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A fuzzy Logic Controller for Isolated Signalized Intersection with Traffic Abnormality Considered

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Abstract—**This paper presents a fuzzy logic controller for an isolated signalized intersection. The controller controls the traffic light timings and phase sequence to ensure smooth flow of traffic with minimal delay. Usually fuzzy traffic controllers are optimized to maximize traffic flows/minimize traffic delays under typical traffic conditions. Consequentially, these are not the optimal traffic controllers under exceptional traffic cases such as roadblocks and road accidents. We propose a new fuzzy traffic controller that can optimally control traffic flows under both normal and exceptional traffic conditions. In this system, sensors are placed strategically at incoming and outgoing links (lanes) and the controller utilize the information received from these sensors to make optimal decisions to minimize the traffic delays. A simulator is developed to evaluate the performance of traffic controllers under different conditions. Results show that the performance of the proposed traffic controller is similar to that of conventional fuzzy traffic controllers under normal traffic conditions and is better that of others under abnormal traffic conditions.**

I. Introduction

The increase in urban traffic demand necessitates suitable approaches to manage traffic flow. Traffic lights are the most common approach to manage traffic flows on various types of intersection. Carefully coordinated signal timings can ensure smooth flow of traffic. However, such systems are usually trained under normal traffic conditions and inadequate to atypical conditions. The result of this is longer delays and increased pollution as well as stress to the drivers. Only signal controllers that can quickly adapt to these changes are able to manage the timings efficiently.

In this study, effects of abnormalities are considered. Abnormalities can be caused by many factors on the road. Some of the factors are stalled vehicles, potholes and road repairs. Most of these factors are only temporary but the authors in [1] argues this can cause increased delays if not factored in the signalized traffic controller.

There have been many studies done related to fuzzy logic controller for signalized intersection[2]-[7]. Fuzzy logic has been used for its simplicity and its capability to adapt to traffic conditions. However, these studies have not considered abnormalities but concentrated more on reducing the average delay of vehicles. In actual sense, the lane that is experiencing abnormalities would naturally have a higher delay. Therefore, other lanes would be affected if more time were given to clear the lane experiencing abnormalities.

We have developed different sets of controllers to evaluate the affect of abnormalities in an isolated intersection. A simulator is developed using MATLAB with the Fuzzy Logic tool box for performance evaluation. In the next section, some basic concepts of traffic control and fuzzy logic theory is explained. The Developed model is discussed in section III followed by the simulation results. Finally, the conclusion and extension of work is discussed in the final section.

II. Overview of Traffic Control Methods

There are many approaches used to manage flow of traffic at intersections. One of the initial approaches was to use a roundabout with rules that the driver has to follow. This approach is suitable for light traffic condition and is still widely used in many areas. Roundabouts are used mainly to reduce vehicle speed as well as to avoid accidents in intersections. However, when traffic demand increases this approach results in a bottleneck that is caused by frequent deadlocks at the round about[8]. Therefore, traffic lights were introduced to resolve this problem.

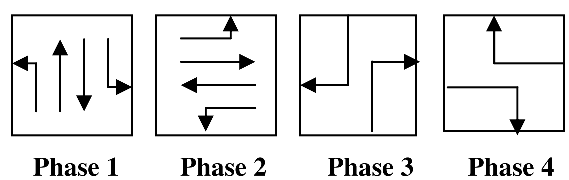

Fig. 1. Phases of four way isolated cross junction

Traffic lights works on a few basic principles. A phase is where traffic in a set of lanes are free to exit the intersection. A cross junction may have four or more phases. Fig. 1 shows four typical phases for a crossed junction. The completion of all phases is known as a cycle. The length of a cycle is determined by the length of the phases that complete the cycle. In a fix time approach where phase length is predetermined, cycle length is fixed. However, if a dynamic approach is used, cycle length may vary depending on traffic condition. The color of lights is used to indicate the start or end of a phase. Green light indicates an active phase, amber light indicates the ending of a phase and finally red light is the end of the current phase and the start of the next phase. Typically phases move in sequence for every cycle.

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Two typical approaches are used in the control of traffic lights[9]. The crudest method is using the fixed time approach. The green duration for a phase is fixed based on studies done on the traffic condition where the controller is placed. More green time is allocated during peak periods and reduced green time during off peak periods. This approach although may work quite effectively during normal traffic condition, a sudden change in traffic condition results in the failure of this approach. Hence, it is desirable to develop approaches that can dynamically adapt changing traffic conditions. One approach that can adapt to change in traffic is the vehicle actuated method. In this approach, vehicle detectors are placed at a certain distance from the lane. A minimal green period is allocated for each phase and gradually extended when vehicle arrival are detected during the extension period. The extension is limited to the maximum green time that is preset. Although this approach is more dynamic compared to fixed time approach, more green time may be allocated to a particular phase as long as the vehicles arrive during the extension interval. Both approaches do not consider traffic conditions on lanes that are in the red phase. In other words, coordination of phases are absent in both this approaches.

Alternatively, a Fuzzy Logic Controller takes conditions of other phases into consideration. Fuzzy logic enables the use of human like approach to make decisions which is not possible in fixed time or traffic actuated controller that is purely based on a quantitative value. For example, *"IF MANY cars arriving AND GREEN TIME is FEW then EXTEND GREEN"* is a linguistic approach used in fuzzy logic. The simplicity of this approach compared to mathematical models[3,10], makes fuzzy logic a desired approach in developing the controller. To develop the fuzzy rule for the fuzzy logic controller, authors[3, 4, 6] use performance parameters such as queue length during red signal, arrival of vehicles during green period, remaining green time and rate of vehicle exiting the intersection. These parameters are used to determine whether a green phase should be extended or terminated. Thus, a phase with high arrival of vehicles will be given more green time except if the queue length in other phases has exited beyond a threshold value. Unfortunately, these studies have not considered abnormalities in the traffic flow caused by accidents, poor road conditions or temporary obstruction that can significantly upset the flow of traffic. These abnormalities are common on most roads as incidents are due to happen and unavoidable where traffic concentration is high. Thus, studies that do not consider this phenomenon may not be able to optimize flow control efficiently. Although lane queue length is a good indicator of traffic density, it becomes a false alarm when abnormalities are present in these lanes. Extension of green time in this scenario, results in wastage of green time and increased delay for vehicles in other phases. Therefore, in the following section, a fuzzy logic model that considers the abnormalities is presented.

III. Fuzzy Logic Model for an Isolated Intersection

A. *Formulation of Fuzzy Input Parameters*

We study an isolated intersection with four approaches as shown in Fig. 2. Each approach has 3 lanes incoming and three lanes outgoing. Straight and turning vehicles are considered in this model. However, at this time pedestrian crossing are not considered at this time. There are four phases in this model. The first phase is vehicles traveling from north to south (straight), north to east (turning), south to north (straight) and south to west (turning). The second phase is vehicles traveling from west to east (straight), west to north (turning), east to west (straight) and east to south turning. The third phase is vehicles traveling from north to west (turning) and south to east (turning). Finally, the fourth phase is vehicles traveling from west to south (turning) and east to north (turning).

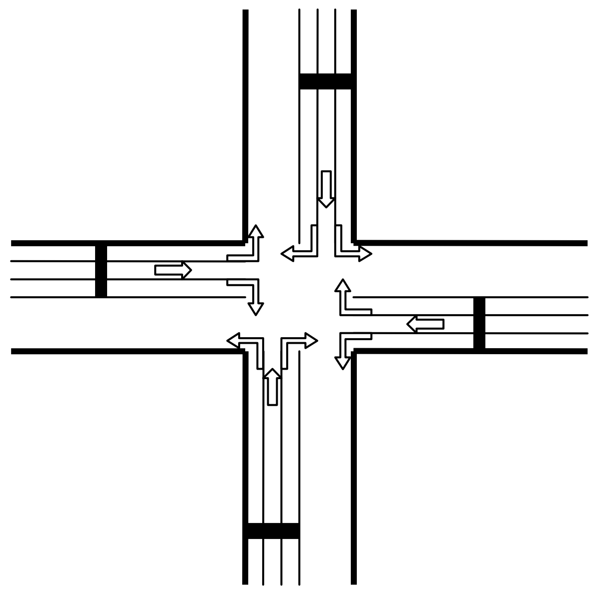


Fig. 2 Single Isolated Intersection

There are four parameters used as an input vector to the fuzzy logic controller. The first is the red phase queue length (RQL) which is the residue of vehicles since the last green signal plus the arrival during the current red signal:

$$RQL = Q_{gr} + \sum Vr(i), \quad (1)$$

where Q_{gr} is the vehicles that did not exit the intersection in the green phase and $\sum Vr(i)$ is sum of arrived vehicles in the i^{th} second for the red phase.

The second parameter (RGT) is the ratio of the amount of green time left in the current green phase to the total time allocated to the green phase:

$RGT = g(t)/ T_g$, (2)

where T_g is the total time allocated to the green phase and g(t) is the remaining green time at time t from the start of the green phase.

The third parameter is the arrival of vehicles during the green period(AG) where $\sum Vg(i)$ is sum of arrived vehicles in the i^{th} second for the green phase. We have

$AG=\sum Vg(i)$. (3)

Finally the fourth crucial parameter for this model is the Average Green Discharge Time (AGDT). The discharge time indicates whether vehicles exiting the intersection within the range of the normal rate or the abnormal rate. We define the AGDT as follows.

$AGDT(n) = \alpha(CDT) + (1-\alpha)AGDT(n-1)$, (4)

where CDT is the current discharge time of the vehicle exiting the intersection, AGDT(n-1) is the previous calculated average discharge time and the α is the smooth coefficient. We set the value of α to 0.8 to quickly adapt to the most recent change in the discharge rate where is not possible in simple averaging.

The output of the fuzzy logic controller is to decrease or increase the green time.

Delay = time vehicle exits intersection – time vehicle enters intersection. (5)

B. *Fuzzy Rules of the Normal Controller*

This controller takes three input parameters. The first two parameters are AG and RGT, which are taken from the current green phase. The third parameter is RQL that is taken from the lanes of the red phase. It compares these parameters to decide whether to extend or decrease the green time of the current phase. The output of this fuzzy controller is the amount of change in green time. Since there can be more than one lane in a particular phase, the maximum value of AG and RQL is used. The fuzzy sets are shown in Fig. 3a to Fig 3c.

If a queue in a red phase is long and the arrival of vehicle in a green phase is very few, then logically the current green phase should be ended so that the controller can move on the next phase. For example, a fuzzy rule can be stated like this: if **RQL** is *Many* and **AG** is *Very Few* and **RGT** is *Many* then **Signal Timing** is *More Decreased*. Fig. 4 shows the fuzzy sets of Signal Timing.

C. *Fuzzy Rules of The Abnormal Controller*

This controller is similar to the above Normal Fuzzy controller except it has an additional parameter AGDT. The AGDT indicates how much time on average it takes for a vehicle to exit the intersection during the green phase. If the AGDT value increases then there is a possibility that the green time allocated would be wasted. For example, a fuzzy rule for this module can be stated as follows: if **RQL** is *Few* and **AG** is *Moderate* and **RGT** is *Many* and **AGDT** is Very Long then **Signal Timing** is *Decreased.* Fig. 3d illustrates the fuzzy sets for AGDT.

IV. ANALYSIS OF THE SIMULATION

A. *The Simulation Setup*

The simulation is carried out using MATLAB and the Fuzzy Logic Toolbox. The Fuzzy logic toolbox is useful to build quickly the required rules and changes are easily made. This significantly reduces the development time of the simulation model. The developed Fuzzy logic with Abnormalities (FLA) model is compared with two other simulated models. The first is the vehicle actuated (VA) model and the second is a fuzzy logic model(FLN) that does not consider abnormalities in its rule. The performance indicator is the average delay for the four different phases. The simulator is run 30000 seconds with the following assumptions:

1. A four arm intersection and each arm has three lanes, one going straight and the other two in turning direction (refer to figure 1)
2. The arrival of vehicles is independent on each lane. The inter-arrival of vehicles is also independent and Poisson distribution is used to generate arrivals. This results in inter-arrival of vehicles between 5 and 25 seconds.
3. Pedestrian crossing is not considered.
4. The discharge rate is set between 2 to 4 seconds
5. Sensors are placed at a certain distant from the intersection, the maximum vehicle that can be detected queuing is 20 vehicles.
6. Maximum green time is 60 seconds and the minimum green time is 10 seconds.

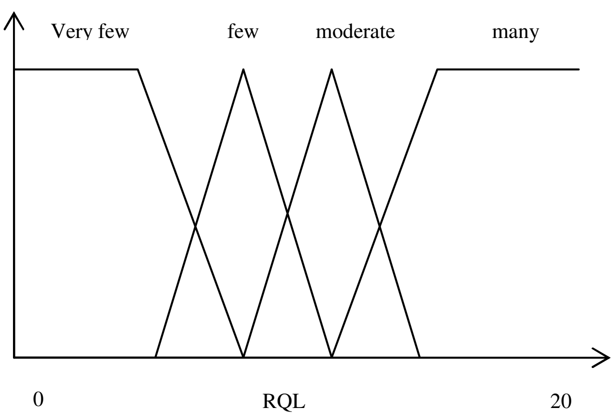
Possible abnormalities in this simulator and the expected consequences are described below:

1. Road partially blocked
    a. Discharge rate of vehicle reduced
2. Poor road condition
    b. Reduced speed. Discharge rate lower than normal
3. Lane completely blocked
    c. Zero vehicles discharged. Queue size keeps increasing. Green time wasted.
4. Upstream lane blocked completely
    d. Zero vehicles discharged. Green time wasted as no vehicles exited the intersection.

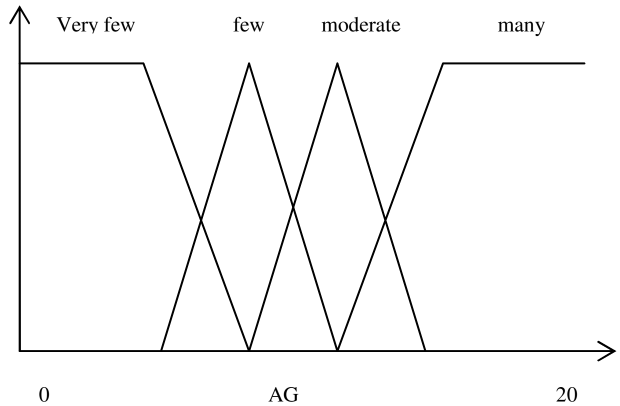
B. *Performance Analysis*

The simulated results for traffic conditions without abnormalities are presented in Table 1. The results for FLA and FLN are almost identical since the absent of abnormality does not effect the discharge rate. However, for the VA method, the average delay is significantly higher than FLA and FGA as Fuzzy Logic approach is know to be superior then the actuated models.

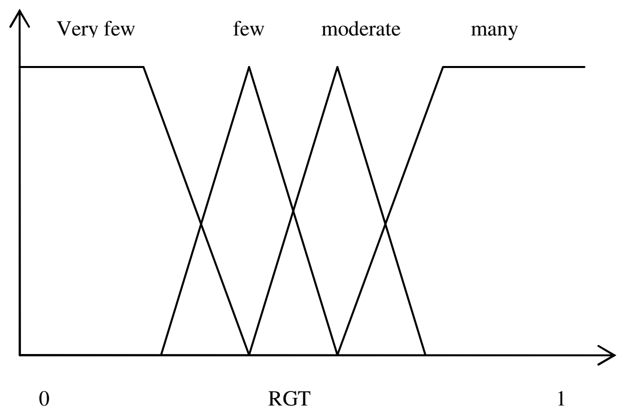
Table 2 present abnormalities at one lane moving from north to south in phase one. The simulated abnormality causes the discharge rate of vehicle to slow down and thus takes more time to discharge vehicles. In the VA approach, the delay for phase 1 is quite high, as it did not consider giving more time for lanes with longer queues. The other phases are not affected by this abnormality. In FLN it can be observed that there is a pattern of increase in delay for all the other phases as queue length is one of the factors that contribute to the change of phase and the duration of the phase. Thus, vehicles with higher waiting delay or a lane with longer queue is given priority. This actually creates a false alarm to the fuzzy controller. However, for the FLA model, the delay for the phase that is experiencing abnormalities is much higher while the other phase delays have hardly changed.



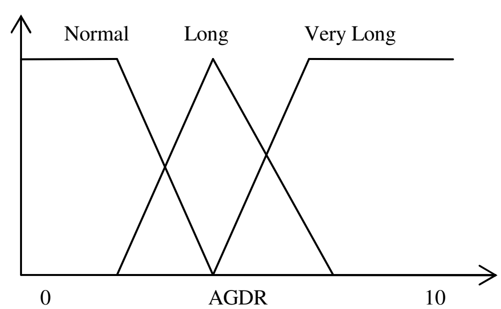
(a) RQL



(b) AG



(c) RGT



(d) AGDT

Fig. 3 Fuzzy sets of RQL, AG, RGT and AGDT

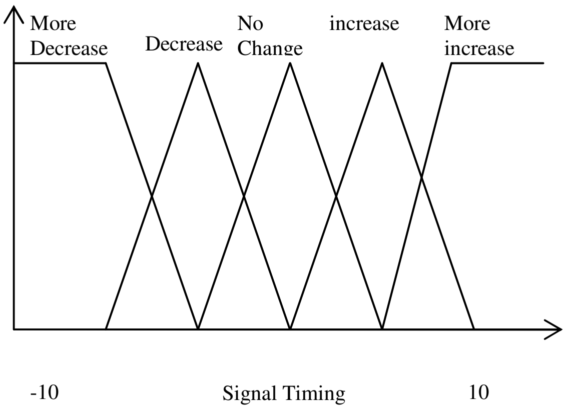


Fig. 4 Fuzzy sets for Signal Timing (Green Phase)

TABLE I

AVERAGE DELAY WITHOUT ABNORMALITIES

	Average Delay(sec)		
	FLA	**FLN**	**VA**
Phase 1	22	21	35
Phase 2	18	18	30
Phase 3	20	20	33
Phase 4	20	20	33

TABLE II

AVERAGE DELAY WITH ABNORMALITIES

	Average Delay(sec)		
	FLA	**FLN**	**VA**
Phase 1	32	30	51
Phase 2	19	25	32
Phase 3	20	23	33
Phase 4	20	23	33

V. CONCLUSION

This paper proposes a fuzzy logic controller with abnormalities factor considered in its rule. The results show that the efficiency of the controller to adapt to abnormalities in the signalized intersection. It is important to tune the fuzzy rule correctly, as the performance of the fuzzy controller depends highly on this. During the initial experiment stage, the model performed poorly since the fuzzy parameters were not configured properly. After repeated tuning and simulation, we manage to get it performing better than the VA method.

This FLA model can be further extended for multiple intersections. This study is to proof that the FLA model performed according to the hypothesis that was suggested. This model will be further extended in our ongoing research on multiple intersections which are common in urban roads.

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