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Design and Analysis of a Two Stage Traffic Light System Using Fuzzy Logic

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Abstract

Traffic congestion is a growing problem in many countries especially in large urban areas. The reason behind this is the increase in number of vehicles all over the world. Due to this vehicles do not run efficiently which increasestravel time, noise pollution, carbon dioxide emissions and fuel usages.In large urban cities, traffic signal controller plays an important role to improve the efficiency of vehicles, traffic congestion and hence reduces travel time, noise pollution, carbon dioxide emission and fuel used. In this paper, a two stage traffic light system for real-time traffic monitoring has been proposed to dynamically manage both the phase and green time of traffic lights for an isolated signalized intersection with the objective of minimizing the average vehicle delay in different traffic flow rate. There are two different modules namely traffic urgency decision module (TUDM) and extension time decision module (ETDM). In the first stage TUDM, calculates urgency for all red phases. On the bases of urgency degree, proposed system selects the red light phase with large traffic urgency as the next phase to switch. In second stage ETDM, calculatesgreen light time i.e., extension time of the phase which has higher urgencyaccording to the number of vehicles. Software has been developed in MATLAB to simulate the situation of an isolated signalized intersection based on fuzzy logic. Simulation results verify the performance of our proposed two stage traffic light system using fuzzy logic.

Keywords: Traffic congestion; Traffic urgency; TSTLS; TUDM; DTDM

Introduction

Traffic congestion of streets and roads constitutes a critical problem which is aggravated by the rise in the number of vehicles and by greater urbanization. The slow pace in the development of new highways and roads and public opposition to the widening of existing streets in some locations has forced the city managers to optimally use the existing infrastructures in order to effectively manage the flow of traffic. Moreover the loss of valuable time during traffic congestion can directly affect the production, productivity, performance and the utilization of fuel. The control of traffic light signal is one of the subjects of intelligent or advance systems being investigated by researchers because this kind of control has a direct impact on the effectiveness of urban transportation systems [1].

Traffic signals operate in pre-timed, actuated or adaptive mode. Pre-timed control consists of a series of intervals that are fixed in duration. They repeat a preset constant cycle. In contrast to pre-timed signals actuated signals have the capability to respond to the presence of vehicles or pedestrians at the intersection. Vehicle actuated signals require actuation by a vehicle on one or more approaches in order for certain phases or traffic movements to be serviced. They are equipped with detectors and the necessary control logic to respond to the demands placed on them. Vehicle-actuated control uses information on current demands and operations obtained from detectors within the intersection to alter one or more aspects of the signal timing on a cycle-by-cycle basis. Timing of the signals is controlled by traffic demand.

Adaptive or area traffic control system sometime called as ATCS. It is the latest generation of traffic control system. ATCS continuously compute optimal signal timings based on this detected volume and simultaneously implement them. ATC system to effectively respond to the rapid changes in dynamic traffic conditions which are designed to have intelligent real-time dynamic traffic control systems. These systems use data from vehicle detectors and optimize traffic signal time in real time that's why ATCS called as adaptive traffic signal. The timing plan of ATCS controller changes automatically for these purpose digital computers are used.

Over the course of performing a literature review, adaptive traffic signal systems have been operating successfully in many countries since the early 1970. Adaptive traffic signal control systems are normally complicated and include prediction and estimation modules. More than twenty Adaptive traffic signal controls are available on the market. They are significant due to their relative acceptance in the field as well as the relative extent of their real world implementation. The most widely deployed control systems are discussed here.In the early 1980, Nathan Gartner at the University of Massachusetts at Lowell proposed a traffic control system called asOptimized Policies for Adaptive Control for the Federal Highway Administration. Optimized Policies for Adaptive Control sometime called as OPAC. The Split Cycle Offset Optimization Technique (SCOOT) was also developed in the early 1980 by the Transport Research Laboratory in the United Kingdom. The Sydney Coordinated Adaptive Traffic System (SCATS) is slightly newer, having been created in the early 1990 by the Roads and Traffic Authority of New South Wales, Australia. A major difference between SCATS and SCOOT is that SCATS does not have a traffic model or a traffic signal control plan optimizer. Timing of signals is controlled by digital computer based control logic. It has ability to modify signal timings on a cycle-by-cycle basis using traffic flow information collected at the intersection. It is not model based but has a library of plans that it selects from and therefore banks extensively on available traffic data. The Real-time Hierarchical Optimized Distributed Effective System (RHODES) is the newest of these four systems, having been produced in the mid-1990 at the University of Arizona at Tucson.

A decentralized adaptive traffic signal control method known as ALLONS-D (Adaptive Limited Look-ahead Optimization of Network Signals – Decentralized) presented by Porche [2] in his dissertation

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based on a depth-first branch and bound algorithm.More recently, Yu and Recker [3] developed a stochastic adaptive traffic signal control model. The authors formulated traffic signal control as a Markov Decision Process (MDP) and solved it by dynamic programming. Although dynamic programming algorithm can be used to solve this MDP problem and is guaranteed to find the optimal policy [4], it needs a well-defined state-transition probability function. In practice this state transition probability function is difficultto define. In the case of intersection traffic control state transition probability function are affected by the arrival of actual traffic and often time is different. Thus it is even more difficult to give a precise estimate. An intersection traffic signal control application in addition to the number of states is usually very large. The dynamic programming algorithm to calculate the time could make a serious problem.

However this type of methods still has the problems that under certain circumstances, the excessive computation requirement makes some systems based on dynamic programming and Markov decision process require accurate traffic arrival information for the next one or two minutes to determine the best control plans. This information is very difficult to obtain. These systems take ordinary variable in computation. Therefore it is necessary to improve the traffic controller for effective traffic management and better traffic flow, we use linguistic variable in place of ordinary variable.

Fuzzy logic enables the implementation of rules very similarly to what goes on in the human thinking process. In other words, fuzzy controllers have the ability to take decision even with incomplete information. More and more sophisticated controllers are being developed for traffic control. These algorithms are continually improving the safety and efficiency by reducing the waiting delay of vehicles on signals. This increases the tempo of travel and thus makes signals more effective and traffic flow smooth. The key motivation towards fuzzy logic in traffic signal control is the existence of uncertainties in signal control. Decisions are taken based on imprecise information and the effect of evaluation is not well known.

In this paper we discuss the design and analysis of atwo stage traffic lightsystem for isolated intersectionusing fuzzy logic basedtechnology which has the capability of mimicking human intelligence for controlling traffic light. We used fuzzy logic tools available with MATLAB and developed software to simulate the situation of traffic at an isolated junction. The simulated model used for the analysis of efficiency of traffic light controller. The average vehicle delays will be used to evaluate the performance of a two stage traffic light system using fuzzy logic. The software can also be used as an exercise for undergraduate and graduate students to understand the concept of fuzzy logic and its application to a real life environment. The rules and membership functions of the fuzzy logic controller can be selected and changed their outputs can be compared in terms of several different representations.

Related Work

In this section, we discuss different research work in the field of traffic light system using fuzzy logic. The first attempt made to design fuzzy traffic controller was in 70s by Pappis and Mamdani[5]. Kelsey and Bisset also designed a simulator for signal controlling of an isolated intersection with one lane. Same work was also done by Niittymaki and Pursula [6]. They observed that Fuzzy Controller reduces the vehicle delay when traffic volume was heavy. Niittymaki and Kikuchi developed Fuzzy based algorithm for pedestrians, crossing the road.

Initially fuzzy logic was used to control traffic in multiple intersections by Chui [7]. In this research only two way streets are evaluated without considering any left or right turn. A two stage traffic light controller proposed by Trabia, et al. [8]. In the first stage, observed approach traffic flows are used to estimate relative traffic intensities. These traffic intensities are then used in the second stage to decide current green signal should be extended or terminated for through movements without considering any left or right turn. The isolatedintersection model proposed by Soh AC, et al. [9], used consists of two lanes in eachphase. There are two inputs i.e., vehicles queue lengthand waiting times for each phase. The maximum values of these inputs are selected for controllerto optimized control of traffic flows. A fuzzy logic traffic system proposed by Zaied ANH, et al. [10], that considers the two two-way intersections and is able to adjust changes in time intervals of a traffic signal based on traffic situation level.

Indrabayul, et al. [11], proposed an adaptive timely traffic light is as solution for congestion in typical area in Indonesia. Makassar City, particularly in the most complex junction is observed for months using static cameras. The condition is mapped into fuzzy logic to have a better time transition of traffic light as opposed to the current conventional traffic light system. Fuzzy logic based traffic light shows significant number of potential reduced in congestion.

Shahraki, et al. [1] a new fuzzy logic based algorithm is proposed in this research not only can reduce the waiting time and the number of vehicles behind a traffic light at an intersection but also can consider the traffic situations at adjacent intersections as well. The fuzzy control system comprises three stages. These three stages include the next green phase, green phase extender, and the decision stage. The inputs are applied through the green phase selector. The next green phase stage selects the most urgent phase from the phases waiting to become green. If necessary, the green phase extender increases the duration of the green light. In the decision making stage, by deciding either to increase the green light duration or to change to another phase, the most urgent stage is selected from the two stages of next green phase and green phase extender.

Collotta, et al. [12], a novel approach to dynamically manage the traffic lights cycles and phases in an isolated intersection. The proposed solution is a traffic lights dynamic control system that combines Wireless Sensor Network for real time traffic monitoring with multiple fuzzy logic controllers, one for each phase that work in parallel. Each fuzzy controller addresses vehicles turning movements and dynamically manages both the phase and the green time of traffic lights.

Wu, et al. [13], a dynamic control technique for traffic lights is presented, which is based on the queue detection in the left and straight lanes assuming that the vehicles in the right lane are not in conflict with the others. For queue detection purposes, two induction coils are used, the first one to detect oncoming vehicles, the second to measure the vehicles that leave the intersection. The work considers 12 phases, scheduled according to the priority of each phase that depends on the queue lengths of the specific phase lanes. The additional green time is then calculated using a fuzzy logic controller that processes two parameters, i.e., the queue length of the lane with the green light and that of the lanes with the red light. The phase duration depends on the traffic flow that the phase should serve and in this respect the main limitation of the works presented by Shahraki, et al. [1] and Wu, et al. [13] is that the green time extension is calculated by a single fuzzy controller for all the phases whereas for better performance, fault-tolerance and flexibility, as explained before a controller for each phase would be needed to determine the green time duration of the specific phase. The same problems in Shahraki, et al. [1] and Wu, et al. [13] also characterize the approach presented in Zaied and Othman [10] whose aim is to dynamically regulate through a fuzzy controller, the green time duration of an 8-phase traffic lights in an isolated intersection. In this case, 8 inputs (i.e., the queues) and 16 outputs (i.e.,, the calculated green time for each allowed direction) have to be handled. This means that the fuzzy controller is characterized by multiple input variables.

Traffic Engineering and Traffic Congestion Estimation

Traffic signals are designed to ensure safe and orderly flow of traffic protect pedestrians and vehicles at busy intersections and reduce the severity and frequency of accidents between vehicles entering intersections. In other words traffic signals are one of the most effective and flexible active control of traffic and is widely used in several cities worldwide. The conflicts arising from movements of traffic in different directions are addressed by time sharing principle. The advantages of traffic signal include an orderly movement of traffic an increased capacity of the intersection and require only simple geometric design. However the disadvantages of the signalized intersection are large stopped delays and complexity in the design and implementation. Although the overall delay may be lesser than a rotary for a high volume a user may experience relatively high stopped delay [14].

Cycle length

According to Mathew [14], a signal cycle is one complete rotation through all of the indications or phases that are provided. Cycle length is the time that it takes a signal to complete one full cycle of indications or phases.

Interval

It indicates the change from one stage to another stage. Intervalis oftwo types i.e., change interval and clearance interval

Change interval: The change interval some time called as yellow time. It is provided after green time for movement. The purpose is to inform a driver approaching the intersection during the end of a green time about the coming of a red signal. They normally have a value of 3 to 6 seconds. Institute of transportation engineers (ITE) has recommended following methodology for computing the appropriate length of change interval

$$Y = t + \frac{v}{2\,(g_n + a)}$$

Where **t** is the reaction time (about 1.0 sec), **v** is the velocity of the approaching vehicles, **g** is the acceleration due to gravity (9.8 m/sec^2), **n** is the grade of the approach in decimals and **a** is the deceleration of Change interval. It can also be approximately computed as y = SSD/v, where **SSD** is the stopping sight distance and **v** is the speed of the vehicle.

Clearance interval: The clearance interval some time called as all-red time. It will facilitate a vehicle just crossed the stop line at the turn of red to clear the intersection without being collided by a vehicle from the next phase. Institute of transportation engineers (ITE) recommends the following policy for the design of all read time, given as

$$R_{AR} = \begin{cases} \dfrac{w+L}{v} & \text{If no pedestrians} \\ \max\left(\dfrac{w+L}{v}, \dfrac{P}{v}\right) & \text{If pedestrians crossing} \\ \dfrac{P+L}{v} & \text{If protected} \end{cases}$$

Where **w** is the width of the intersection from stop line to the farthest conflicting traffic, **L** is the length of the vehicle, **v** is the speed of the vehicle, and **P** is the width of the intersection from STOP line to the farthest conflicting pedestrian cross-walk.

Phase

A phase follows the time of green interval plus the change and clearance intervals. Therefore during green interval, non-conflicting movements are assigned into each phase. The objective of phase design is to separate the conflicting movements in an intersection into various phases so that movements in a phase should have no conflicts. If all the movements are to be separated with no conflicts then a large number of phases are required. In such a situation the objective is to design phases with minimum conflicts or with less severe conflicts as discuss by Mathew [14].

Lost time

Lost time is the interval in which there is no effectivemovement at the intersection.

Delay

There are a number of measures used for capacity analysis and simulations for signalized intersection. The most common measures the average delays per vehicle, average queue length and number of stops. The delay is a measure that is most directly related to the experience of the driver. It is the measure of extra time consumption through the intersection. Any time is a useful measure of the queue length and the intersection of an adjacent upstream intersection will begin to hinder the discharge is important in determining. The number of stops made in particular in the air quality model, is an important input parameter. It is directly perceived by the driver. Apart from these three, the effects of delay signalized intersections are the most frequently used measures. Due to the delay estimation is complicated by the arrival of vehicles at random, over saturated flow conditions, lost time due to stopping of vehicles etc. although delay can be quantified in several different ways. Thus, as the most frequently used forms of delay are following-

- Stopped time delay
- Approach delay
- Travel time delay
- Time-in-queue delay
- Control delay

Traffic congestion

Traffic congestion means there are more people trying to use a given transportation facility during a specific period of time than the facility can handle with what are considered to be acceptable levels of delay or inconvenience. Delays at particular locations in a transportation network are certainly provoking to those using the system but these delays are part of a much larger picture of how a transportation system allows people and goods to move around a metropolitan area [15]. Congestion management are designed to improve the operating efficiency of the existing transportation system by increasing the use of alternative transportation modesaltering trip patterns through the application of measures and improving traffic flow through measures such as route guidance systems, traffic signal improvements and incident management.

In TSTLS, four-phase signal are designed as shown in Figure 1. In a cycle, each approach goes through two time intervals, green interval and red interval. The green interval has three timing parameters namely lost time T_{LOST}, minimum time T_{MIN}, and maximum time T_{MAX}.

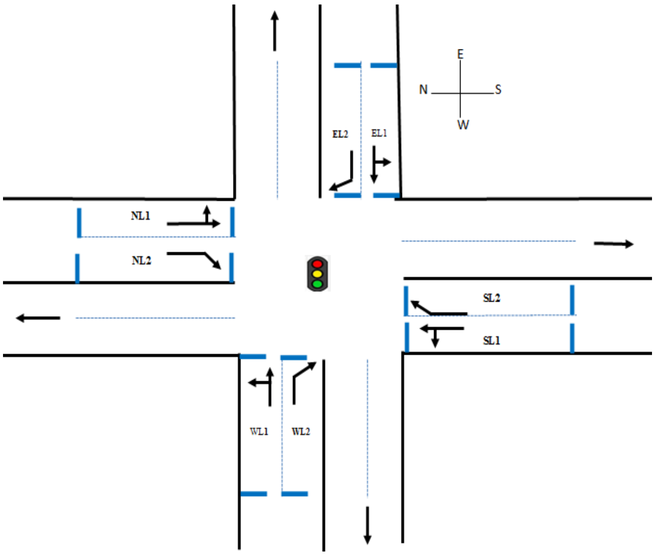


Figure 1: General Structure of intersection.

Lost time T_{LOST} represents the green time not utilized by the vehicles waiting in queue. It consists of startup lost time at the beginning of a green phase and clearance lost time at the end of the phase [16]. In Our proposedTSTLS, we assume that the entire lost time per phase occurs only at the beginning of the green phase. When a phase is initiated minimum green time to be provide and it represented by Minimum time T_{MIN}. This ensures that the green signal stays long enough for safe passage of a single vehicle to clear the intersection. The maximum green time that can be provided to any phase and represented by Maximum time T_{MAX}. In fixed-cycle traffic light system each cycle can be approximated to a periodic task with period T characterized by a fixed green time T_g, yellow time T_y and red time T_r described as

$$T = T_g + T_y + T_r$$

Whenever, a phase has the least Urgency than all other phases in a cycle. This phase can be skip. Therefore green time not provided to this phase because traffic system is based on urgency. If this phase will be skip into this cycle and next one or more consecutive cycle then congestion may occur. In our proposed system this type of congestion can be estimated and hence minimum green time T_{MIN} will be provided to this phase in each cycle.

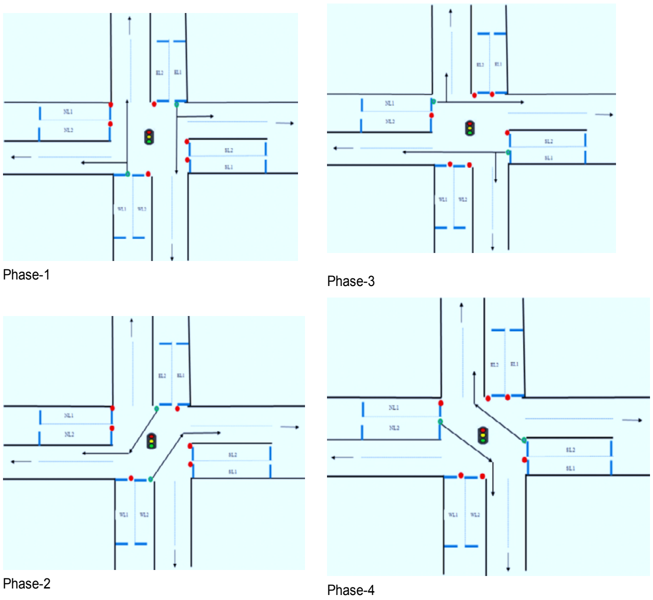
Description of the Proposed Two Stagetraffic Lightsystem (TSTLS)

Investigation on the driving behaviors indicates that it is dangerous to change dynamic phase compositionbecause this may disturb the drivers' mental status and may get nervous. In our proposed two stage traffic light system using fuzzy logic model it is assumed that phase composition is predetermined and the phase sequence as well as signal timing are changeable.

From the review of literature related with traffic light system it has reported that fuzzy logic controllers perform better than pre-timed, actuated and adaptive controllers. However the phase changes in sequential order without considering the urgency of the red phases. In this paper, a two stage traffic light system using fuzzy logic will not only decide whether to extend or terminate a current green phase but also decide which red phase will be set as green phase then determine the extension time of green phase. Therefore in this traffic light system the phase sequence is uncertain.The average vehicle delays will be used to evaluate the performance of the two stage traffic light system using fuzzy logic [17].

The general structure of an isolatedintersection is illustrated as in Figure 1. Each lane equipped with two electromagnetic. The first sensor is located behind each traffic light and second sensor is located behind the first sensor at distance S. The first sensor counts the number of cars passing the traffic light and the second sensor counts the number of cars coming to the intersection. The number of cars waiting at the traffic light is determined by the difference of the reading between the two sensors. Each traffic light in front of it is a proximity sensor and can only sense the presence of a car waiting at the junction, which is contrary to the traditional control systems.

The isolated intersection considered as in Figure 1 is characterized by four phases as in Figure 2 with eight lanes. Each phase has two lanes. As we discuss earlier the objective of phase design is to separate the conflicting movements in an intersection into various phases so that movements in a phase should have no conflicts. For example, when Phase 1 is enabled, only the cars of Lane EL1 of the Road directionE and Lane WL1 of the Road direction W can go straight or turn left, while all the other lanes will have the red light to stop [18]. Table 1 summarizes the notation adopted in two stage traffic light system.As shown in Figure 1 the length of each phase is obtained as the maximum of the queue lengths intended as the number of vehicles during the green/red light in their respective lanes as shown



Phase-1

Phase-3

Phase-2

Phase-4

Figure 2: Phases of Traffic light.

Symbol	Lane	Movement Allowed
EL 1	East Lane- 1	Straight and left
EL 2	East Lane- 2	Right
WL 1	West Lane- 1	Straight and left
WL 2	West Lane- 2	Right
NL 1	North Lane- 1	Straight and left
NL 2	North Lane- 2	Right
SL 1	South Lane- 1	Straight and left
SL 2	South Lane- 2	Right

Table 1: Notation.

Phase1= maximum (WL1, EL1)

Phase2 = maximum (WL2, EL2)

Phase3 = maximum (NL1, SL1)

Phase4 = maximum (NL2, SL2)

Vehicle arrival distribution

There are four phases or approaches in this isolated intersection model with twelve total movements and a server traffic light. Each phase consists of three movements which are through movement, right and left turn movements. This model is based on an M/M/1 queuing theory using three basic concepts of queuing theory i.e., customer, queue, and server. The first and the second M in M/M/1 stand for memory less distribution of inter-arrival times and service times respectively. The "1" indicates that the isolated intersection has single server, which means one traffic signal, to service single signal phase at one time [19].

In this model First-In-First-Out (FIFO) principle is applied to the vehicles queue. The vehicles are known as customers while services time is the time for the vehicles to depart and to cross the intersection. Traffic at the intersection arrival and service time are independent random variables with Poisson distribution.Therefore, the arrival of vehicles at the intersection with arrival rate λ and the average of the inter-arrival times between vehicles are 1/ λ. The arrival of the vehicles in a Poisson process and the time period in order to reach the number of vehicles is as follows Poisson distribution.

$$P(x)=\frac{(\lambda t)^X.e^{-\lambda t}}{x!} \qquad x = 0, 1, 2, 3,........$$

Where P(x) is the probability of vehicles x during counting interval t and λ is the average arrival rate per unit time, t is the duration of each counting interval.The vehicle arrival rate is 0~1 per second.

Put n= λt, where n is the average number of vehicles during counting interval. The equation can be written as follows

$$P(x)=\frac{n^X.e^{-n}}{x!}$$

Computation of the average vehicle delay (AVD)

In this research paper the average delay of vehicles is the performance evaluation for traffic signal control of intersection. If the value of average vehicle delay is small then the traffic signal control effect is better. The amount of queuing vehicles in red light phase at time *t*i.e.,(*t*) can be calculated using the following ways-

$$\mathrm{Q_r}(t)=\sum_{i=1}^{k}\left(Q_{gi}+\sum_{t_1=1}^{t}q_{it_1}\right)$$

where i is one of the red light phase branches, Q_{gi} is the amount of queuing vehicles in the red light phase branch i when the current green signal ends,$t_1$is the time interval during the red light, qi_{t1} is the amount of arriving vehicles in the red light phase branch i during time interval $t_{1,}$ $k$is the number of red phase branch. In our proposed system $k = 6$. The total vehicle delay in red light phase i.e., D_r can be calculated as-

$$\mathrm{D_r}=\sum_{t=1}^{t_r}\left[\sum_{i=1}^{k}\left(Q_{gi}+\sum_{t_1=1}^{t}q_{it_1}\right)\right]$$

Where$t_r$is the red light time of red light phase.

The amount of queuing vehicles at time *t*seconds during green light i.e.,Q_g(t) can be calculated as follows:

$$\mathrm{Q_g}(t)=\sum_{i=1}^{k}z_i\left(Q_{\dot{r}}+\sum_{t_1=1}^{t}q_{\dot{t}_1}-S_f.t\right)$$

Where Q_{ri} is the amount of arriving vehicles in the green light phasebranch *i*during last red light phase, *k*is the vehicles flowin green light phase, S_f is saturation flow, q_{it1} is the amount of arrivingvehicles in the green light phase branch *i*during time t_1. In our research paper there are four phases in anintersection.The value z_i can show whether there are queuing vehicles ornot in current green light phase branch *i*. If $Q_{\dot{r}}+\sum_{t_1=1}^{t}q_{\dot{t}_1}-S_f.t>0$, then $z_i = 1$, otherwise, $z_i = 0$.The total vehicle delay of green light phase i.e.,, D_g can becalculated as follows:

$$\mathrm{D_g}=\sum_{t=1}^{t_E}\left[\sum_{i=1}^{k}z_i\left(Q_{\dot{r}}+\sum_{t_1=1}^{t}q_{\dot{t}_1}-q_s.t\right)\right]$$

Where t_E is the green light time i.e., extension time provided by extension time decision module during green light phase. The total vehicle delay in the *x*cycle i.e.,D_x can be calculated as follows:

$$\mathrm{D_x}=\mathrm{D_r}+\mathrm{D_g}$$

The average vehicle delay (AVD) can be calculated as follows:

$$\mathrm{AVD}=\frac{\sum_{x\in cycle}\mathrm{D_x}}{A_T}$$

Where $A_1$is the total amount of arriving vehicles from all directions in an intersection during all cycles.

Traffic urgency decision module

Traffic urgency decision module (TUDM) calculates urgency for all red phases as shown in Figure 3. On the bases of urgency degree, proposed system selects the next red light phase to switch. There are two input variables namely *Queue, Time$_r$* and one output variable namely *Urgency*. The input variable *Queue* count the number of vehicles of current red light phase and variable *Time$_r$*count the duration of red light since the last end of the green light. The output variable *Urgency* is traffic urgency of red light phases. Therefore for instance in the case of Phase 1, TUDM will determine the urgency (U1) by processing the queue length and duration of red light since the last end of the green light of phase 1. Similarly, for phase 2, TUDM will determine the urgency (U2) by processing the queue length and duration of red light since the last end of the green light of phase 2 and so on.

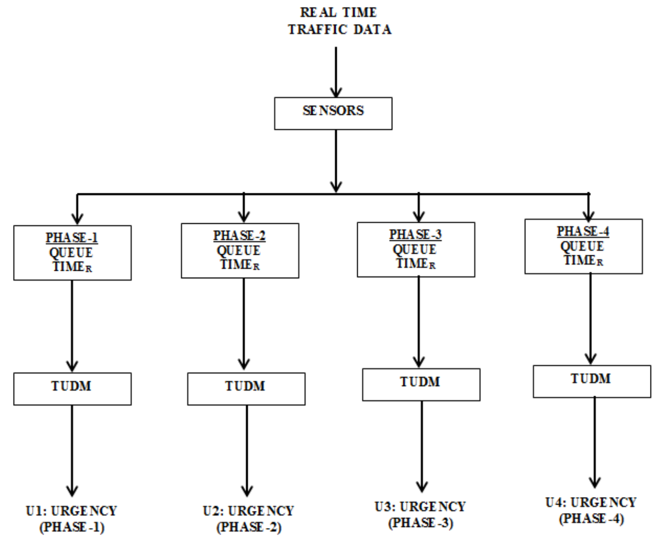


Figure 3: Proposed Traffic urgency decision module.

Extension time decision module

Extension time decision module (ETDM),calculate green light time i.e., extension time of the phase which has higher urgency can be calculated according to the number of vehicles as shown in Figure 4**.** There are two input variables namely *Queue-Lane-1, Queue-Lane-2* and one output variable *Extension-Time*. The input variable *Queue-Lane-1*count the number of vehicles of lane 1 and input variable *Queue-Lane-2*count number of vehicles of other side i.e., lane 2 of red light phase which has big traffic urgency. The output variable *Extension-Time* is the extension time of current green light phase. Therefore for instance in the case of Phase 1, ETDM will determine the green light duration i.e., extension time (E1) by processing the queue length of the Lane EL1 of the Road direction E and Lane WL1 of the Road direction W. Similarly, for phase 2, ETDM will determine the extension time (E2) by processing the queue length of the Lane EL2 of the Road direction E and Lane WL2 of the Road direction W and so on.

Fuzzy Parameters and Their Membership Functions Design

For a two stage traffic lightsystem, there are five membership functions such as Zero, Small, Medium, Large and Very-Large for each of the input as well asoutput fuzzy variable of the system. There are two input variables *Queue*and $Time_r$ and one output variable*Urgency*for traffic urgency decision module as shown in Figure 5-7 respectively. For extension time decision module, we designed two input variables namely *Queue-Lane-1, Queue-Lane-2* and one output variable *Extension-Time* as shown in Figure 8-10 respectively. Each input and output fuzzy variable is design using triangular membership function.

Fuzzy Rules and Defuzzification

The inference mechanism in the fuzzy logic controller resembles that of the human reasoning process. Fuzzy logic technology is associated with artificial intelligence. For example, a traffic policeman managing a junction say, one from the east and one from the north he would use his expert opinion in controlling the traffic more or less in the following way:

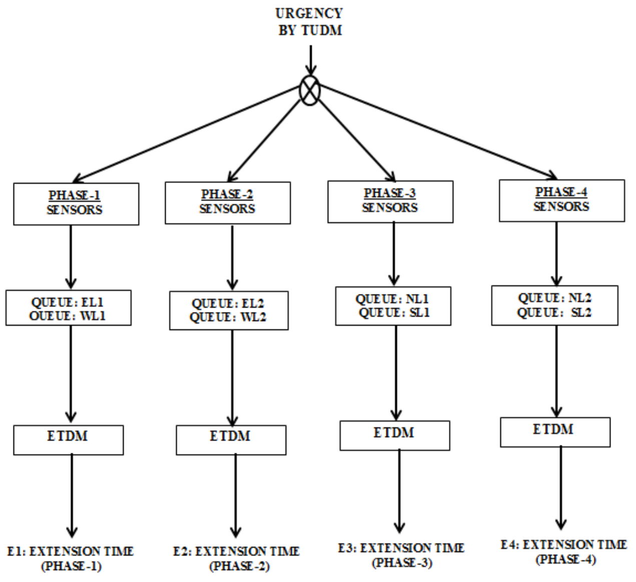


Figure 4: Proposed extension time decision module.

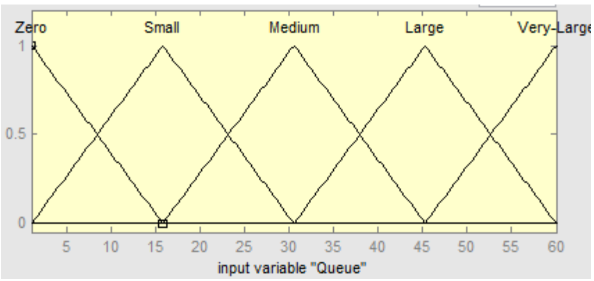


Figure 5: Queue membership.

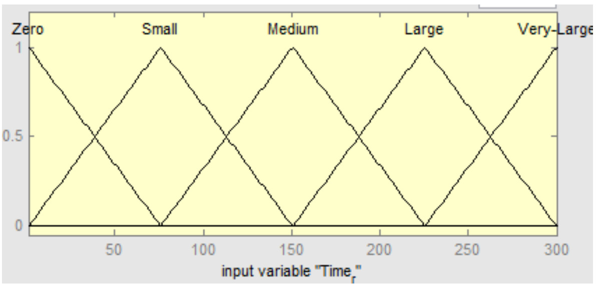


Figure 6: $Time_r$ membership.

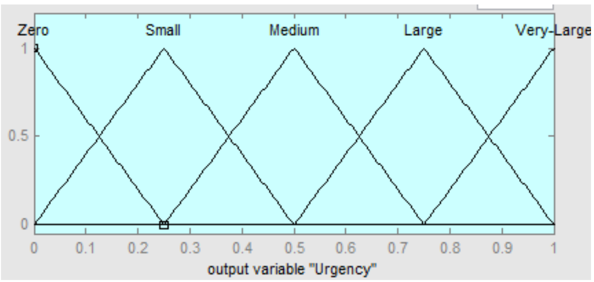


Figure 7: Urgency membership.

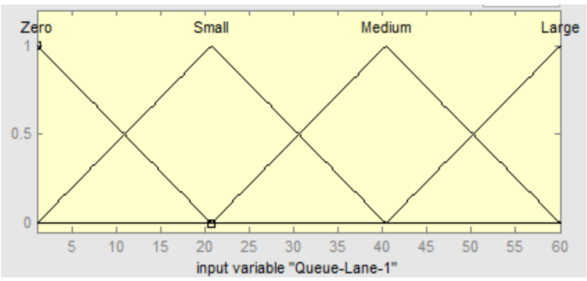


Figure 8: Queue-Lane-1 membership.

IF traffic from the east side of the city is VERY-LARGEand traffic from the north sides is SMALLthen allow movement of traffic to the east side LONGER

In two stage traffic light system using fuzzy logic, we develop two different modules namely traffic urgency decision module (TUDM) and extension time decision module (ETDM). In TUDM 25 fuzzy rules have been found and for ETDM 16 rules have been found.The some

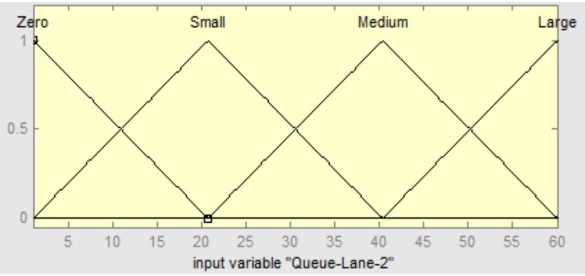


Figure 9: Queue-Lane-2 membership.

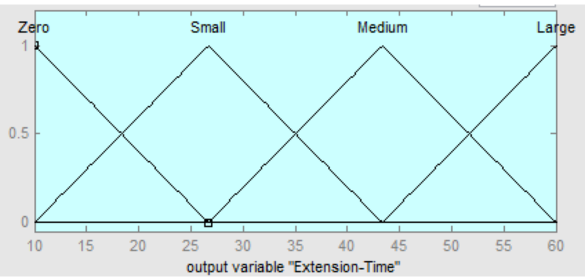
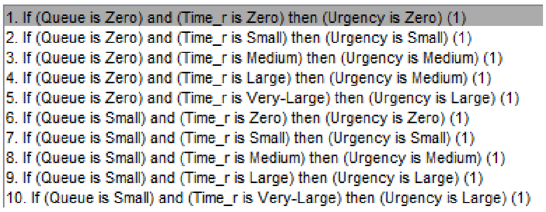
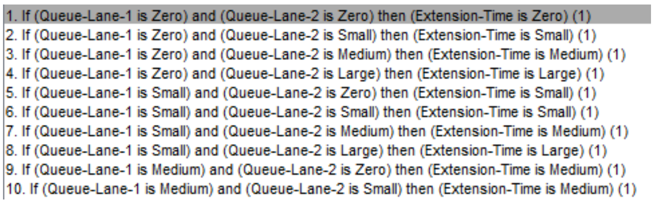


Figure 10: Extension-Time membership.



1. If (Queue is Zero) and (Time_r is Zero) then (Urgency is Zero) (1)
2. If (Queue is Zero) and (Time_r is Small) then (Urgency is Small) (1)
3. If (Queue is Zero) and (Time_r is Medium) then (Urgency is Medium) (1)
4. If (Queue is Zero) and (Time_r is Large) then (Urgency is Medium) (1)
5. If (Queue is Zero) and (Time_r is Very-Large) then (Urgency is Large) (1)
6. If (Queue is Small) and (Time_r is Zero) then (Urgency is Zero) (1)
7. If (Queue is Small) and (Time_r is Small) then (Urgency is Small) (1)
8. If (Queue is Small) and (Time_r is Medium) then (Urgency is Medium) (1)
9. If (Queue is Small) and (Time_r is Large) then (Urgency is Large) (1)
10. If (Queue is Small) and (Time_r is Very-Large) then (Urgency is Large) (1)

Figure 11: Fuzzy rules for TUDM develop in MATLAB.



1. If (Queue-Lane-1 is Zero) and (Queue-Lane-2 is Zero) then (Extension-Time is Zero) (1)
2. If (Queue-Lane-1 is Zero) and (Queue-Lane-2 is Small) then (Extension-Time is Small) (1)
3. If (Queue-Lane-1 is Zero) and (Queue-Lane-2 is Medium) then (Extension-Time is Medium) (1)
4. If (Queue-Lane-1 is Zero) and (Queue-Lane-2 is Large) then (Extension-Time is Large) (1)
5. If (Queue-Lane-1 is Small) and (Queue-Lane-2 is Zero) then (Extension-Time is Small) (1)
6. If (Queue-Lane-1 is Small) and (Queue-Lane-2 is Small) then (Extension-Time is Small) (1)
7. If (Queue-Lane-1 is Small) and (Queue-Lane-2 is Medium) then (Extension-Time is Medium) (1)
8. If (Queue-Lane-1 is Small) and (Queue-Lane-2 is Large) then (Extension-Time is Large) (1)
9. If (Queue-Lane-1 is Medium) and (Queue-Lane-2 is Zero) then (Extension-Time is Medium) (1)
10. If (Queue-Lane-1 is Medium) and (Queue-Lane-2 is Small) then (Extension-Time is Medium) (1)

Figure 12: Fuzzy rules for ETDM develop in MATLAB.

fuzzy rules are used for designingTUDM and ETDM shown in the Figure 11 and 12 respectively.

In the fuzzy logic controller once the appropriate rules are fired, the degree of membership of the output fuzzy variable i.e.,, Urgency is determined by encoding the antecedent fuzzy subsets in this case Queue, Time$_r$ and the output fuzzy variable i.e., Extension-time is determined by encoding the antecedent fuzzy subsets, in this case Queue-Lane-1, Queue-Lane-2. In two stage traffic light system using fuzzy logic the max-min implication technique is used. Using this technique the final output membership function for each rule is the fuzzy set assigned to that output by clipping the degree of truth values of the membership functions of the associated antecedents. Once the membership degree of each output fuzzy variable is determined all of the rules that are being fired are then combined and the actual crisp output is obtained through defuzzification. The procedure of converting each aggregated fuzzy output set into a single crisp value is called defuzzification. In traffic urgency decision module and extension time decision modules we use centroid defuzzification method.

Simulation Result and Discussion

After a two stage traffic light system was carefully designed, we test the system and discuss the impact of the input variables on the output variable.With thehelp ofsimulation we show the effect of the two inputs*Queue, Time*$_r$and *Queue-Lane-1, Queue-Lane-2*to resulted *Urgency* and*Extension-Time*respectively.

As shown in Figure 13, the Urgency (z-axis) is small when the value of Queue (x-axis) and Time$_r$ (y-axis) have a small value. The urgency grows fastly and gets a maximum value when the queue side is being too many and the time$_r$ density become small. On the other hand, urgency grows fastly and gets a maximum value when the queue side is being small and the time$_r$ density become too large.

As shown in Figure 14 as well as Table 2, the extension time (z-axis)

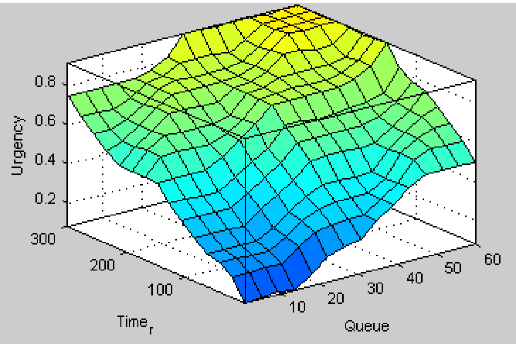


Figure 13: Input variables Queue, Time$_r$ Vs output variable Urgency using centroid defuzzification method.

No of Vehicles (Maximum = 60)		Extension Time (in Seconds)	
Queue Lane-1	**Queue Lane- 2**	**ETDM**	**Actual Method**
3	3	15	10
5	5	18	12
10	10	22	16
15	15	25	21
20	20	26	26
25	25	31	31
30	30	35	36
35	35	38	40
40	40	42	45
10	20	26	26
10	25	31	31
10	30	35	36
10	35	38	40
10	40	42	45
20	10	26	26
25	10	31	31
30	10	35	36
35	10	38	40
40	10	42	45
50	10	46	55
60	10	54	64

Table 2: Comparison of ETDM and Actual method.

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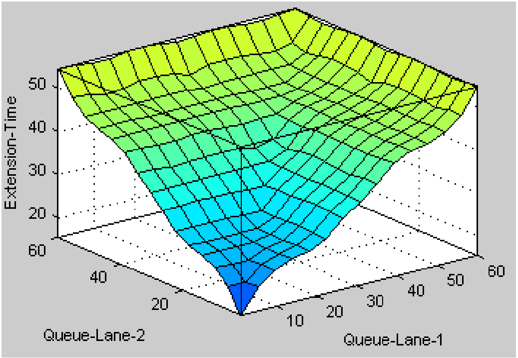

Figure 14: Input variables Queue-Lane-1, Queue-Lane-2 Vs output variable Extension-Time using centroid defuzzification method.

Maximum detectable queue per lane (Vehicles)	60
Maximum Length queue per lane (meters)	160
Maximum Length between parallel stop line (meters)	20
Maximum queue per phase (vehicles)	120
Lost time per phase, T_{LOST} (Seconds)	4
Saturation flow rate (Vehicles/hour/lane)	2400
Maximum allowable green phase, T_{MAX} (Seconds)	60
Maximum allowable green phase, T_{MIN} (Seconds)	8
Low arrival rate (Vehicles/minute)	0-18
Medium arrival rate (Vehicles/minute)	18-36
High arrival rate (Vehicles/minute)	36-60
Fixed yellow time, T_Y (Seconds)	4

Table 3: Simulation parameters for intersection.

is small when the value of queue-lane-1 (x-axis) and queue-lane-2 (y-axis) have a small value. The extension time grow slowly and have a long value when both the queue-lane-1 side and the queue-lane-2 go to medium to large value. If one of the queue-lane sides constant and other side increase then extension time also increase this is equivalent to actual method.

In this research paper, the vehicle arrival rate is Poisson distribution which is divided into three types such as low traffic rate, middle traffic rate and high traffic rate. The ranges of each vehicle rate are as 0~0.3 car per second, 0.3~0.6 car per second and 0.6~ 1 car per second respectively. Table 3 summarizes all the simulation parameters used in TSTLS (Figure 15).

As shown in Table 2 result of extension time decision module and actual method are very close. In maximum situation extension time taken by ETDM is similar to actual method. But ETDM take less time than fixed time controller without making unstable conditions in the traffic flow. Extension time of actual method are found with the help of the following formula-

$$\text{Extension Time} = \frac{\text{Average Distance}}{\text{Average Speed}} = \frac{2.67 \times n + 20}{2.78}$$

Where*n* is no of vehiclesand average distance is 180 meter (160+20) the distance from last vehicle in the queue to cover the intersection and average speed is 10 km/h or 2.78 m/sec (Figure 16 and 17).

The average vehicle delay of pre-timed control system and TSTLS are shown in following tables. The average vehicle delay of low traffic rate, middle traffic rate and high traffic rate is shown in Tables 4, 5 and 6 respectively.

Table 7 shows theimprovement percentage of TSTLS with pre-timed control system which is taken with different traffic rate. The average vehicle delay in low traffic rate of TSTLS is reduced by 48.91% compared to pre-timed control system. The average vehicle delay in middle traffic rate of TSTLS is reduced by 58.65% compared to pre-timed control system and the average vehicle delay in high traffic rate of TSTLS is reduced by 39.73% compared to pre-timed control system.

Conclusion and Future Works

The two stage traffic lightsystem using fuzzy logic performed better than the fixed time system or even vehicle actuated system due to its flexibility. The flexibility involves the number of vehicles sensed at the incoming junction and in first stage, determines the maximum urgency

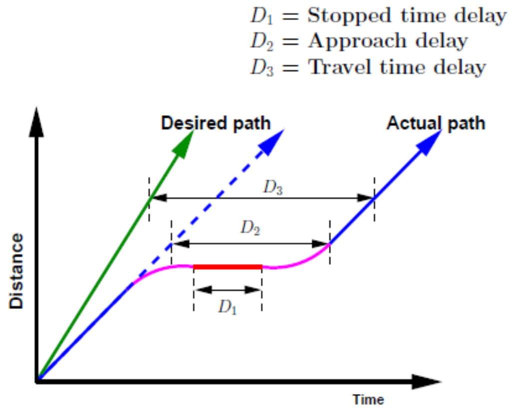

Figure 15: Delay Measures.

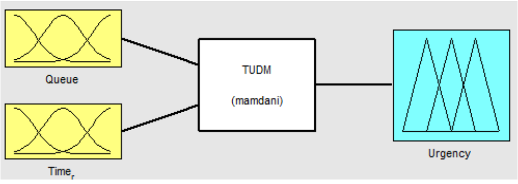

Figure 16: The whole design structure of TUDM using Mamdani Method.

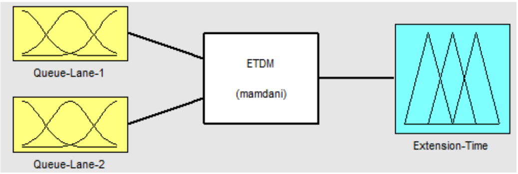

Figure 17: The whole design structure of ETDM using Mamdani Method.

No. of Simulation	Pre-timed control system	Two stage traffic light system (TSTLS)
1	61.98	31.11
2	73.56	39.35
3	69.63	36.69
4	57.33	27.38
5	64.85	32.73
Average	65.47	33.45

Table 4: Average vehicle delay of low arrival rate.

No. of Simulation	Pre-timed control system	Two stage traffic light system (TSTLS)
1	167.56	78.63
2	136.38	59.34
3	156.74	67.21
4	143.23	51.86
5	121.81	42.97
Average	145.14	60.01

Table 5: Average vehicle delay of medium arrival rate.

No. of Simulation	Pre-timed control system	Two stage traffic light system (TSTLS)
1	302.78	186.34
2	290.56	173.67
3	287.45	168.96
4	308.67	189.48
5	293.39	175.18
Average	296.57	178.73

Table 6: Average vehicle delay of high arrival rate.

	Arrival rate		
	Low	Medium	High
Pre-timed control system	65.47	145.14	296.57
TSTLS	33.45	60.01	178.73
Improvement TSTLS vs. Pre-timed Control	48.91%	58.65%	39.73%

Table 7: Improvement TSTLS vs. Pre-timed control system.

degree ofred phases then in second stage, determines the extension time of the green phase. In the fixed time system, being an open loop system phase sequence is not changeable and the green time is not extended whatever the density of carat the junction. In addition to the fuzzy variables as mentioned, the fuzzy system also has an advantage of performing according to linguistics rules in the manner of how a human would use.

It can be observed from the result that a two stage traffic light system (TSTLS) provide better performance in terms of average vehicle delay than pre-timed control system. Therefore TSTLS, improve the efficiency of vehicles, traffic congestion and hence reduce travel time, noise pollution, carbon dioxide emission, fuel used and save the time of human being.

One direction for future research on a proposed two stage traffic light system is that to enhance the system with a neural network which is able to forecast the traffic conditions i.e., to predict the traffic conditions at different times of the day or on different days of the week. This combination would allow the fuzzy control system to make its decision taking into account not only the current traffic situation as detected by the sensor but also the probable short term evolution of the traffic conditions. In this way the choice of the phase would depend on the number of vehicles in the queue while the green time duration of the traffic lights would be determined based on the traffic flow forecast by the neural network.

Moreover,prospect research direction is to provide the system with the ability of detecting emergency situation such as the presence in the queue of ambulance, VIP vehicle and fire trucks etc. through non-expensive sensors and of implementing suitable contingency actions so as to prioritize the phase that hosts those vehicles. A further area of investigation refers to the adoption of low power mechanisms to reduce the sensor node power consumption as shown in Collotta, et al. [20] and hence increase the network lifetime.

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