AN INTELLIGENT TRAFFIC LIGHT CONTROL SYSTEM BASED ON FUZZY LOGIC ALGORITHM

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ABSTRACT

Traffic light control systems have increased in use on our roads particularly in the urban areas. Every year, more cities are starting to implement traffic light control systems to control traffic in and out of the city. Much of this increase is due to the increasing number of motorists and pedestrians in the cities and urban areas. This study aimed at showing how Fuzzy logic can be used in the development of an intelligent traffic light control system. Traffic light control algorithm plays a vital role in enhancing control of traffic flow in the cities , however despite the fact that traffic lights have been successfully used by many cities, little has been done to establish how fuzzy logic can be used to enhance traffic light control algorithm. Building on sparse literature regarding use of fuzzy logic in traffic light control algorithm, where motorists are allowed to interact collectively and intelligently with the environment, intelligent traffic light algorithm system based on fuzzy logic concept is appropriate and suited for our roads due to its adaptive nature. This research paper has adopted a cross sectional study targeting traffic control in the city of Nairobi Central Business District and its surroundings. The three junctions at Railways, Haile Salessie and General Post Office were used to collect data through observations of traffic behavior at the intersection points. Data was analyzed and presented using descriptive statistics; tables and graphs by using excel 2003. For testing our adaptive traffic light controllers, we developed a simulation system using Qt, C++ software integrated with MATLAB tools. The simulation runs results showed that the adaptive algorithms can strongly reduce average waiting times of cars compared to the conventional traffic controllers.

Key Words: *intelligent traffic light control system, fuzzy logic algorithm*

INTRODUCTION

The idea of traffic light controller using fuzzy logic is an adaptation from conventional traffic light control system. Traffic light is an important system to control the traffic flow especially at junctions. But, we find some problem with the conventional traffic light control systems at times. Conventional traffic light cannot operate as efficiently as expected. Because of that problem, the idea to develop an intelligent traffic light control system based on fuzzy logic is taken into consideration (Ahmad, 2005). The essence of any urban transportation problem is lack of mobility, severely limited mobility and mobility purchased at a very high social and economic cost. In Nairobi, the current situation of urban transport is alarming. Despite the relatively low levels of private automobile ownership, the city's transportation problems are severe in degree, daily duration and areas affected .These problems are especially felt during the peak demand hours which are often characterized by considerable jostling and stampeding among the travelling public in search of the means of public transport. The chaotic situation is further exacerbated by the carelessness and apparent lack of concern among the public service vehicle

(PSV) operators (Obudho, 1993). For most commuters the problems faced include increasing walking distance, long waiting hours, severe struggles while getting on and off the available PSVs, insecurity and pick pocketing, accidents, traffic jams, vehicle breakdowns and a general atmosphere of bad temper. Basically the major problem is that of congestion, mainly witnessed in the form of overloaded buses and matatus and traffic jams experienced, especially in the Central Business District. The centralization of activities in this zone has ensured that the commuting trend involves a movement to the surrounding expanding residential areas (Obudho, 1993).

Right now, the length of time it takes to move from one part of the city of Nairobi to another has reached a totally inefficient point. There is hardly any difference between the volume of traffic on the road at peak hours and off-peak hours. The reason why i am convinced the problem is traffic management problem is because sometimes, the roads are clear during off-peak hours as you expect them to be, and even during peak hours, yet there is no plausible reason to explain this anomaly (Butoy,2009). The existing environment consists of traffic lights, which are conventional. The traffic lights, in the absence of a vehicle on any particular session, will continue to operate as if traffic always exists and assume an equal distribution of traffic flow. In the conventional traffic light controller, the duration allocated for each junction is at a constant cycle time, which is clearly not an optimal solution. Using this system, traffic light cycle time is fixed without care of the traffic flow at the time. For example when the incoming traffic is in low condition and the outgoing traffic is in high condition the traffic light cycle is still in the fixed time mode. The release time for the incoming traffic is set on a long period but the release time for the outgoing traffic is set in a short period. This makes the outgoing traffic to be congested and sometimes the vehicles get stuck at the centre of the intersection. There have been increased cases of congestions due to poor traffic controls in our Roads particularly at our roundabout junctions. Motorists and pedestrians will be able to spend less time travelling and will not be frustrated or delayed when travelling. The research project addressed the congestion problem in our Roads. This has necessitated the need for effective and efficient traffic control systems to alleviate the fears of the Government and uncertainty of the travel times by motorists.

LITERATURE REVIEW

Zaimu (2009) stated that traffic light systems do consist of two parts. First part is traffic light and the second part is controller unit. Traffic light is used to control traffic flow at the busy intersections. Normanyo (2009) described a traffic light signal or stop light, as a signaling device positioned at road intersections, pedestrian crossings and other locations to control the movement of vehicles and pedestrians. Furthermore, Traffic lights normally have three main lights: a red light meaning" stop", a green light meaning “go” and the amber light meaning “stop if possible”. In the subsequent section are two common strategies employed for controlling traffic; Fixed-

Time (FT) based traffic light control mechanism and Real-time (RT) based traffic light algorithm.

Pre-timed Signal Control Algorithm

The control (signal plan) is calculated in advance, using statistical data (Askerzade, 2006). The control uses preset cycle time to change the lights (fixed time). The general structure of the preset traffic control is shown in fig.2.1. The main control measure in urban road networks is the traffic lights at intersections. Traffic lights besides ensuring the safety of road crossings may also help in the minimization of total time spent by all vehicles in the network, provided that an optimal control strategy is applied.

Actuated Signal Control Algorithm

Askerzade (2006) stated that the real-time data about traffic processes are used to determine control or its modification. The control combines preset cycle time with proximity sensors which can activate a change in the cycle time or the lights. Actuated signal control, one of the most widely deployed traffic control strategies, taking advantage of the data collected by the detectors, is more adaptable to the real traffic condition. The signal control decision is made according to a set of rules considering the traffic condition.

Neural Network Algorithm

The human brain, according to Bradley (2004) is constructed of cells called neurons. Each cell accepts some inputs and then, based on the total value of inputs, the neural decides whether or not to fire an output. In the brain vast numbers of neurons are wired together, sending their outputs to other neurons, and ultimately allowing humans to make complex decisions about things. Neural networks attempts to replicate this process electronically. Neural network follow the same architecture as the brain, except the neurons are represented electronically. In a biological neuron, messages pass from cell to cell over gaps called synapses. Input messages then travel along dendrites. After the cell generates its output, an output message is sent out along an axon. Just as with biological neurons, neuron in a neural network has a set of inputs that it accepts then uses to calculate its outputs. The traffic lights adjust their signaling patterns according to the number of cars waiting in each direction, how long it has been since the light last changed the status of its neighbors. Neural networks provide the traffic lights with brains allowing them to make decisions.

Genetic Algorithm

Ayad (2009) introduces Genetic algorithm in the traffic light control system to provide an intelligent green interval response based on dynamic traffic load inputs, thereby overcoming the inefficiencies of conventional traffic controllers. In this way the challenges are resolved as the number of vehicles are read from sensors put at every lane in a four-way, two lane junction and pedestrians are motivated at the road junction. The features inherent in genetic algorithm play a critical role in making them the best choice for practical applications, namely optimization, computer aided design, scheduling, economics and game theory. It is also selected because it does not require the presence of supervisor or observer. However, genetic algorithm without prior training, continuously allow permanent renewal of decisions in generating solutions. Instead of trying to optimize a single solution, they work with a population of candidate solutions that are encoded as chromosomes. These chromosomes are separate genes that represent the independent variables for the problem at hand. Bradley (2004) explained that Genetic algorithm attempts to mimic natural selection and Darwinian evolution. A group of individual object is given a task; the ones that perform the task the most efficiently are considered the fittest. Just as in a biological evolution, where the fittest individuals are the ones most likely to reproduce, genetic algorithms select the fit objects and use them as templates to create a new generation of objects.

Reinforcement Learning Algorithm

Wiering (2004) explained that there are two types of agents that occupy an infrastructure; vehicles and traffic lights. All agents act autonomously, following some simple rules, and get updated every time-step. Vehicles enter the network at the edge-nodes. Each edge-node has a certain probability of generating a vehicle at each time step. Each vehicle that is generated is assigned a destination, which is one of the other edge-nodes. The distribution of destinations for each edge-node can be adjusted. There are several types of vehicles, defined by their speed, length, and number of passengers. Wiering (2004) further stated that Reinforcement learning is used to learn agent control by letting the agent (for example a car) interact with its environment, learn from the obtained feedback (reward signals).Using a trial and error process, a reinforcement learning (RL) agent is able to learn a policy (or plan) that optimizes the cumulative reward intake of the agent over time. Markov decision problems can be used for modeling the interaction of an agent with its environment. The agent’s goal is to select actions that maximize the expected long-term cumulative discounted reinforcement, given arbitrary initial state (SD) using Dynamic programming techniques. Reinforcement learning for traffic light control was studied by Thorpe (1997); Thorpe and Anderson (1996). He used a traffic light-based value function, and neural network for the traffic-light based function which predicts the waiting time for all cars standing at the junction. This means that Thorpe’s traffic light controller has to deal with a huge number of states, where learning time and variance may be quite large. Furthermore, Thorpe used somewhat other form of RL; SARSA (State-Action, Reward-State Action) with eligibility traces (Sutton, 1996).

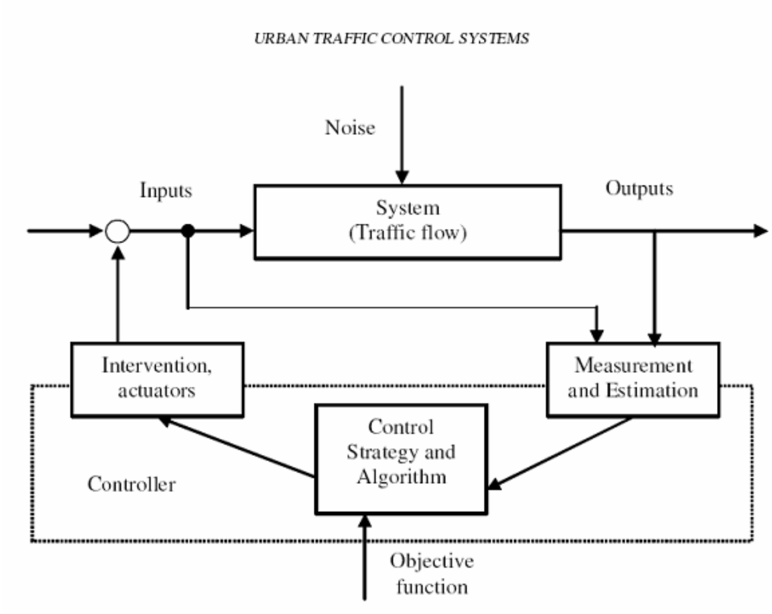

Figure 1: The structure of Road Traffic control

Fuzzy Rule-Based Traffic Flow Algorithm

Syed (2009) stated that conventional methods of traffic signal control based on precise models fail to deal efficiently with the complex and varying traffic situation. They are modeled based on the preset cycle time to change the signal without any analysis of traffic situation. Due to fixed cycle time, such systems do not consider which intersection has more load of traffic, so should be kept green much longer or should terminate earlier then complete cycle time. Fuzzy rule-based controllers are proved to be well managers of traffic light system in such scenarios. Fuzzy controllers have the ability to take decision even with incomplete information. These algorithms are continually improving the safety and efficiency by reducing the waiting times of vehicles. These increases the tempo of travel and this makes signals more effective and traffic flow smooth.

Wiering (2004) explained that Fuzzy logic offers a formal way of handling terms like “more”, ”less” ,”longer” etc., so rules like “If there is more traffic from north to south, the lights should stay green longer” can be reasoned with. The fuzzy logic controller determines the time that the traffic light should stay in a certain state, before switching to the next state. The order of states is predetermined, but the controller can skip a state if there is no traffic in a certain direction. The amount of arriving and waiting vehicles are quantized into fuzzy variables, like many, medium and none. The activation of the variables in a certain situation is given by a membership function, so when there are 5 cars in the queue, this might result in an activation of 25% of ‘many’ and ‘75%’ of medium. Fuzzy rules are used to determine if the duration of the current state should be extended .In experiments the fuzzy logic controllers, allow traffic to flow more smoothly, and reduce waiting time. A disadvantage of the controller seems to be its dependence on the preset quantification values for the fuzzy variables. They might cause the system to fail if the total amount of traffic varies and reaches an oversaturated point.

Azadeh (2008) stated that simplicity and accuracy of models are crucial criteria of their construction in general and in road traffic system especially. The quality of models is indeed a tradeoff between them because complicated models are computational inefficient and cannot be used in online control and simulation of large systems and accuracy has tendency to saturate. These goals fulfills the group model of traffic flow (Kaczmarek, 1986), in which vehicle moving dependently are grouped in one object. At the level of abstraction, meso-models constructed on vehicle group approach are detailed for control and simulation purposes. The group model was successfully applied in traffic control on roundabouts (Kaczmarek, 1990) and in open street networks (Kaczmarek, 1994; Hawas, 2002) utilized a microscopic simulation based calibration approach to derive the speed density relationships. Niitymaki (2002) used microscopic simulation called HUTSIM developed in Helsinki University to evaluate their fuzzy logic control system.

Syed (2009) characterized traffic flow by randomness and uncertainty. Fuzzy logic is known to be well suited for modeling and control problems. Applications of fuzzy logic in traffic signal control has been made since 1970. The first attempt made to design fuzzy traffic controller was in 70’s by pappis and mamdani. After that niitymaki, kikuchi, chiu and other researchers developed different algorithms and logic controllers to normalize traffic flow. Kelsey (1993) also designed a simulator for signal controlling of an isolated intersection with one lane. The same was also done by Niitymaki and Pursula. They observed that fuzzy controller reduces the vehicle delay when traffic volume is heavy.

Niitymaki (2002) developed fuzzy based algorithm for pedestrians crossing the road. Nakatsuyama, Nagahashi and Nishizuka applied fuzzy logic to control two adjacent intersections on an arterial with one-way movements. Fuzzy control rules were developed to determine whether to extend or terminate the green signal for the downstream intersection based on the upstream traffic. Chiu (1993) was the first who used fuzzy logic to control traffic in multiple intersections. In his attempt, only two-way street were evaluated without considering any turnings .In recent years, Lin Zhang and Honglong Li also worked on designing fuzzy traffic controller for saturated junctions.

Hyong (1995) presented direction-varying traffic signal control but assumed that right turn traffic flow do not disturb any other traffic flows in an intersection. Rezapour (2009) presented fuzzy traffic signal control with phase selector and green extender functions and evaluated its performance by simulation. They proposed a newly changeable phase- sequence signal control method. Tahere (2010) invented traffic Signal Control Intersections based on Fuzzy Neural

Network and Genetic Algorithm. They proposed that an intersection signal control model should consider three factors: (1) Simplified computing model, control schemes should output in a specified period; (2) Consider both under intersection and its adjacent intersection, for realizing linear or group control; and (3) Self learning ability. They tried to consider these factors in intersection control model.

Askerzade (2011) described the implementation of an intelligent traffic control system using fuzzy logic technology which has the capacity of mimicking human intelligence for controlling traffic light. They developed MATLAB software to simulate an isolated traffic junction. Khalid (2004) stated that in traffic light control, a number of research have applied the fuzzy control technique, however, in most cases only one intersection or traffic junction were considered .They proposed a new fuzzy traffic lights control system that can be effectively used for complex traffic junction with multiple intersections. The system allows communications with neighboring controllers and manages phase sequences and phase lengths adaptively according to traffic density, waiting time of vehicles and congestion.

RESEARCH METHODOLOGY

Research Design

Cooper and Schilder (2003) described two major research designs. These are qualitative and quantitative designs. Qualitative design includes techniques and measures that do not produce discrete numerical data. It is mostly used for a case study, education critique and participatory research. This design allows further explanation on any statistical results realized relating to qualities, values or value assessment such as people's opinion (Chandran, 2004). Quantitative research design on the other hand includes discrete numbers or quantified data (Cooper and Schilder, 2003). This study utilized both qualitative and quantitative research designs.

Target Population and Sampling Technique

The target population was total traffic volume, that is, the traffic flow observed as incoming and outgoing traffic for every roundabout within Nairobi City. However, sampling for the fuzzy logic traffic algorithm system was based on a study of the three roundabouts which are: Railway (RWS), HaileSalesie (HSA) and General post office (GPO) junctions. The traffic flow along the three junctions and paths (roads) were analyzed and evaluated .Observations were made every 15 minutes from 6.00a.m to 6.00p.m on a daily basis for six consecutive days on the traffic behavior on roads, these observations were analyzed and results were interpreted to determine the performance of the intelligent traffic light algorithm system under study.

Data Collection

Secondary data on traffic situation for the entire city of Nairobi which was collected earlier (i.e the year, 2004) by "KIPPRA" was used to check the validity. The data included the Dates, Time, Traffic volumes for each roundabouts detail, and the point of traffic entry at the roundabouts. It acted as a framework when observations were made and recorded. Primary data collected by observations along the three roundabouts. The observations were made on the traffic flow behavior at the three junctions and recorded. During the observation process, a time frame was provided and agreed with the research assistants. The recorded observations were cross-checked and analyzed using descriptive statistical method (the mean and standard deviation was calculated for each junction state). This method was adopted because it was cheap, data could be collected conveniently and it also enabled a collection of a larger sample thus making results more dependable. To aid in data collection, observation data sheets were designed to collect data of relevance from the ground in respect to this project. The sample data sheets are shown in appendix I. There were two modes of data collection: physical observations on site and recording of physical measurements; and interview session held with the traffic police officers manning the roads. The data collection exercise was done on six consecutive days from Monday 20th June to Saturday 25th June, 2011. Four resource persons, one at each junction of Railways, Haile Salesie and General Post Office on the consecutive days carried out the data collection as per the guidelines given by the researcher. The traffic volume was recorded. The sample data for the three junctions on 25th June, 2011 is presented in table 2.0 with the accompanying characteristics in the time domain for this specific date shown in figures 2.1, 2.2 and 2.3. Personal interviews were also conducted with the traffic police officers manning traffic on the roads to determine their experience on the traffic patterns at the three roundabouts. The data collected was then subjected together with the observations made on the junctions then analyzed and comparison made with data received by simulating the system.

Data Analysis

The analysis of the observed data was done using descriptive statistics method by computing the mean and standard deviations from the data collected. The mean and standard deviation were then used to generate random model cars for the simulation utilizing Lognormal Distribution.

Simulation of both fuzzy logic traffic light algorithm system and fixed time-based traffic control is done by comparing the fixed time-based system functionality and the fuzzy rule-based traffic control system; this will take place by: (1). Running the two simulation processes of the two different systems; (2). The output data is taken in terms of traffic volume throughputs and the specified times then recorded.

SIMULATION RESULTS

The intelligent traffic light algorithm system was simulated using traffic data obtained through 12 hour observation made at the three junctions under study. The mean and standard deviation for every road junction was computed and Lognormal Distribution was utilized to generate the dummy cars in a random fashion. In order to undertake performance evaluation for both traffic control systems, the researcher then undertook three (3) ten minutes simulation runs for each traffic control system, that is pre-timed (fixed) and fuzzy logic, and computed an average of the simulation runs in order to generate frequency (number of cars completing the cycle) and average waiting time (for each junction). Simulation data was then converted into real-life data by converting the frequency and average waiting time by a factor of 1.5 and 0.25 respectively. In order to further illustrate the performance results of both traffic control systems, the researcher developed a flow-rate (number of cars completing the cycle per minute) based on the following formula: Cumulative Frequency/time

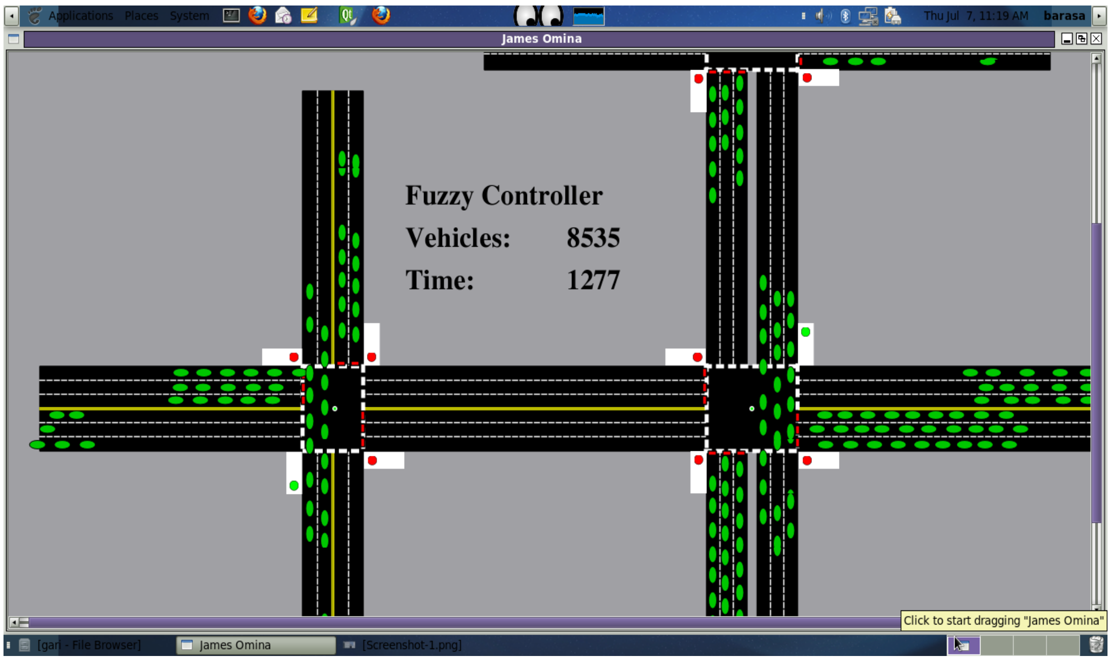

Figure 2: The Traffic Flow screen

The simulation results were evaluated through comparison between the performance of pre-timed (fixed) and fuzzy logic traffic control system. Figure 3 illustrates the simulation results of frequency (number of cars completing the cycle) per minute for both the pre-timed (fixed) traffic control and fuzzy logic traffic control system. According to the figure, fuzzy logic traffic control system was consistently exhibiting better performance as it had a higher frequency (number of cars completing the cycle) at any given point in time. However, it can be noted that there was a performance variation at some specific points in time whereby, the number of cars completing the cycle were relatively higher for fuzzy logic traffic control system as compared to pre-timed (fixed) traffic control system. The researcher interpreted this finding as further indication of better performance on the part of fuzzy logic traffic control system based on the assumption that at those specific points in time the traffic density at the junctions is high, hence the number of cars completing the cycle is marginally higher as compared to those points in time with low traffic density.

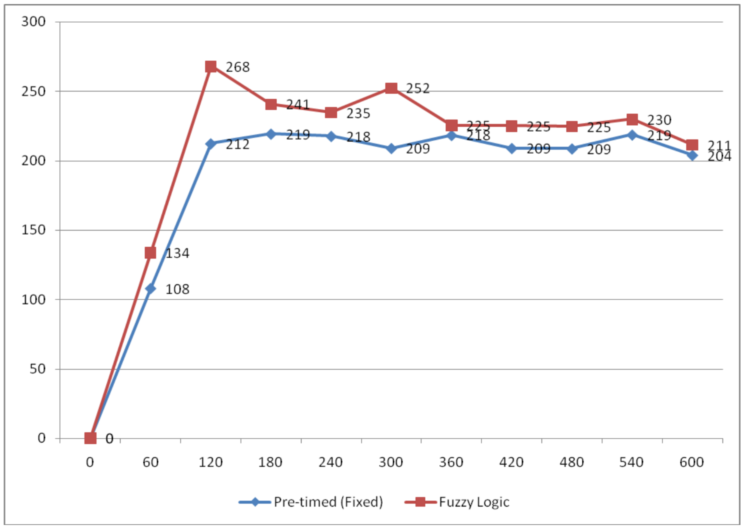

Figure 3: The Frequency Performance Chart

Figure 4 illustrates the simulation results of average waiting time at each junction for both the pre-timed (fixed) traffic control system and fuzzy logic traffic control system. According to the figure, the average waiting time for fuzzy logic traffic control system was consistently lower than that of the pre-timed (fixed) traffic control system at any given point in time. However, it can be noted that for pre-timed (fixed) traffic control system the average waiting time was constant while that of fuzzy logic traffic control system varied for each junction and at different points in time. This finding can be interpreted as further support for better performance on the part of fuzzy logic traffic control system whereby the average waiting time is lower as compared to pre-timed (fixed) traffic control system based on the assumption that such variations are as a result of different traffic densities at the junctions at different points in time.

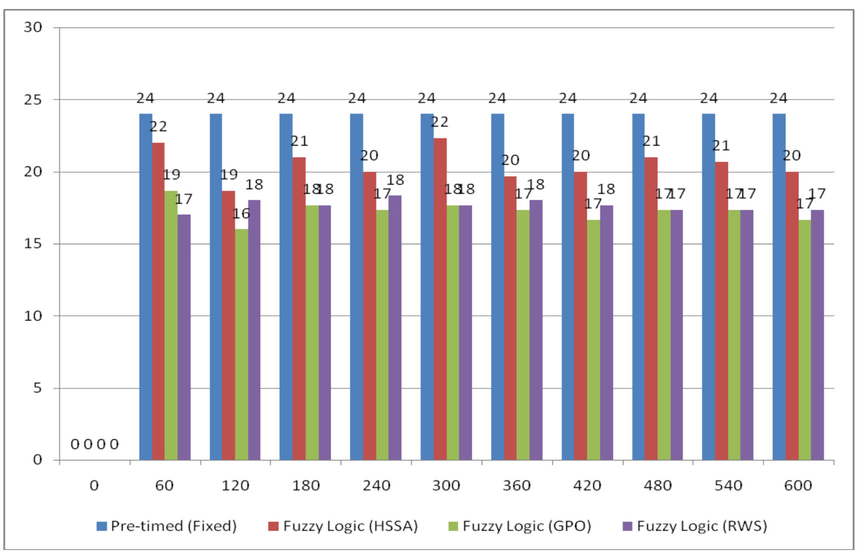

Figure 4: The Average Waiting Time Performance Chart

From the tabulation above it was found out that the volume of traffic (i.e., the vehicles that complete and exit the scene) is higher in fuzzy system than in time based system (FT). Therefore fuzzy systems performed better than time based systems. The graph in the Figure 5 and 6 illustrate the frequency (number of cars completing the cycle) per minute and average waiting time at each junction for both the pre-timed (fixed) traffic control system and fuzzy logic traffic control system respectively, based on real-life data. According to the figures, fuzzy logic traffic control system performs better that pre-timed (fixed) traffic control system as it had a higher frequency (number of cars completing the cycle) and lower average waiting time at any given point in time respectively.

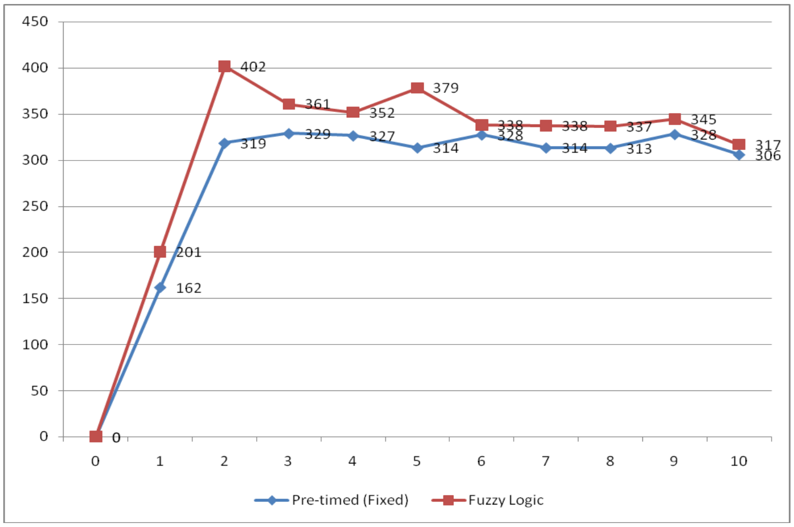

Figure 5: Real-life Frequency Performance Chart

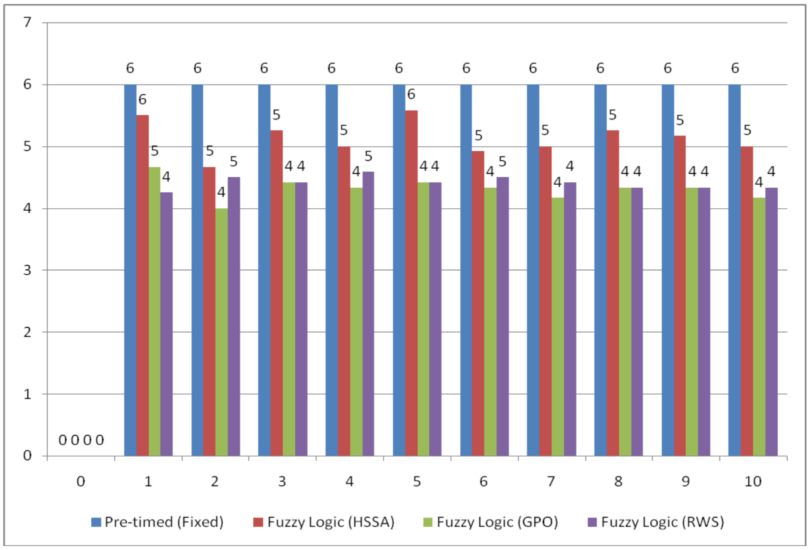

Figure 6: Real-life Average Waiting Time Performance Chart

Figure 7 and 8 illustrate the flow-rate (number of cars completing the cycle per minute) based on the simulation data and real-life data respectively. According to the figures, fuzzy logic traffic control system exhibited better performance with a higher flow-rate as compared to pre-timed (fixed) traffic control system at any given point in time. However, it can be noted that the flow-rate for fuzzy logic is optimum from the fifth minute onwards, while that of pre-timed nears its optimum as from the sixth minute. This is in line with the findings on the average waiting time of both traffic control systems whereby the average waiting time for fuzzy logic is five minutes with a low of 4 minutes, while that of pre-timed (fixed) traffic control system is fixed at 6 minutes.

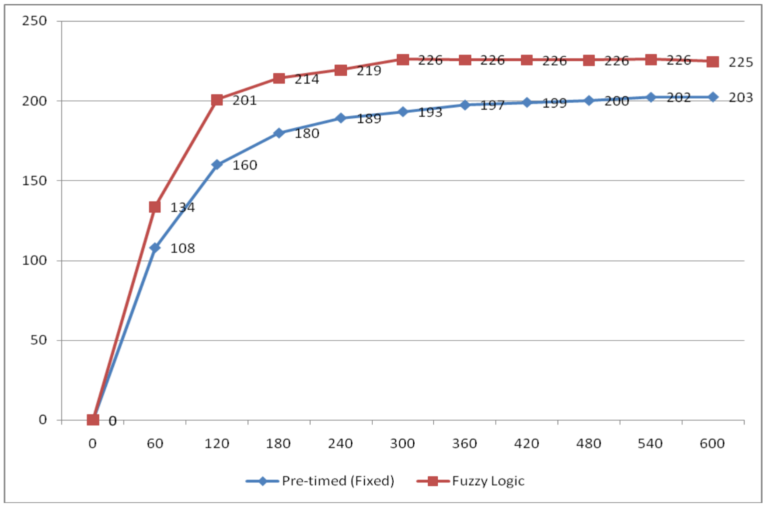

Figure 7: Simulation Flow-rate Performance Chart

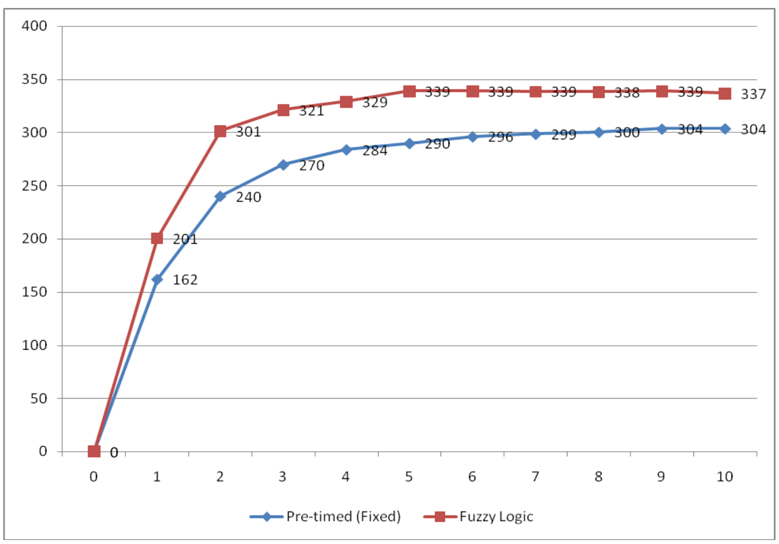

Figure 8: Real-life Flow-rate Performance Chart

DISCUSSION

Fuzzy logic traffic control system was found to perform better than pre-timed (fixed) traffic control system at any given point in time with respect to the frequency (number of cars completing the cycle), average waiting time and flow-rate. It was noted that fuzzy logic performance was much higher at some specific points in time as compared to pre-timed (fixed) and the researcher inferred that this was as a result of variations in traffic density, for instance traffic is higher at peak times (morning and evening hours), hence fuzzy logic was more efficient during high traffic density as compared to pre-timed (fixed). However, this assumption could not be verified as the simulation did not capture traffic density at each junction and at different points in time which is a limitation of the fuzzy logic traffic control simulation model.

CONCLUSIONS

Traffic signal control has been regarded as one of the most important traffic control methods. In this project, a new simple traffic signal alteration control algorithm based on Fuzzy Logic was proposed and tested in Qt, C++ framework. Simulation results showed that it had a better control effect than the conventional pre-timed algorithm under a non-saturated traffic condition. This demonstrates the effectiveness of Fuzzy logic in traffic signal control.

RECOMMENDATIONS

This model can be developed in the future to make it more usable. For example, cooperative traffic network can be treated in this way with respect to the factors that will affect this type of traffic control system, or using fuzzy controller for deciding the most urgent phase that should be open. Moreover, a lot of research is needed to enhance the algorithm, like definition of the reward and a more flexible phase sequence. And to verify the effectiveness of the algorithm in real dynamic traffic control, it should be tested under more complex and various traffic conditions.

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