEM FOR T-JUNCTION

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ABSTRACT

Traffic congestion has been the major problem on most Nigeria roads. This is particularly due to the rapid increase in urban migration. Majority of the traffic control schemes adopted in the country to alleviate this problem are the fixed time controllers employed at all signalized intersections. This has resulted in increased traffic jam especially during the peak periods at most intersections on our highways. In this study, a fuzzy logic system to control traffic on signalized intersection has been proposed. The Fuzzy Logic Controller regulates the traffic signal timing, the green light extension and phase sequence to ensure smooth flow of traffic, thereby reducing traffic delays and thus increasing the intersection capacity. A fuzzy logic traffic control simulation model was developed and tested using MATLAB/ SIMULINK software. Comparative analysis was carried out between the fuzzy logic controller and a conventional fixed-time controller in order to determine the efficiency of the developed system. Evaluation results of the fuzzy logic traffic controller shows that vehicles spent less time at the intersection compared to the fixed time controller, that is, improved vehicular movement. Moreover, simulation results show that the fuzzy logic controller has better efficiency and that a huge improvement could be realized by adapting it in controlling traffic flow at intersections.

Keywords: Fuzzy logic, Networked system, Traffic control

INTRODUCTION

Signal control system is vital to the operation and management of urban traffic in reducing congestion and resolving traffic effect issues. Generally, control approaches are classifiable into two broad groups: non-adaptive and adaptive control methods. The main difference between the two methods is the ability to condition signal parameters in real-time or not with respect to detected traffic situations. Usually, on-street detectors such as loop detectors are deployed to improve the performance of the signal control system. Vehicle Actuated (VA) control system is one of the celebrated non-adaptive system for traffic control. Literature has ample accounts on VA systems for traffic control. Few of these include Ravikumar & Mathew (2011); Yun & Park (2012); Newell (1998); Joyoung et al, (2012); Francesco & Henk, (2009); Cassidy & Coifman, (1998); Swaminathan et al., (2014), Sadguna & Mathew, (2015). One thing is clear from each of the above cited efforts; VA presents a sophisticated approach to street network management in that it makes provision for vehicles based on their service requirements. However, proper and detailed analyses are required prior implementation of VA in order to achieve the much needed goal (Ravikumar & Mathew, 2011).

In the area of adaptive control scheme, fuzzy logic has been employed in facilitating timely and real-time implementation of traffic controllers for different traffic scenarios. Aisawaria & Rani (2013) proposes intelligent algorithm aimed at scheduling traffic signals for a two-lane cross junction, where each intersection serves two lanes. In another development, Yulianto & Setiono (2012) presented adaptive traffic signal controller based on fuzzy logic. The controller is demonstrated for isolated four-way intersection with specific reference to mixed traffic conditions. The real-time capability of adaptive traffic controllers is premised on existence of robust and effective feedback network.

Networking has received increasing attention in recent years because of popularization and merits of using network cables in control systems. Systems where feedback control loops are closed through a real-time network are often referred to as Networked Control Systems (NCSs). The system elements are typically spatially isolated from one another, operating in an asynchronous manner and communicating over a wide area via both wired and wireless links (Antsaklis, 2007). An NCS is a distributed control structure where the communication between the nodes of the control system is provided by a communication network. The basic elements of a NCS are sensors, controllers, actuators and the communication network. It is gaining increased attention in many control application areas due to their cost-effectiveness, reduced weight and power requirements, simple installation and maintenance, and high reliability. At the same time, the underlying required control theory is starting to offer mature and methodological results (Yu & Wang, 2005).

Transportation research has the goal to optimize transportation flow of people and goods. The monitoring and control of city traffic is becoming a major problem in many countries. Traffic congestion is a severe problem in many modern cities around the world as it continues to pose critical challenges to the dwellers of major and most populated cities. Movement within the city is increasingly difficult due to traffic congestion. Individually, people lose man-hour time, miss opportunities, and get frustrated un-necessarily. To corporate organizations, traffic congestion leads decrease in workers' productivity loss of trade opportunities, delayed delivery thereby the overall cost of services are increased. Solving congestion problems will involve the construction of new facilities and improvement of existing infrastructures to enhance their efficiency. The disadvantage of constructing new roads or facilities is the resultant congestion of the surroundings. For this reason, it better to change and improve on the system rather than making new infrastructure twice (Krishnani et al., 2008).

Several measures had been deployed to address the problem of road traffic congestion in large cities in Nigeria; namely: the construction of interchanges and bypass roads, construction of ring roads, deployment of traffic wardens to trouble spots and construction of conventional traffic signals based on counters. These measures however, have failed to meet the target of decongesting of major cross intersections on our roads, leading to loss valuable man hour on daily basis, especially during the working days (Osigwe et al., 2011). As the number of road users constantly increases, and resources provided by current infrastructures are limited, the Traffic Monitoring Authority or the Transport Ministry has to find new ways or measures of ameliorating congestion problems at intersections. It is understandable that automatic control systems should relieve humans from manual control however such automatic system does not work well in many circumstances especially during oversaturated or unusual load conditions which could be due to limitations of the algorithms or sensing devices.

OVERVIEW OF NETWORKED CONTROL SYSTEM

NCS is one where the control loops are closed through a real-time network. The defining feature of an NCS is that control and feedback signals are exchanged among the system's components in the form of information packages through a network.

A control system functions is to regulate the behaviour of other systems. Traditional control systems are feedback control systems in which the feedback signals are transmitted through cable or wires. When a traditional feedback control system uses a network to connect the controller to the system, it is called an NCS. More specifically, an NCS exchanges information (i.e. reference input, plant output, control input) among control system components such as sensor, controller, and actuator among others using a shared network. A graphical representation of a typical NCS model is shown in Figure 1 (Gupta & Chow, 2010). The functionality of a typical NCS is established by the use of four basic elements namely:

- Sensors, to acquire information,
- Controllers, to provide decision and commands,
- Actuators, to perform the control commands and
- Communication network, to enable exchange of information.

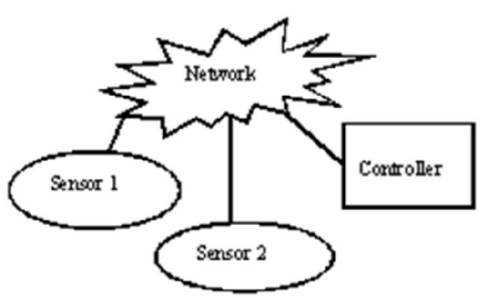

Figure 1: An Abstract model of an NCS

The most important feature of a NCS is the connection of the cyberspace to physical space thus, allowing for the execution of several tasks from long distance. Likewise, networked control systems helps in minimizing unnecessary wiring usage thus, reducing the complexity and the overall cost in designing and implementing the control systems. They can also be modified or upgraded by adding sensors, actuators and controllers to them with relatively low cost and no major changes in their structure. Moreover, featuring efficient sharing of data between their controllers, NCS can easily fuse global information to make intelligent decisions over large physical spaces (Gupta & Chow, 2010).

Their potential applications are numerous and cover a wide range of industries such as: space and terrestrial exploration, access in hazardous environments, factory automation, remote diagnostics and troubleshooting, experimental facilities, domestic robots, aircraft, automobiles, manufacturing plant monitoring, nursing homes and tele-operations.

GENERAL STRUCTURE OF TRAFFIC SIMULATION MODEL

The selection of route with the utmost right of way is achieved by using SIMULINK sub-system blocks for fixed time controller and fuzzy traffic controller for representing each approach as shown in Figures 2 and 3, respectively. The outputs of the approaches sub-systems are combined into the traffic signal intersection block that comprises of the FLC control unit and the input switch block. The input switch block shown in Figure 4 selects the path to be granted the green phase based on the FLC control unit.

This differ from the traditional control systems which place a nearness sensor at the front of each traffic light and can only sense the presence of a car waiting at the junction, not the number of cars waiting on the traffic.

The distance between the two sensors $, x$, is determined accordingly following the traffic flow pattern at that particular intersection. The function of the fuzzy logic controller is to control the length of the green time according to the traffic conditions at a particular lane. The state machine controls the sequence of states that the fuzzy traffic controller should cycle through. There is one state for each phase of the traffic light. There is another 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 presence of vehicle for the corresponding approach. Figure 5 illustrates the position of the sensor for each lane.

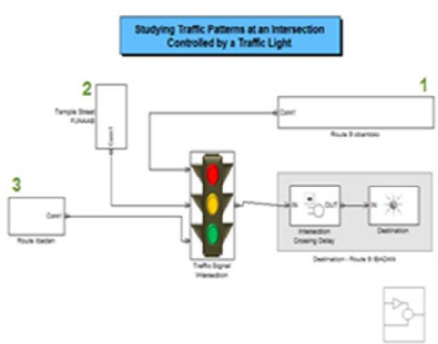

Figure 2: Fixed time controller for each of the approaches

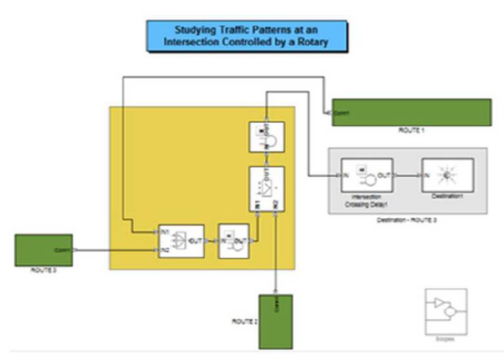

Figure 3: Fuzzy logic controller for each of the approaches

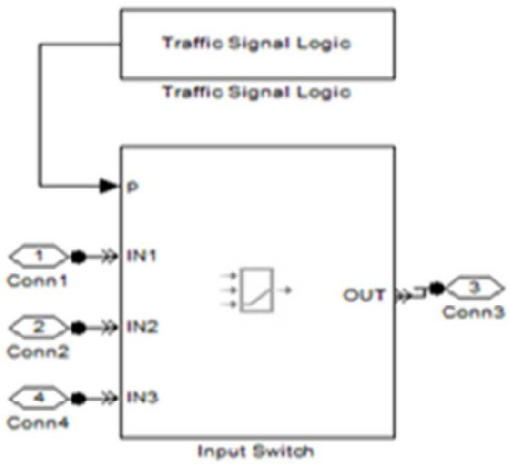

Figure 4: Input switch block

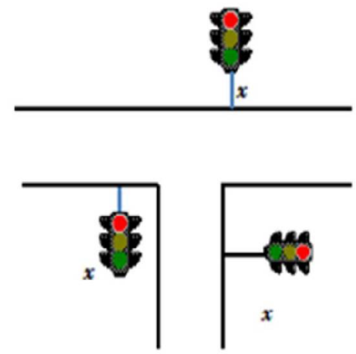

Figure 5: Overview of T junction

DESIGN OF FUZZY TRAFFIC CONTROLLER

The design of fuzzy traffic signal controller involves the use of MAMDANI-Type fuzzy inference system in MATLAB Toolbox. The design is divided into three different parts which are Green Phase, Next Phase, and Switch mode.

In the traffic lights controller two fuzzy input variables are chosen: the quantity of the traffic on the arrival side (Arrival) and the quantity of traffic on the queuing side. If the EAST and WEST side is green then this would be the arrival side while the NORTH would be considered as the queuing side, and vice-versa. The output fuzzy variable would be the extension time needed for the green light on the arrival side (Extension). Thus based on the current traffic conditions the fuzzy rules can be formulated so that the output of the fuzzy controller will extend or not the current green light time. If there is no need to extend of the current green time, the state of the traffic lights will immediately change to another state, allowing the traffic from the alternate phase to flow.

Green Phase - Determining whether to extend or terminate the current green phase is based on a set of If - Then Embedded MATLAB code rules. The rules evaluate the traffic condition with current green phase and traffic condition with the other candidate green phase. This module contains "Fuzzy Controller" block that has one set of fuzzy rules of MAMDANI-type fuzzy inference system which is used to determine the length of the extension time of green light. The set of fuzzy rules consists of a total of 25 rules as shown in appendix. The fuzzy inference system (FIS) which contains these rules takes the vehicles waiting time and the queue length at current green phase as its antecedents and generates "extension" as output. Then, the value of "extension" is sent to the "Embedded MATLAB Function" block for evaluation as shown in appendix. The "Embedded MATLAB Function" block which contains the simple if-else statements evaluate the likelihood that the green phase should extend based on the generated 'extension' output from the first fuzzy inference system and the queue lengths in the other two phases Waiting time and vehicles queue length are used as the two input variables for fuzzy inference system in traffic signal controller as shown in Figure 6.

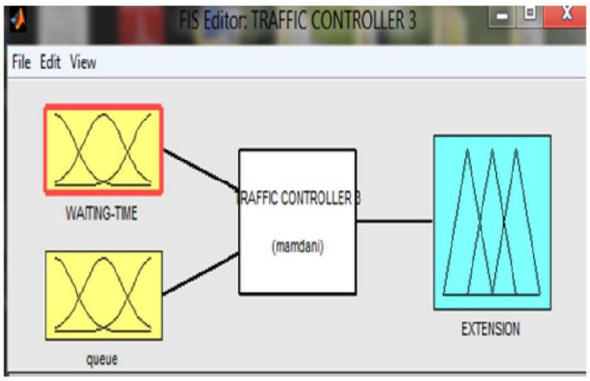

Figure 6: Fuzzy traffic control unit

The membership functions (MFs) of the fuzzy sets of the input and output parameters for the next phase and Green phase extensions are represented using Gaussian MFs. The waiting time of a vehicle is assumed to be at most 30 seconds, The input membership function of waiting time is subdivided into five ranges: very short (VS), short (S), long(L), very long (VL), and extremely long (EL), the constant for Gaussian membership functions of VS, S, L, VL, and EL are 0 seconds, 6 seconds, 12 seconds, 18seconds, and 24 seconds, respectively Gaussian membership functions has standard deviation (σ) of 1.2 as shown in Figure 7

Likewise, the queue length is subdivided into 0 to 20 vehicles in each lane on each approach at the intersection respectively. The input Membership functions input of Q membership functions are subdivided into five ranges: very short (VS), short (S), long (L), very long (VL), and extremely long (EL). The value for membership functions of VS, S, L, VL, and EL are 0 vehicle, 4 vehicles, 8 vehicles, 12 vehicles, and 16 vehicles, respectively. Gaussian membership functions have standard deviation (σ) of 0.8 as shown in Figure 8.

The output fuzzy variable, for the extension time of green light, is subdivided into five ranges corresponding to fuzzy sets: zero (Z), short (S), long (L), very long (VL), and extremely long (EL) . So, it consists of five membership functions represented with Z, S, L, VL, and EL where these membership functions are Gaussian membership functions with standard deviation, σ equals 2.124 as shown in Figure 9.

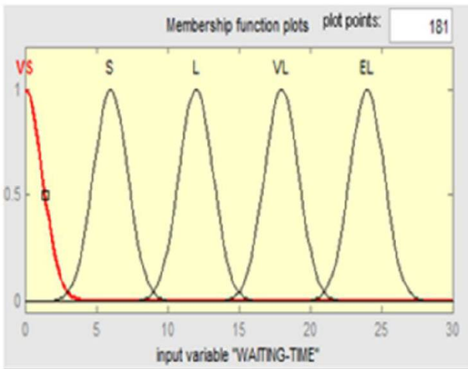

Figure 8: Input membership functions of vehicles queue

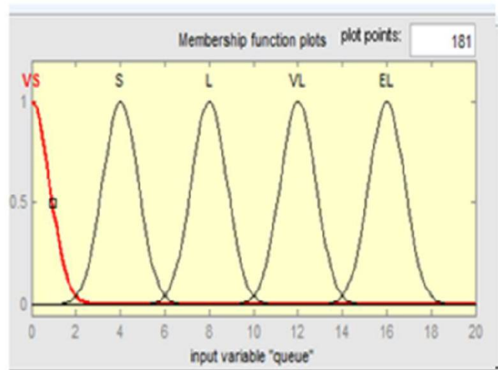

Figure 9: Output membership functions of extension

Right of way of each of the Phases - The right of way of an approach is derived from determining the delay and the number of queuing vehicles in each of the approaches. It is assumed that one of the approaches is given right of way i.e. green signal is given to the vehicles on one of the approaches. Figure 10 shows the internal structure of each of the intersection approach subsystem.

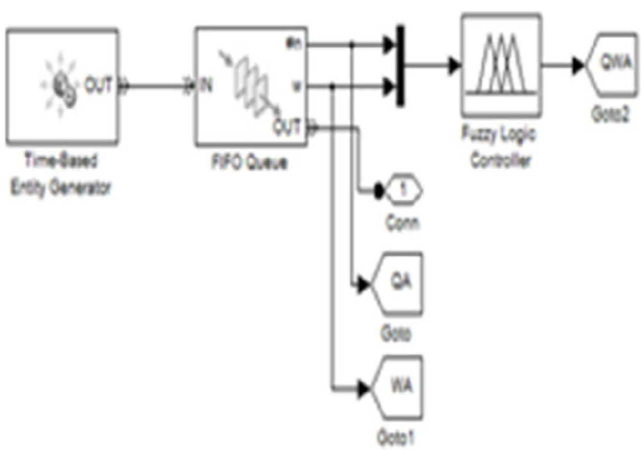

Figure 10: FLC subsystem model of each approach

Next Phase Module - Next Phase module controls the phase sequence based on the vehicle's queue length and extension time of green light from Green Phase module. It selects one of the routes for the green phase and it extends the green time of green phase based on traffic conditions of all phases. This is done by the "phase extension block" block that contains simple programming code; The If-Then rules determine the current phase and use the traffic data depicting the weight of the other phases from the fuzzy logic unit to determine the next phase.

In determining whether to extend or terminate the current green phase is based on a set of If-Then Embedded MATLAB code rules. The If-Then rules compares the traffic condition with current green phase and traffic condition with the other candidate green phase (the red phase with the highest priority degree). Each phase has a minimum green time (T_{min}) of 5sec and a maximum green time (T_{max}) of 15sec.

Fuzzy Logic Control Unit

The fuzzy logic control unit in figure 6 forms the brains that control the selection and extension of the green phase. Inputs depicting the load or level of priority on each approach are inputted to the phase extension sub-system which determines whether to extend or terminate the green phase. The value from the phase selection subsystem is added to the minimum time of 5sec to get the duration of the green time extension, Time extension, which is used as an attribute for determining the server duration. Every time an entity is served by the server, a function call is generated which activates the phase selected by the phase selector subsystem.

Switch Mode - The Switch Module switches current phase to the appropriate next phase. Basically, this module switches the current phase to the next phase based on the outputs of Next Phase. This was achieved through the use of the embedded block, if the other phases have longer queue than the queue of current phase, then, the Next Phase Module will give signal to Switch Module to switch to the phase that has the longer queue.

Simulation Results

The simulation for the fuzzy logic traffic signal controller was carried out using MATLAB, SIMULINK and the Fuzzy Logic Toolbox. The developed Fuzzy logic model was compared with the distinctive traffic controller system. The simulator was run for 1000 seconds with the following conditions:
The green time (in sec) of each phase is determined by the server

FLC: min (5) and max (10)
Fixed-time controller: Route 1(20), Route 2 (20) and Route 3(30)
The arrival of vehicles on each approach is Route 1 (2secs), Route 2 (3secs), and Route 3 (6secs).

DISCUSSION

In Figure 11, it can observed that in the spaces of 2 seconds for Route 1, the maximum numbers of vehicle that could be withheld at the intersection was 10 vehicles within the simulation sample time 1000 seconds, for Route 2, in the spaces of 3seconds, it was approximately less than 10 vehicles and for Route 3, in the spaces of 6 seconds it was less than 20 vehicles, in the spaces of 2 seconds in Route 1, the maximum numbers of vehicle withheld at the intersection was greater than 10 vehicles, Route 2 was approximately less than 40 vehicles and Route 3 were more than 200 vehicles. It could be seen that more vehicles were held up at the intersection in Figure 12 compare to Figure 11.

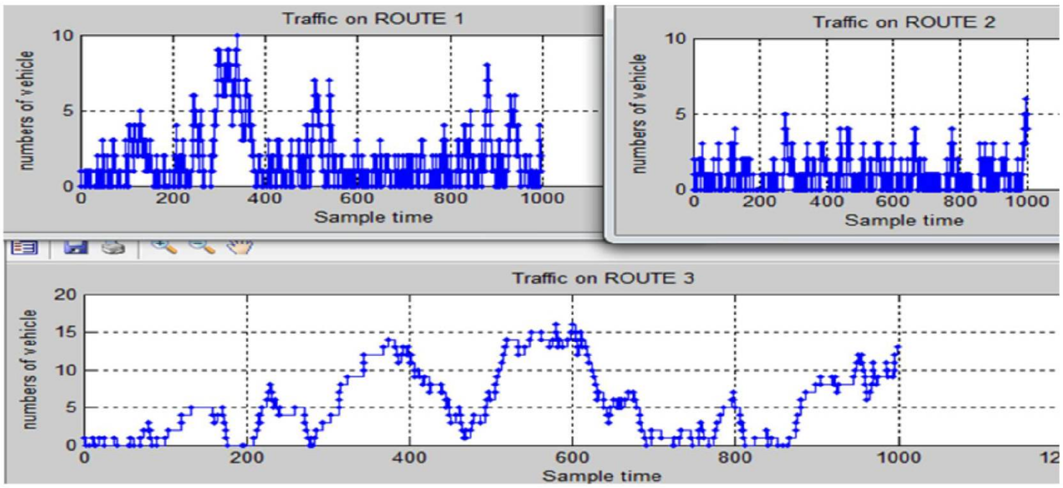

Figure 11: Results for the fuzzy controller

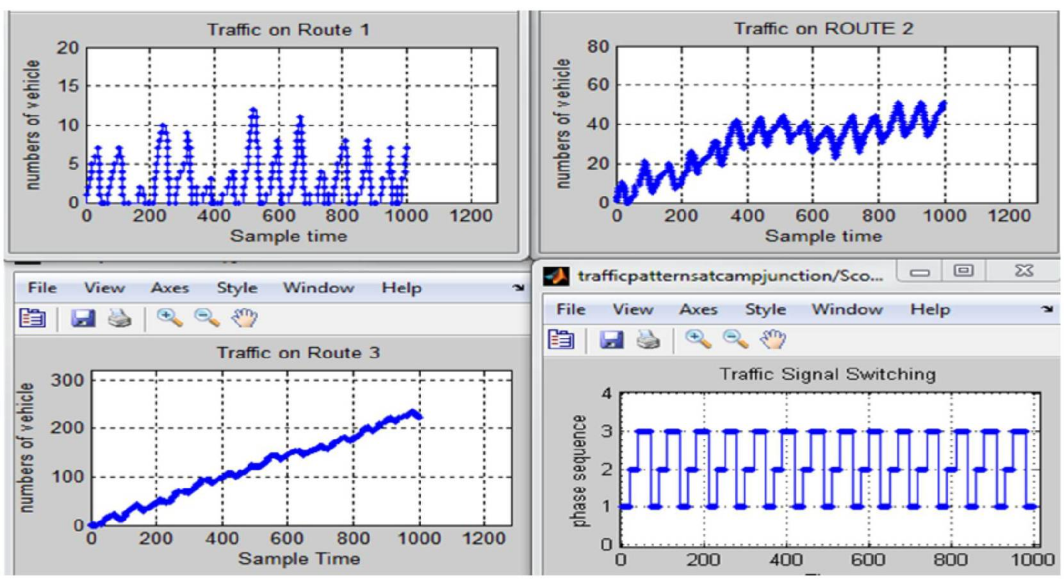

Figure 12: The result for the fixed time controller

Figure 12 shows the phase sequence of the fixed-time controller and it was seen that the sequence of fixed-time controller representing the three approaches were the same irrespective of the weight of each phase. Comparing Figures 11 and 12, it was seen that the length of the queue at the intersection for the fixed traffic controller was longer compare to the fuzzy logic controller. In the case of the fuzzy logic, it considered the weight of each phase and does not follow the same sequence of the traffic signal switching like that of the fixed controller. The fuzzy controller was able to increase the green time for an increasing traffic for a particular lane.

CONCLUSION

Both the fixed traffic controller and the fuzzy logic controller were developed using MATLAB software in other to test the effectiveness of fuzzy controller in controlling the traffic flow at an isolated intersection, the MATLAB simulation was done. From the results gathered it could be seen that the fuzzy logic controller showed good performance for controlling traffic flow than the fixed time controller. In the absence of traffic from a lane, the fuzzy was able to switch to the next phase with the next highest traffic. It was seen that the performance of fuzzy traffic controller was better than fixed -time controller in terms of average number of cars waiting and it was to maximize the capacity of the intersection, minimizing the delays at the intersection, and influencing the route choices.

This work has been able to address the similarity between fuzzy logic and observed its human like decision making technique through the use of the fuzzy inference system

The use of FIFO (first in first out) technique in the modeling which acted as server for each of the approach with the sensors has provided a better communication system between the traffic systems. The use of networked control system such as traffic control system optimized the decision making at the road intersection junction compare to using a traffic warder which decision could be impaired due to weariness.

The effectiveness of the fuzzy logic traffic controller to control the traffic flow at isolated intersection was carried out using MATLAB simulation. The comparison proposed controller, fixed time traffic controller also was simulated, overall, the fuzzy logic traffic controller shows good performance for controlling traffic flow at isolated intersection. The efficiency of the fuzzy traffic controller was better to the fixed time controller due to the former's ability to adapt to different traffic conditions.

The time extendibility for the fuzzy logic traffic controller was not set which gave the ability to freely determine the length of the green phase according to traffic conditions at the intersection, which has also improve the efficiency of the controller.

Appendix

Fuzzy Rules

1. If (waiting time is VS) and (queue is VS) then (extension is Z)
2. If (waiting time is VS) and (queue is S) then (extension is Z)
3. If (waiting time is VS) and (queue is L) then (extension is S)
4. If (waiting time is VS) and (queue is VL) then (extension is S)
5. If (waiting time is VS) and (queue is EL) then (extension is L)
6. If (waiting time is S) and (queue is VS) then (extension is Z)
7. If (waiting time is S) and (queue is S) then (extension is S)
8. If (waiting time is S) and (queue is L) then (extension is S)
9. If (waiting time is S) and (queue is VL) then (extension is L)
10. If (waiting time is S) and (queue is EL) then (extension is L)
11. If (waiting time is L) and (queue is VS) then (extension is S)
12. If (waiting time is L) and (queue is S) then (extension is S)
13. If (waiting time is L) and (queue is L) then (extension is L)
14. If (waiting time is L) and (queue is VL) then (extension is L)
15. If (waiting time is L) and (queue is EL) then (extension is L)
16. If (waiting time is VL) and (queue is VS) then (extension is S)
17. If (waiting time is VL) and (queue is S) then (extension is S)
18. If (waiting time is VL) and (queue is L) then (extension is L)
19. If (waiting time is VL) and (queue is VL) then (extension is VL)
20. If (waiting time is VL) and (queue is EL) then (extension is EL)
21. If (waiting time is EL) and (queue is VS) then (extension is L)
22. If (waiting time is EL) and (queue is S) then (extension is L)
23. If (waiting time is EL) and (queue is L) then (extension is L)
24. If (waiting time is EL) and (queue is VL) then (extension is VL)
25. If (waiting time is EL) and (queue is EL) then (extension is EL)

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