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Calculation of the Change and Clearance Intervals of Traffic Signal by Fuzzy Logic System

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Abstract

In this paper, a new procedure that calculate the change and clearance intervals of a traffic signal from a rule-based fuzzy logic system was developed. This procedure is based on the theory that driver decision making at signalized intersections is based on imprecise or fuzzy information. The system's input variables consist of three primary variables and two secondary variables which reflect driver behavior as well as intersection traffic conditions and geometric layout. The primary variables contribute to the system's flexibility in that they are easily collected by sensors or detectors. Thus, the procedure provides dynamic change and clearance intervals, which improve the intersection throughput. Several scenarios were tested, and the resulting system indicates a simple but efficient way of determining the change and clearance intervals.

1. Introduction

One of the most important criteria in traffic flow is safety. Each motorist is expected to make an appropriate decision based on a set of fuzzy driving rules. During the change interval at a signalized intersection, approaching drivers are faced with the decision of either proceeding to cross or preparing to stop. An unexpected stopping decision may result in rear-end collision when the following driver follows too closely for the prevailing speed and environmental conditions. The decision to stop or go has fuzziness associated with it. Most of the factors affecting the driver's decision can not be precisely determined, but the driver is expected to make a decision based on the fuzzy information presented.

The main goal of this study is to improve driver safety through the new decision-making a signalized intersections for the change interval. Aside from the benefits of reduced accidents (rear-end and right-angle collisions), increased efficiency and reduced environmental costs are also the immediate benefits as a direct result of increased safety. Fuzzy sets theory and logic represent a methodology for dealing with phenomena that are too complex or too ill-defined to be susceptible to analysis by conventional means. Most studies have focused on developing formula for the calculation of the change interval to reduce accidents [1,2,5,6,7,8,9,10], but they have failed to examine the fuzzy information presented to drivers. However, this study will recognize the fuzziness of the information and will apply fuzzy sets and logic to analyze this information. Most of the selected fuzzy variables in this study could be sensed concretely by detectors to provide a computerized signal system. Such a computer system using fuzzy rule based logic could analyze sensed fuzzy variables to select the appropriate change interval timings.

2. Dilemma Zone

Imagine a driver passing through a signalized intersection as the traffic signal changes from green to yellow. The driver must make a decision about whether to stop or to run through the yellow light.There are many circumstances when such a simple driving decision becomes complex. For example, approach speed and the time remaining in the signal change interval are known to him only approximately, based on his experience and feelings. Then the imaginary line becomes "fuzzy" or it becomes so thick that it degenerates into a "zone," commonly referred to as a dilemma zone. Given the characteristics of the intersection as following:
w = the width of the intersection, v = the prevailing speed, Y = the signal change interval (yellow plus all-red), t = the driver's reaction time, and a = the deceleration rate, where $a = fg$, (f is coefficient of fricition and g is the gravita-tional constant).

We could calculate the "stop zone," which is a distance far enough from the intersection for a driver to stop when the yellow indication on. The formula [1] for the stop zone is

$$D_s = \frac{v^2}{2fg} + vt$$

Thus, if the yellow light turns on when the driver is at a distance longer than the stop zone from the intersection, he should be able to brake his vehicle to a safe halt. In a similar way, the "clear zone" is defined as a distance from the intersection that, if the light turns yellow when the driver is within this distance, he should be able to run through the cross street and clear it safely. According to current design practice, the expression [1] for the clear zone is

$$D_c = v(Y-(w+L)/v)$$

The concept of the dilemma zone is illustrated in Figure 1. Mathematically, the expression for the dilemma zone (D_z) is

$$D_z = D_s - D_c = v^2/(2fg) + t \times v - v(Y - (w+L)/v)$$

A change interval should ideally be set in such a way that it would eliminate the dilemma zone.

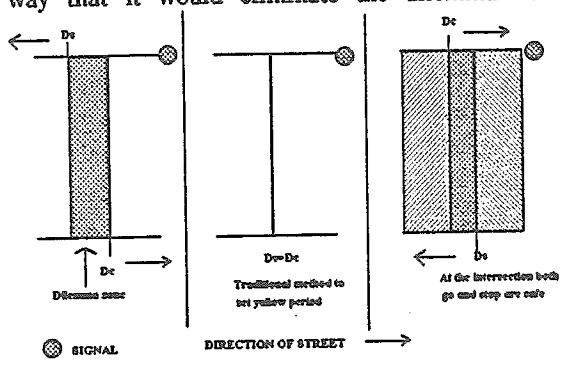

Figure 1: Illustration of Dilemma Zone

2.1. Fuzzy Model of Go/Stop

When a driver approaches an intersection, there exists a point on the approach roadway before which it is impossible for him to enter the intersection during the signal change interval. Similarly there exists a point beyond which it is not possible for the driver to stop. In reality, the driver's understanding of his situation is not clear. He can only approximate the quantities of the parameters that affect the his decision based on his experience. Among the lists of fuzzy parameters are fuzzy speed, V; fuzzy stopping distances, D_s; fuzzy clearing distances, D_c; fuzzy driver location, x; fuzzy brake performance, B, and fuzzy reaction times, R. Any distance greater than the fuzzy set of stopping distances (D_s) is called a safe-stopping distance (SSD). Similarly, any distance less than the fuzzy set of clearing distances (D_c) is called a safe-clearing distance (SCD).Determining SCD and SSD involves comparing crisp distances on the street with the fuzzy sets of D_s and D_c. This task will involve possibility and necessity measures, because that crisp value compared with a fuzzy set can only be determined to a degree. The possibility and necessity distributions of SCD and SSD, with respect to the distance from the intersection, are specified as the location of a driver where a clearing maneuver is possible and the location of a driver where a stopping maneuver is possible, respectively.

2.2. The Reasonable Result

If the location of the driver (x)is greater than the fuzzy stopping distance from the stop line, the vehicle can stop safely. We can define the membership function of the safe stop to the location of the driver by possibility ($x > D_s$)Thus, if the membership function of safe stop is denoted by U_s, then

$U_s = 0 \quad if\ x < E_1 \qquad U_s = F(t,x) \quad if\ x \geq E_1$;
where E_1 is a constant, t belongs to (R, V, B).

Similarly, if the location of the driver is smaller than the fuzzy clearing distance, the vehicle can clear safely. We can then define the membership function of the safe clear to the location of driver by possibility ($x < D_c$). Thus, if the membership function of safe clear is denoted by Uc, then

$U_c = 0 \quad if\ x > E_2 \qquad U_c = F(V,x) \quad if\ x \leq E_2$;
where E_2 is a constant, V is speed.

The driver's judgment that the condition requires a stop or go action is based on two measures, the stopping distance D_s and the clearing distance D_c which are perceived as fuzzy. The driver compares his location to the fuzzy values of D_s and D_c in a possibilistic-based or necessity-based manner and takes an action. The reasonable schematic diagram of the membership function of the safe stop and safe clear are shown in Figure 2. Let x=location of driver; U_s (x) = The membership function of the driver's location in safe stop; U_c (x) = The membership function of the driver's location in safe clear

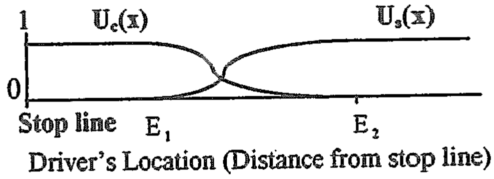

Figure 2. The Reasonable Schematic Diagram of the Membership Function of the

3. System and Its Membership Function

The first step in designing the fuzzy logic control system is determining the systems inputs. The inputs are: speed of vehicles, traffic density, capacity, grade, width of intersection, and location of driver. To accurately represent the system or problem, one must include all the variables that drive the process. However, the complexity of the fuzzy logic system increases with the number of input variables. As such, one must strike a balance or a trade off between accuracy and simplicity. There are a number of techniques available to reduce the complexity of a fuzzy logic system.

(1) Using variables which are a combination of two or more input variables e.g., the use of the variable C.F (congestion factor) instead of two separate variables, volume of traffic and capacity of intersection or approach. (2)Prioritizing the input variables into primary variables and secondary variables, where the secondary variables are used to modify the system. In this research, there is a discussion about specific application of knowledge-based expert system to the traffic signal systems.

The concepts of the system process are the following: (1) The information of intersection treated as secondary inputs (width and grade) is used to trigger the different designed cases. (2) The combination of primary input (average speed, congestion factor (CF), and location of last vehicle) are detected in each cycle of change interval and used to trigger the different rules of each fired case. (3) The defuzzification of trigger rules provide the appropriate change interval (green extension, yellow, and all red). The illustration of the systems process is shown in Figure 3. The basic structure of a fuzzy rule-based system is shown in Figure4.

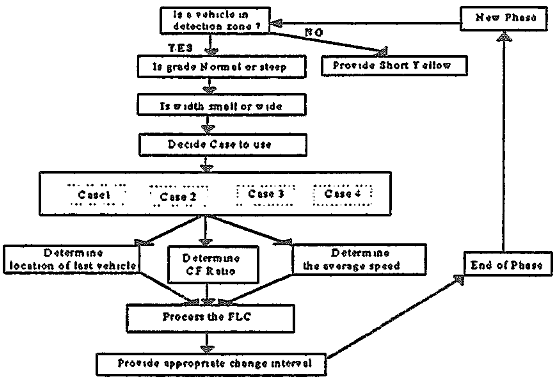

Figure 3. Graphic Representation of System Process

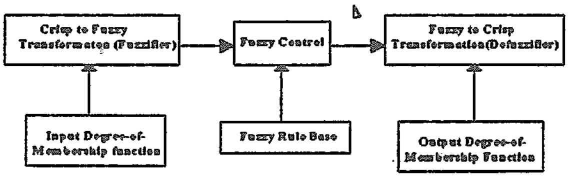

Figure 4. Basic Structure of a Fuzzy-Rule-Based System

3.1 Designing the Input Membership Function

1. The Primary Inputs Membership

a. Membership function of speed and CF.

Vehicle speed is an important consideration in highway transportation because it has significant implication for the safety, comfort, and convenience of highway travel for motorist. To the fuzzy variable SPEED we will assign three fuzzy values. SLOW - vehicle moving relatively slow; MEDIUM - neither slow nor fast moving vehicle; HIGH - vehicle moving at or above speed limit. The degree-of-membership function for SPEED are in Table 1. To the fuzzy variable CFRATIO, we will assign three fuzzy values. HIGH - congested or high density intersection, long queues; MEDIUM - average, approaching congestion, medium density, short intermittent queues; LOW - Low density, no queues, low delay. The membership function for the CFRATIO for the various fuzzy values are shown in Table 2. The membership functions for SPEED and CF are shown in Figures 5 and 6.

b. Membership function of driver location

One critical variable is the driver location at the onset of the yellow interval. In determining the signal change, the distance from the intersection at the onset of the yellow interval is used as a surrogate variable for the true measurement of time from the intersection. Therefore, driver behavior is analyzed in two ways: (1) the time for the last vehicle to pass through the intersection at the onset of the yellow interval and (2) the time for the first vehicle to stop [13].

To the fuzzy variable DRIVER-LOCATION we will assign three fuzzy values. CLOSE - relatively close to the intersection, MEDIUM - neither close nor far from the intersection, FAR - far from the intersection but within zone of detection. The degree-of-membership function for DRIVER-LOCATION is expressed mathematically in Table 3. Figure 7 shows its membership function.

Table 1: Fuzzy Subsets and Membership Function for SPEED (=SP)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
SLOW SPEED	$f(sp)=\begin{cases}1 & sp\le 30\\ (30-sp)\times(1/10)+1, & 30<sp\le 40\\ 0 & 40<sp\end{cases}$
MEDIUM SPEED	$f(sp)=\begin{cases}0 & sp\le 25\\ (sp-25)\times(1/15), & 25<sp\le 40\\ (40-sp)\times(1/15)+1, & 40<sp\le 55\\ 0 & 55<sp\end{cases}$
HIGH SPEED	$f(sp)=\begin{cases}0 & sp\le 40\\ (sp-40)\times(1/10), & 40<sp\le 50\\ 1 & 50<sp\end{cases}$

Table 2: Fuzzy Subsets and Membership Function for CFRATIO (=CF)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
LOW CFRATIO	$f(CF)=\begin{cases}1 & CF\le 0.2\\ 1.67-3.33VC, & 0.2<CF\le 0.5\\ 0 & 0.5<CF\end{cases}$
CFRATIO MEDIUM	$f(CF)=\begin{cases}0 & CF\le 0.2\\ 3.33CF-0.67, & 0.2<CF\le 0.5\\ 2.67-3.33CF, & 0.5<CF\le 0.8\\ 0 & 0.8<CF\end{cases}$
HIGH CFRATIO	$f(CF)=\begin{cases}0 & CF\le 0.6\\ 2.25CF-1.5, & 0.6<CF\le 1.0\\ 1 & 1.0<CF\end{cases}$

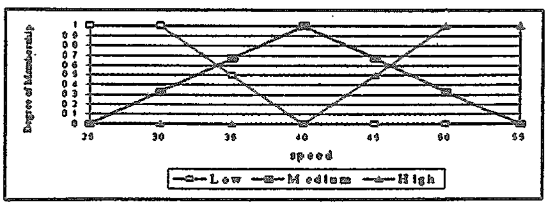

Figure 5. The Membership Function of Speed

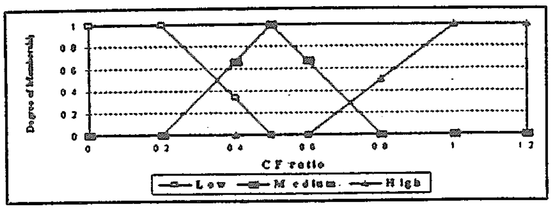

Figure 6. The Membership Function of CF Ratio

Table 3: Fuzzy Subsets and Membership Function for DRIVER-LOCATION (=DL)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
CLOSE LOCATION	$f(DL)=\begin{cases}1 & DL \le 75\\ 1.33-(DL/225), & 75<DL\le 300\\ 0 & 300<DL\end{cases}$
MEDIUM LOCATION	$f(DL)=\begin{cases}0 & DL \le 75\\ -1/2+(1/150)DL, & 75<DL\le 225\\ 2.5-(1/150)DL, & 225<DL\le 375\\ 0 & 375<DL\end{cases}$
FAR LOCATION	$f(DL)=\begin{cases}0 & DL \le 300\\ (1/150)DL-2, & 300<DL\le 450\\ 1 & 450<DL\end{cases}$

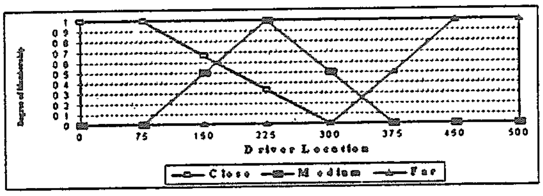

Figure 7: The Membership Function of Driver Location

2. The Secondary Input Membership

We characterize the intersection by the grade and the width of membership as secondary input to modify the whole system.

a. <u>The membership function for width</u>

The ranges of intersection width for this study are designed based on a number of factors including the following: (1) lane width (between 10 to 12 feet), (2) the presence (or absence) of a median (ranges from 2 to over 10 feet), (3) intersection curd radius, (4) location of the stop line. A two-lane intersection width with no median can be 24 feet or shorter while an eight-lane intersection width including median setback stop lines may be as wide as 120 feet or greater.

To the fuzzy variable WIDTH we will assign two fuzzy values. SMALL - three or less lanes across, WIDE - more than four lanes across. The degree-of-membership function for WIDTH are shown in Table 4. The membership function for WIDTH is shown in Figure 8.

Table 4: Fuzzy Subsets and Membership Function for WIDTH (=WD)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
SMALL WIDTH	$f(WD)=\begin{cases}1 & WD \le 20\\ (95/75)-(WD/75), & 20<WD\le 95\\ 0 & 95<WD\end{cases}$
WIDE WIDTH	$f(WD)=\begin{cases}0 & WD \le 4\\ (WD/75)-(45/75), & 45<WD\le 120\\ 1 & 120<WD\end{cases}$

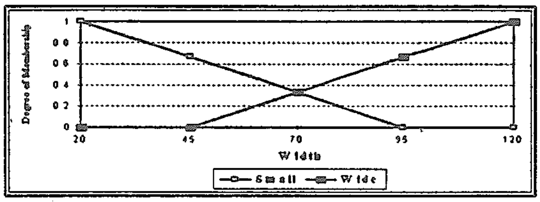

Figure 8: The Membership Function of Width

b. <u>The membership function for approach grade</u>

The grade of the roadway affects acceleration and deceleration of all vehicles. In this study, we assume the acceleration is not permitted for the downhill situation. So we do not consider the down grade fuzzy set. The positive grade can be as high as 7 % or 8 % or more in certain locations. To the fuzzy variable GRADE we will assign two fuzzy values. NORMAL - not likely to decrease speed of vehicle. STEEP - likely to decrease speed of vehicle. The degree-of-membership function for GRADE are shown in Table 5. The membership function for GRADE is shown in Figure 9.

Table 5: Fuzzy Subsets and Membership Function for GRADE (=GD)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
NORMAL GRADE	$f(GD)=\begin{cases}1 & GD \le 2\\ (9.5/7.5)-(GD/7.5), & 2<GD\le 9.5\\ 0 & 9.5<GD\end{cases}$
STEEP GRADE	$f(GD)=\begin{cases}0 & GD \le 4.5\\ (GD/7.5)-(4.5/7.5), & 4.5<GD\le 12\\ 1 & 12<GD\end{cases}$

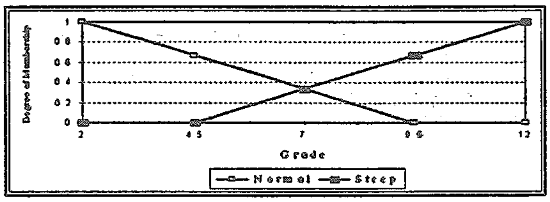

Figure 9: The Membership Function of Grade

3.2. Designing the Output Membership Function

The system has three outputs, YELLOW-TIME, ALL-RED, and GREEN-EXTENSION. Like the input variables, the output variables are expressed in terms of fuzzy values. Three fuzzy values are defined for each output variable.

For YELLOW-TIME, we have the following fuzzy values, SHORT for short change interval, MEDIUM for an average change interval, and LONG for long change intervals. These fuzzy values are represented by fuzzy sets which define the degree-of-membership function are shown in Table 6.

For ALL-RED, we have created the following fuzzy values, SHORT for provision of no all-red or short all-red time duration, MEDIUM-LONG for an average clearance interval, and LONG for long clearance intervals. The degree-of-membership functions for these fuzzy values are shown in Table 7.

Similarly, for GREEN-EXTENSION we have created the following fuzzy values, SHORT for provision of no green-extension or short green-extension time duration, MEDIUM-LONG for an average green-extension interval , and LONG for long green-extension intervals. The degree-of-membership functions for these fuzzy values are shown in Table 8.

The membership functions for these three outputs are shown in Figure 10, Figure 11, and Figure 12.

Table 6: Fuzzy Subsets and Membership Function for YELLOW TIME (=YL)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
SHORT YELLOW	$f(YL)=\begin{cases}1 & YL \le 3\\ 4-YL, & 3<YL\le 4\\ 0 & 4<YL\end{cases}$
MEDIUM YELLOW	$f(YL)=\begin{cases}0 & YL \le 3.5\\ 4YL-14, & 3.5<YL\le 3.75\\ 1 & 3.75<YL\le 4.25\\ 18-4YL, & 4.25<YL\le 4.5\\ 0 & 4.5<YL\end{cases}$
LONG YELLOW	$f(YL)=\begin{cases}0 & YL \le 4\\ YL-4, & 4<YL\le 5\\ 1 & 5<YL\end{cases}$

Table 7: Fuzzy Subsets and Membership Function for ALL-RED (=RD).

FUZZY SUBSETS	MEMBERSHIP FUNCTION
SHORT ALL-RED	$f(RD)=0$
MEDIUM ALL-RED	$f(RD)=\begin{cases}RD & RD \le 1\\ 2-RD, & 1<RD\le 2\\ 0 & 2<RD\end{cases}$
LONG ALL-RED	$f(RD)=\begin{cases}0 & RD \le 0.5\\ (2/3)RD-(1/3), & 0.5<RD\le 2\\ 1 & 2<RD\end{cases}$

Table 8: Fuzzy Subsets and Membership Function for GREEN-EXTENSION (GE)

FUZZY SUBSETS	MEMBERSHIP FUNCTION
SHORT GREEN.EXT	$f(G.E)=0$
MEDIUM GREEN.EXT	$f(G.E)=\begin{cases}1 & GE \le 1\\ -2GE+3, & 1<GE\le 1.5\\ 0 & 1.5<GE\end{cases}$
LONG GREEN-EXT	$f(G.E)=\begin{cases}0 & GE \le 0.5\\ 2GE-1, & 0.5<GE\le 1\\ 1 & 1<GE\end{cases}$

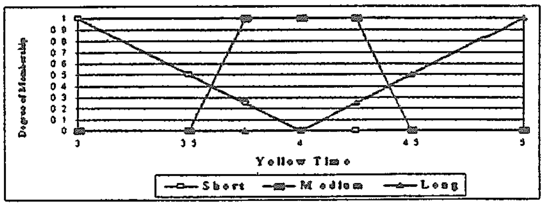

Figure 10: The Membership Function of Yellow Time

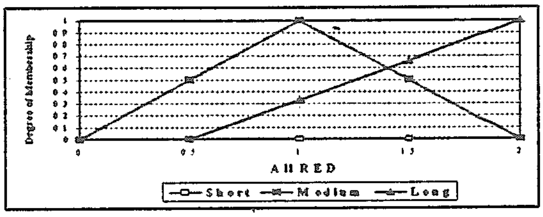

Figure 11: The Membership Function of All Red

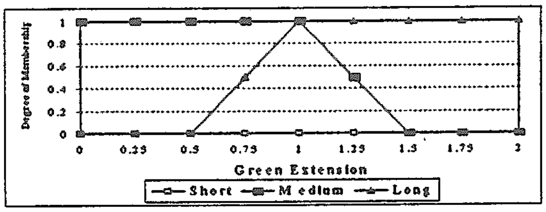

Figure 12: The Membership Function of Green Extension

3.3. The Combination of Four Scenarios

By combining the WIDTH and the GRADE, we have four scenarios which modify the system. They are illustrated in Figure 13 below. The output examples for two of the 4 scenarios are shown is Tables 9 through 10.

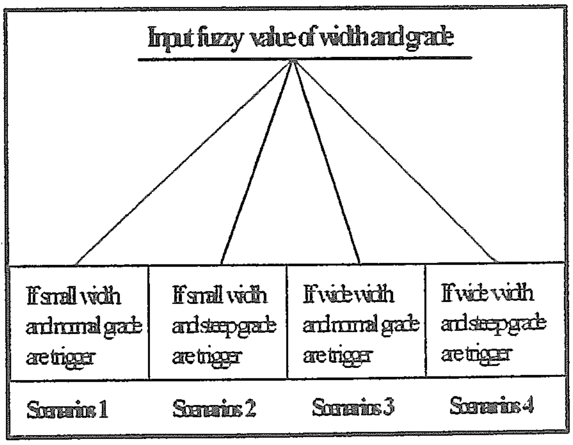

Figure 13. Illustration of System Modification

Table 9: Combination of Primary Inputs and Output for Scenario 1(Small Intersection Width with Normal Grade)

CASE	CFRATIO	LOCATION	SPEED	GREEN EXT	YELLOW	RED
1	High	Far	High	Long	Long	Long
2	High	Far	Medium	Long	Long	Long
3	High	Far	Slow	Long	Medium	Long
4	High	Medium	High	Long	Long	Long
5	High	Medium	Medium	Long	Long	Long
6	High	Medium	Slow	Long	Medium	Long
7	High	Close	High	Long	Long	Long
8	High	Close	Medium	Long	Medium	Long
9	High	Close	Slow	Long	Short	Long
10	Medium	Far	High	Medium	Long	Medium
11	Medium	Far	Medium	Medium	Long	Medium
12	Medium	Far	Slow	Medium	Medium	Medium
13	Medium	Medium	High	Medium	Long	Medium
14	Medium	Medium	Medium	Medium	Long	Medium
15	Medium	Medium	Slow	Medium	Medium	Medium
16	Medium	Close	High	Medium	Long	Medium
17	Medium	Close	Medium	Medium	Medium	Medium
18	Medium	Close	Slow	Medium	Short	Medium
19	Low	Far	High	Short	Long	Short
20	Low	Far	Medium	Short	Long	Short
21	Low	Far	Slow	Short	Medium	Short
22	Low	Medium	High	Short	Long	Short
23	Low	Medium	Medium	Short	Medium	Short
24	Low	Medium	Slow	Short	Short	Short
25	Low	Close	High	Short	Long	Short
26	Low	Close	Medium	Short	Medium	Short
27	Low	Close	Slow	Short	Short	Short

Table 10: Combination of Primary Inputs and Output for Scenario 2 (Small Intersection Width with Steep Grade)

CASE	CFRATIO	LOCATION	SPEED	GREEN EXT	YELLOW	RED
1	High	Far	High	Long	Long	Long
2	High	Far	Medium	Long	Long	Long
3	High	Far	Slow	Long	Medium	Long
4	High	Medium	High	Long	Long	Long
5	High	Medium	Medium	Long	Long	Long
6	High	Medium	Slow	Long	Medium	Long
7	High	Close	High	Long	Long	Long
8	High	Close	Medium	Long	Medium	Long
9	High	Close	Slow	Long	Medium	Long
10	Medium	Far	High	Medium	Long	Medium
11	Medium	Far	Medium	Medium	Long	Medium
12	Medium	Far	Slow	Medium	Medium	Medium
13	Medium	Medium	High	Medium	Long	Medium
14	Medium	Medium	Medium	Medium	Long	Medium
15	Medium	Medium	Slow	Medium	Medium	Medium
16	Medium	Close	High	Medium	Long	Medium
17	Medium	Close	Medium	Medium	Medium	Medium
18	Medium	Close	Slow	Medium	Medium	Medium
19	Low	Far	High	Short	Long	Short
20	Low	Far	Medium	Short	Long	Short
21	Low	Far	Slow	Short	Medium	Short
22	Low	Medium	High	Short	Long	Short
23	Low	Medium	Medium	Short	Medium	Short
24	Low	Medium	Slow	Short	Medium	Short
25	Low	Close	High	Short	Long	Short
26	Low	Close	Medium	Short	Medium	Short
27	Low	Close	Slow	Short	Short	Short

4. Experiment Design

Two scenarios were tested in the experiment. For each scenario all the outputs from the 27 different combinations formed from the crossing of the primary variables (speed (SP), congestion factor (CF), and driver location (DL)) were included in the experiment. The two scenarios are, namely:

(1) Scenario 1 - Medium intersection width and flat grade, and

(2) Scenario 2 - Wide intersection width and flat grade.

The results of the two scenarios are shown in Table 11 and Table 12. Detailed analysis of Scenario 2 is presented. Descriptive statistics are also used to describe the results of the rule-based fuzzy logic system.

Descriptive statistics of the yellow time for Scenario 2 is shown in Table 13, 14, and 15 for the primary variables. The general trend is that the yellow interval timing increases directly with the speed of approaching vehicles and driver location.

Descriptive statistics of the all-red time for Scenario 2 is shown in Table 16 for the secondary variable (medium and wide intersection width). The general trend is that the all-red interval timing increases directly with the width of intersection. Descriptive statistics of the green extension for Scenario 2 is shown in Tables 17,18 and 19 for the primary variable congestion factor (CF). The result for speed of approaching vehicle (SP) and driver location (DL), indicates little or no variation across these two primary variables. The descriptive statistics support the traffic engineering practice of providing green extension intervals based on the degree of congestion.

Table 11: Simulation Run for Scenario 1 - Medium Intersection (90 ft) and Flat Grade (1%)

Run	Speed	Congestion Factor	Driver Location	Yellow	All-Red	Green Extension
1	50	0.9	400	4.6388889	1.45833333	1.555556
2	40	0.9	400	4.6666667	1.5	1.6666667
3	30	0.9	400	4.1944445	1.4583333	1.5555556
4	50	0.9	250	4.546634	1.370353	1.505838
5	40	0.9	250	4.532182	1.486255	1.630013
6	30	0.9	250	4.076106	1.439689	1.505838
7	50	0.9	100	4.491421	1.439338	1.514706
8	40	0.9	100	4.098485	1.491477	1.643939
9	30	0.9	100	3.732843	1.443015	1.514706
10	50	0.6	400	4.638889	1.229167	0.555556
11	40	0.6	400	4.666667	1.25	0.6666667
12	30	0.6	400	4.194445	1.229167	0.5555556
13	50	0.6	250	4.528817	1	0.4530668
14	40	0.6	250	4.501894	1	0.5560154
15	30	0.6	250	4.080515	1	0.4530668
16	50	0.6	100	4.468759	1	0.458355
17	40	0.6	100	4.108329	1	0.5666972
18	30	0.6	100	3.776028	1	0.4583551
19	50	0.3	400	4.616666	0.775	0.1333333
20	40	0.3	400	4.638889	0.72916	0.1111111
21	30	0.3	400	4.233333	0.775	0.1333333
22	50	0.3	250	4.423322	0.7172203	0.125109
23	40	0.3	250	4.135239	0.6920402	0.1106037
24	30	0.3	250	3.81617	0.7172203	0.1251059
25	50	0.3	100	4.389881	0.7142857	0.1190476
26	40	0.3	100	4.067708	0.6875	0.1041667
27	30	0.3	100	3.788691	0.7142857	0.1190476

Table 12: Simulation Run for Scenario 1- Medium Intersection (90 ft) and Flat Grade (1%)

Run	Speed	Congestion Factor	Driver Locatio	Yellow	All-Red	Green Extension
1	50	0.9	400	4.638888	1.4583333	1.555556
2	40	0.9	400	4.666666	1.5	1.6666667
3	30	0.9	400	4.194444	1.4583333	1.5555556
4	50	0.9	250	4.546634	1.439685	1.505838
5	40	0.9	250	4.532182	1.486255	1.630013
6	30	0.9	250	4.076106	1.439689	1.505838
7	50	0.9	100	4.491421	1.443015	1.514706
8	40	0.9	100	4.098485	1.491477	1.643939
9	30	0.9	100	3.732843	1.443015	1.514706
10	50	0.6	400	4.638889	1.458333	0.555556
11	40	0.6	400	4.666667	1.5	0.6666667
12	30	0.6	400	4.194445	1.458333	0.5555556
13	50	0.6	250	4.528817	1	0.4530668
14	40	0.6	250	4.501894	1	0.5560154

Table 12 - Continue

15	30	0.6	250	4.080515	1	0.4530668
16	50	0.6	100	4.468759	1	0.458355
17	40	0.6	100	4.108329	1	0.5666972
18	30	0.6	100	3.776028	1	0.4583551
19	50	0.3	400	4.616666	1.15	0.1333333
20	40	0.3	400	4.638889	1.125	0.1111111
21	30	0.3	400	4.233333	1.15	0.1333333
22	50	0.3	250	4.423322	1	0.125109
23	40	0.3	250	4.135239	1	0.1106037
24	30	0.3	250	3.816617	1	0.1251059
25	50	0.3	100	4.389881	1	0.1190476
26	40	0.3	100	4.067708	1	0.1041667
27	30	0.3	100	3.788691	1	0.1190476

Table 13: Descriptive Statistics of Yellow Interval Timing by Speed

Speed	30 mph	40 mph	50 mph
Mean	4.00	4.38	4.53
Standard Deviation	0.20	0.27	0.09
Minimum	3.73	4.07	4.39
Maximum	4.23	4.67	4.64
Range	0.50	0.60	0.25

Table 14: Descriptive Statistics of Yellow Interval Timing by Driver Location

Driver Location	100 ft	250 ft	400 ft
Mean	4.10	4.30	4.50
Standard Deviation	0.30	0.26	0.22
Minimum	3.73	3.86	4.19
Maximum	4.49	4.54	4.66
Range	0.76	0.69	0.47

Table 15: Descriptive Statistics of Yellow Interval Timing by Congestion Factor

Congestion Factor	0.3	0.6	0.9
Mean	4.24	4.33	4.33
Standard Deviation	0.31	0.30	0.32
Minimum	3.79	3.78	3.73
Maximum	4.64	4.67	4.67
Range	0.85	0.89	0.93

Table 16: Descriptive Statistics of All-Red Interval Timing by Width

	Wide Width	Small Width
Mean	1.22	1.08
Standard Deviation	0.23	0.31
Minimum	1.0	0.7
Maximum	1.5	1.5
Range	0.5	0.8

Table 17: Descriptive Statistics of Green Extension Timing by Speed

Speed	30 mph	40 mph	50 mph
Mean	0.71	0.78	0.71
Standard Deviation	0.63	0.68	0.63
Minimum	0.12	0.10	0.12
Maximum	1.56	1.67	1.56
Range	1.44	1.56	1.44

Table 18: Descriptive Statistics of Green Extension Timing by Congestion Factor

Congestion Factor	0.3	0.6	0.9
Mean	0.12	0.52	1.57
Standard Deviation	0.01	0.07	0.06
Minimum	0.10	0.45	1.50
Maximum	0.13	0.67	1.67
Range	0.03	0.22	0.17

Table 19: Descriptive Statistics of Green Extension Timing by Driver Location

Driver Location	100 ft	250 ft	400 ft
Mean	0.72	0.72	0.77
Standard Deviation	0.65	0.64	0.65
Minimum	0.10	0.11	0.11
Maximum	1.64	1.63	1.67
Range	1.54	1.52	1.56

5. Conclusion

This paper has shown that the use of a rule-based fuzzy logic system for estimation of the change and clearance intervals of traffic lights is feasible. The fuzzy logic approach has many advantages over the traditional model in estimating the yellow interval. The fuzzy logic approach is not based on a mathematical model and requires no analytical or theoretical knowledge. Aside from this, the fuzzy logic approach is flexible and lends itself easily to modification. While the traditional approach yields fixed values for the change and clearance intervals, the fuzzy logic approach gives dynamic values depending on the intersection and geometric conditions.

6. Reference

1. Chan, Y. and Liao, T. (1987), "Setting Change Intervals at Signalized Intersections." *ITE Journal*, February, pp. 45-50.
2. Chang, M. S., Messer, C. J., and Santiago, A. J. (1985), "Timing Traffic Signal Change Intervals Based on Driver Behavior." *Transportation Research Record 1027*, TRB, National Research Council, Washington DC, pp. 20-30.
3. Federal Highway Adminstration. (1989), Assessment of Current Speed Zoning Criteria, Report No. FHWA-RD-89-161. Washington DC.
4. Herman, R., Olson, P. L., and Rothery, R. R. (1963), "The Problem of Amber Signal Lights." *Traffic Engineering andControl*, 5 (5), pp. 298-304.
5. ITE Technical Committee for A-16. (1985), Proposal Recommended Pratice: Determining Vehicle Change Interval. ITE Journal, May, pp. 61-64.
6. Kikuchi, S., Perincherry, V., Chakroborty, P., and Takahashi, H. (1993), "Modeling of Driver Anxiety During Signal Change Intervals." *Transportation Research Record 1399*, National Research Council, Washington, DC, pp. 27-35.
7. Lin, F. B., Cooke, D., and Vijayakumar, S. (1987), "Utilization and Timing of Signal Change Interval." Presented to TRB, National Research Council, Washington, DC, pp.1-24.
8. Ling, Feng-Bor, and Vijaykumar, S. (1988), "Timing and Design of Signal Change Intervals." *Traffic Engienering and Control*, October, pp. 298-304.

9. Mahalel, D. and Prashker, J. N. (1987), "A Behavioral Approach to Risk Estimation of Rear End Collisions at Signalized Intersections." *Transportation Research Record 1114*, pp. 96-101.
10. May, A. (1967), "A Study of the Clearance Interval at Traffic Signals." *ITTE Special Report*, Berkley, CA: University of California.
11. Olson, P. L., and Rothery, R. R. (1962), "Driver Response to the Amber Phase of Traffic Signals." *Highway Research Bulleton 330*, pp. 40-51.
12. Williams, W. L. (1977), "Driver Behavior During the Yellow Interval." *Transportation Research Record 644*, TRB, National Research Council, Washington DC, pp. 75-78.
13. Wortman, R. H., Fox, T. C. (1986), "Reassessment of the Traffic Signal Change Interval." Prepared for *65th Annual Meeting*, Transportation Research Board, National Research Council, Washington DC.
14. Zadeh, L. A. (1991), "Fuzzy Logic and the Caculus of Fuzzy If-Then Rule." *Proceedings of Synapse '91*, Tokyo, Japan.