Philippine Engineering Journal (1996) XVII (1): 55-62

FUZZY LOGIC BASED DECISION SYSTEM FOR THE LOCAL CONTROL OF SIGNALIZED INTERSECTIONS

Reuben J. Ravago
Computer Software Division
Advanced Science and Technology Institute
Department of Science and Technology
Philippines

ABSTRACT

The objective of this study is to develop a fuzzy logic based system which will effectively control a 4-lane intersection. The controller is based on fuzzy logic and it has two inference engines which determine the actions in the intersection. One fuzzy logic engine decides the phase length for a direction pair while the other decides the phase splits. The system is adaptive in that it makes decisions based on currently available traffic data. Testing of the system against a conventional traffic simulation have shown very favorable results.

INTRODUCTION

It is very important to control vehicular traffic. A large portion of the economy is on wheels. Products, goods, services, and people are constantly being transported from one place to another. Delays brought about by slow traffic or even traffic jams equate to increased costs, wasted time, and underutilized resources. Furthermore, fuel spent in idle traffic is energy wasted, not to mention the pollution that is expunged into the atmosphere. It is thus clear that the effective control of traffic would have a substantial social, economic, and ecological significance.

LOCAL TRAFFIC CONTROL

The local, signalized intersection, controller has the responsibility of scheduling the phase splits of its assigned intersection. Phase splits are the times allocated for each phase, stated in seconds or percentage ratio to cycle length. There are many existing modes of automated local control of signalized intersections. They can be roughly classified into timed-cycle, vehicle actuated, and adaptive. The programming of a timed-cycle controller begins by a statistical survey of the volume of traffic at different times of the day. A signaling scheme is then planned out from this gathered data. The controller is then programmed with this schedule. Thus, the splits cycle through preset duration. The data is gathered manually and at several seasons during the year. The method of adaptive control monitors real-time traffic flow and attempts to change signals with the changing traffic flow for improved performance. Still, in some countries, the oldest and most intuitive mode of traffic control is often employed in the most demanding of situations, the traffic policeman. Programming the local controller with the knowledge of a human expert would lead to what is known as a traffic control expert system.

FUZZY CONTROL

An expert system is a computer program that attempts to emulate a human expert. An expert system draws its knowledge from what is often a large rule base or set of production rules. Attached to the rule base is a frame system or some structure that provides the meaning of the objects occurring in the rules. The rules in the knowledge base are constructed by or with the advice of an expert in the field of the specific problem, hence, the name - expert system. One framework where we can design an expert system is a fuzzy logic system.

A fuzzy expert system embeds an expert's knowledge into its rule base and fashions the inputs and outputs of the system into the antecedents and precedents of the rule base. In essence it gathers numerical data, transforms it into fuzzy sets which fires the rules which controls the output or next step of the system. By gathering real-time information on the counts of the vehicles this system can provide an adaptive method of control which takes advantage of human intuition as well as computational capabilities. Once the controllers have been built, their performance was tested on a simulation of an actual intersection.

THE SIMULATION

The simulation is based on a model of an ideal intersection with four roads. It is simplified with the following assumptions. There are no gradient or turn radius factors. The adjoining roads where the cars traverse to can continuously absorb the incoming cars. The intersection runs from north to south and east to west. Each road has a left turning and through component but no right turning vehicles nor pedestrians. Each pair of parallel roads form a road pair. The north-south road pair forms the ***major road*** pair while the east-west road pair forms the ***minor road*** pair. Each through lane has a saturation rate of 2000 v/h (vehicles per hour) while left turning lanes are rated at 1800 v/h. Only cars are modeled in the simulation. Cars follow each other, i.e. cars depart in the order that they arrived. They can only move either at cruising velocity or at stop. Furthermore, they maintain a minimum headway of two seconds (2.0s) when they are moving and a minimum of 1 second (1.0s) when they are stopped. They do not cross lanes and are in their proper lanes.(i.e. the left turning lane contains only left turning cars and the through lane contains only through going cars.) The random arrival of cars is modeled by a negative exponential distribution. The headway of the cars at departure are determined by the function:

$$h = 8 - \sum_{i=1}^{12} R \qquad (1)$$

and h>= 1.0 as the minimum headway. The simulation takes in the schedule given by the controllers and dispenses the cars accordingly. Information with regards to lane, time-in, time-out, and number of stops are recorded for each car. These will later be used to evaluate the performance of the controller.

THE FUZZY LOGIC BASED CONTROLLER

The purpose of the controller is to inform the intersection on how to properly dispense the cars queued on the roads. It accomplishes this by using two interference engines. A small discussion about road characteristics should be indulged before going on. Each road has a complementary road, i.e. road pairs exist and coordinate with each other and competes with other road pair, In our simulator we have a north-south road pair competing with the east-west road pair for use of the intersection. To further illustrate, simplify the road by not allowing any

- if flow is Z and demand is Z then change is Z
- if flow is Z and demand is L then change is PS
- if flow is Z and demand is M then change is P
- if flow is Z and demand is H then change is P
- if flow is Z and demand is VH then change is PL
- if flow is L and demand is Z then change is NS
- if flow is L and demand is L then change is Z
- if flow is L and demand is M then change is PS
- if flow is L and demand is H then change is P
- if flow is L and demand is VH then change is P
- if flow is M and demand is Z then change is N
- if flow is M and demand is L then change is NS
- if flow is M and demand is M then change is Z
- if flow is M and demand is H then change is PS
- if flow is M and demand is VH then change is P
- if flow is H and demand is Z then change is N
- if flow is H and demand is L then change is N
- if flow is H and demand is M then change is NS
- if flow is H and demand is H then change is Z
- if flow is H and demand is VH then change is Z
- if flow is VH and demand is Z then change is NL
- if flow is VH and demand is L then changes is N
- if flow is VH and demand is M then change is N
- if flow is VH and demand is H then change is NS
- if flow is VH and demand is VH then change is Z

Figure 1. Rule base of the Phase I controller

turning vehicles. In this scenario, so long as one road pair is allowed to let traffic through, the other road pair is left waiting for the permission. Then let each road be assigned a split which is proportional to its current load. If a road pair is given use of the intersection, the intersection will be open for the duration of the longer split. This would imply that one of the roads would probably not be dispensing any cars while the other is not yet finished. This condition is an efficient use of the road. Thus in this scenario the first decision to be made about the intersection is how long each road pair has to use the intersection. The second decision deals with extending the ability of the intersection in allowing left-turning vehicles. This would require pre-empting or extension of the through lane phases. If an opposing lane is pre-empted then the left turn phase may begin earlier and vice-versa.

A. The Phase I Controller

The Phase I controller is meant to adjust the flow value (qi) assigned to the road. This flow value is supposed to be indicative of the amount of traffic flowing through the road. The rule base is designed to take in as inputs, 1) current demand. This is measured density of cars between the intersection and the position of the road sensor. It is normalized to the amount of time a car would need to traverse between these two points since the minimum headway for cars at stop is set at 1.0 sec. 2) The current qi setting. The rule base determines how much to adjust the current flow setting. Simply put it is meant to target the proper qi which will aptly describe the condition of traffic. From the adjusted qi the cycle time is computed using Webster's method of maximizing the use of the intersection given flow and saturation rates. The computation is simplified in that pedestrians are excluded.

B. The Phase 2 Controller

The phase two controller takes into consideration the demand level of the four lanes within the road pair that it is considering. Its output is the ratio of the time given to each lane. There are several ways to configure the phases but typically, it ends up in either a two phase or a three phase split. There is only one two phase split, all through and all left (see Figure 2). If the opposing through is preempted then there would be a three phase split. (see Figure 3).

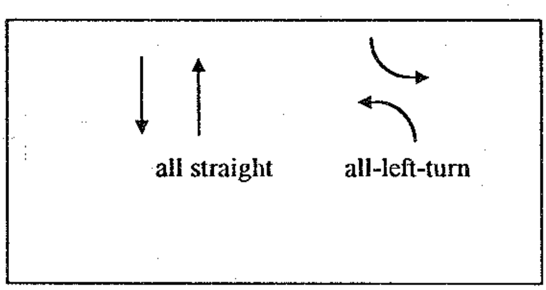


Figure 2. a two phase split for road pairs

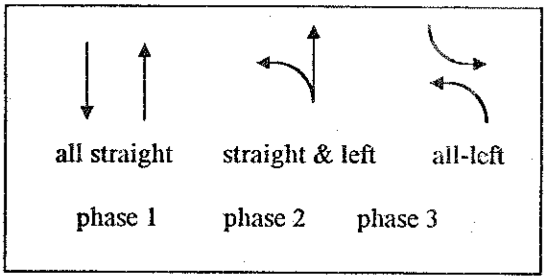


Figure 3. a three phase split for road pairs

The controller has, as antecedents, the difference in flow rates of the opposing through lanes (lane A & B) and the difference between the opposing left-turn lanes (lane C & D) of the demand on the system and, as consequents, the action to be taken (pre-empt or extend) length of time to be alloted. The given action determines the ratio of time given to each lane. These values are then used to divide the green time given to the road pair by the first phase.

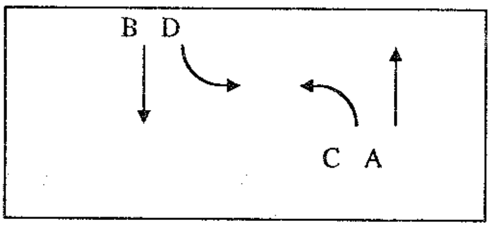


Figure 4. lanes in an intersection

The actions of this controller are effective only if there is a significant difference in the flow rate, qi, between opposing lanes. Otherwise only the phase 1 controller will be utilized.

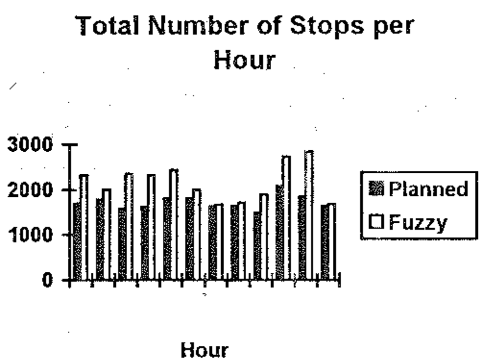
- if delta _AB is N and delta _CD is N then action is N
- if delta _AB is N and delta _CD is Z then action is Z
- if delta _AB is Z and delta _CD is Z then action is Z
- if delta _AB is P and delta _CD is Z then action is Z
- if delta _AB is P and delta _CD is P then action is P

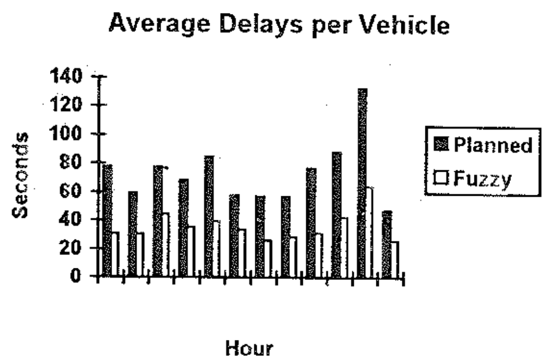
Figure 5. Rule-base of the second phase controller

TESTING AND RESULTS

The simulation was run for a twelve (12) hour day. The changing loads are modeled from actual data collected from an existing intersection. The performance of the controller was evaluated with regards to delay, stops, fuel spent, and emission.

The results have shown a favorable increase in performance over the current automated method of control. However there seems to be a trade-off, this is evident in the graphs shown below..





Although the fuzzy controller is consistently more effective in reducing delay significantly, it apparently does this by creating smaller packets of cars, thus decreasing the cycle time and increasing the number of stops. On the perspective of the driver, one would have spent nearly only half the usual time at the intersection, but may have added another stop to the trip. The stop counts are predominantly 0,1 & 2 stops with very rare occurrences of 3 stops. There were no stops greater than 3. Two stops would seem tolerable as compared to staying in the intersection for nearly twice as long a time.

Economically we can compute for fuel consumed and pollution emitted with the following givens:

1. fuel consumed by moving cars = $\frac{2}{3600}$ l/veh • s, (average).
2. fuel consumed when cars start/stop is = 0.04 l/veh, (average).
3. emissions by moving vehicles = 0.234 g/veh
4. emissions at start/stop = 6 g/veh

Here are the results for the first hour where the number of stops is much larger in the fuzzy controller. Interestingly, the fuzzy controller still comes out ahead even with all the stops incurred.

	Fuel	Emissions
Planned		
• Delay	110.59 l	46583.76 g
• Stops	67.88 l	10182.00 g
• TOTAL	178.47 l	56765.76 g
Fuzzy Control		
• Delay	51.95 l	21885.16 g
• Stops	93.08 l	13962.00 g
• TOTAL	145.03 l	35847.16 g

CONCLUSION

A fuzzy expert system can be employed to efficiently control a four way intersection with left turning vehicles.

EXTENSIONS

The fuzzy controller is still very simple, yet it is adaptable. Modifications for other, more complex road configurations would probably necessitate the addition of input variables, but nonetheless it is possible. If such modifications were found to be simple then such a controller may effectively be used in the real world.

REFERENCES

[1] Aboy, C., et.al (1994). PC Based Adaptive Road Traffic Control System, De La Salle University, April, 1994.

[2] Al-Khalii, A.J. (1985). Urban Traffic Control - A General Approach, IEEE Transactions on Systems Man, Cybernetics, vol. SMC-15 no. 2, March/April, 1985.

[3] Driankov, D. and H. Hellendoorn and M. Reinfrank (1993). An Introduction to Fuzzy Control, Springer-Verlag, Berlin, Heidelberg.

[4] Katakura, M ed. (1988). The Planning and Design of At-Grade Intersections, Japan Society of Traffic Engineers, Japan June 1988.
D.R. Drew (1968). Traffic Flow Theory and Control, Mc Graw-Hill.

[5] Sigua, R.C. (1994). Fundamentals of Traffic Engineering, National Center for Transportation Studies, An Introduction to Fuzzy Control, SPringer-Verlag, Berlin, Heidelberg.