Universiti Teknologi MARA
Cawangan Perlis
Jurnal Intelek

Volume 14 Issue 1 (June 2019)

Fuzzy Logic to Optimize Traffic Signal Control in a Congested Area

Nor Suhaili Abdul Aziz[1], Noraini Noordin[1]*

[1]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA, 02600 Arau, Perlis, Malaysia

*Corresponding author: *norainnoordin@uitm.edu.my*

Received Date: 2 March 2019
Accepted Date: 3 May 2019

ABSTRACT

Traffic congestion is a critical problem to road users worldwide. The present traffic signal control system in Malaysia has not produced optimal solutions for existing traffic congestions. This case study was carried out to test if applying fuzzy logic to traffic signal controllers can optimally solve traffic congestion at the four junctions in a developed urban area on Jalan Kerinchi, Kuala Lumpur. Two input variables (average number of vehicles queueing and arriving at a junction) and one input variable (green time duration) were considered in the study. Five linguistics were associated to each of the input variables thus MATLAB generated 25 fuzzy inference base rules. Results showed large differences between current green time duration (90.81 seconds, 92.72 seconds, 31.58 seconds, 13.88 seconds) and fuzzy logic green time duration (15.30 seconds, 55.00 seconds, 20.00 seconds, 10.00 seconds). Consequently, green time signal durations were minimized. Effectiveness of fuzzy logic applications can be further researched on and tested by adding more input variables or varying the conditions of the junctions.

Keywords: *congestion, fuzzy logic, green light rovide a maximum of 5 keywords*

INTRODUCTION

Urbanization rate has increased from 50.7% in 1991 to 62% in 2000 in Malaysia (Almselati, Rahmat, & Jaafar, 2011; Ho, 2008). It is expected to exceed 70% in 2020. Transport infrastructures will breed incessantly alongside any growing population, thus causing severe traffic congestion (TC) at all urban areas in developed and developing countries. The 2012 statistics reported that the world car population of one billion has surpassed the previous year's global car population of 980 million (Tencer, 2013).
TC problems affect the society and environment. Rising fuel expenses, time loss and environmental issue should provide motivation to minimize traffic delays (Madhavi Arora & Banga, 2012). New facilities, new roads and better infrastructures developed by government agencies and departments of public works are only temporary solutions. Manual police traffic control is used from time to time (Salehi, Sepahvand, & Yarahmadi, 2014). However, all these measures have not solved the TC problems. Current available optimization procedures may not be the best solution for heavy TCs. In general, traffic signal controllers (TSCs) operates using a fixed-time or actuated control. In a fixed-time traffic signal controller (FTSC), the constant green/red phase for each traffic signal cycle is pre-set using historical data (Homaei, Hejazi, & Dehghan, 2015). Most TSCs in major cities like Kuala Lumpur are FTSCs. Random road user behavior affects traffic condition, thus FTSCs can only function well in normal congestion free traffic condition (Mehan, 2011; Murat & Gedizlioglu, 2005; Salehi et al., 2014). A Vehicle Actuated

ISSN: 2231-7716

Traffic Controller (VATC) combines preset cycle time with proximity sensors that detect passing and stopping traffic on all lanes leading into an intersection (Homaei et al., 2015; Salehi et al., 2014). VATC is more effective than FTSC but its real time information is also tainted under heavy traffic conditions (Mehan, 2011). Fuzzy logic-based traffic signal controllers (FLSCs) were found to perform better than conventional TSCs in congested traffic conditions (I.N.Askerzade (Askerbeyli), 2010; Rahman & Ratrout, 2009). In the current study, FLSC enhanced with sensors to detect number of waiting and arriving vehicles at a junction are used to optimally solve traffic congestion at the four junctions in a developed urban area on Jalan Kerinchi, Kuala Lumpur.

LITERATURE REVIEW

Inefficient configuration of the signal plan in an FTSC can cause long waiting times and TC. This inefficiency is catered in FLSC by using sensors. FLSC showed superior performance only under time varying traffics. In addition, FLSC has effectively improved traffic capacity by giving out a suitable green time and reduced waiting time at intersections (Mehan, 2011; Salehi et al., 2014). FLSC has outperformed FTSC and VATC (Budi Yulianto & Setiono, 2012; I.N.Askerzade (Askerbeyli), 2010; Niittymäki & Pursula, 2000). Traditional TSCs most often do not consider number of vehicles arriving at the crossroads. Better performances are observed when information on traffic density in the lane and changing traffic patterns were fed into FLSC.

FLSC

Research works have focused on optimizing TSCs using fuzzy logic at intersections and junctions (Budi Yulianto & Setiono, 2012; Homaei et al., 2015; Kulkarni & Waingankar, 2007; Murat & Gedizlioglu, 2005). Traffic flow is usually random and uncertain, thus using FLSC over FTSC is a more sensible option. Linguistic and inexact traffic data can be manipulated to design signal timings. The fuzziness of TSCs can be divided into three levels. The input level provides only partial picture of the traffic situation using measurements. The control level allows the researcher to work with many possibilities, where one of them is the right one to use. In the output level, the researcher does not have enough information on control criteria such as extension gap (Niittymäki & Pursula, 2000)

This section illustrates how FLSC with sensors was set up by Budi Yulianto and Setiono (2012). Two input data (maximum queue length in meters, average occupancy rate in percent) and one output data (weight of signal group between 0 and 100) were used. Video images of both input and output data were recorded. The stop line defined the start of the queue of vehicles during the red-light period. In addition, the detection area for calculating average occupancy rate was situated one meter downstream of the stop line for each approach during the green light period. The degree of need is measured by the weight of the signal group, thus the heavier signal group required more green time. For example, if the weight of SG1 is 75 and SG2 is 25, then SG1 needs more green light than SG2.

Four different case scenarios were studies by Budi Yulianto and Setiono (2012) provided the following conclusions with regards to FLSC and FTSC.

Table 1: Conclusions on use of FLSC in four different situations

RESULT		DESCRIPTION
Case 1	During one-hour period, the traffic flow is constant.	A little difference in value between the FLSC and FTSC was observed.
Case 2	Traffic changes every 15 minutes.	FLSC produced better results on traffic volume than FTSC.
Case 3	The traffic composition is different.	FLSC did not perform well in mixed conditions unlike

		FTSC but produced same results in saturated condition.
Case 4	A real data from Sutomo-Diponegoro is used for traffic flow.	FTSC showed longer delay and travel time in contrast to FLSC.
CONCLUSION - FLSC did better adjustment of the extension of green light in a certain period.		

The following sections will discuss the processes in FLSC: Fuzzification and Membership Functions; Fuzzy Rule Base and Fuzzy Inference Engine; and Defuzzification.

Process 1: Fuzzification and Membership Functions

Figure 1 displays the basic configuration of a fuzzy logic system. Fuzzification translates scalar values obtained from statistical sampling or other derived numerical quantities into triangular or trapezoidal types of membership function. The fuzzy system uses Mamdani and Assilian method to compute simplicity and efficiency of the model's common sense.

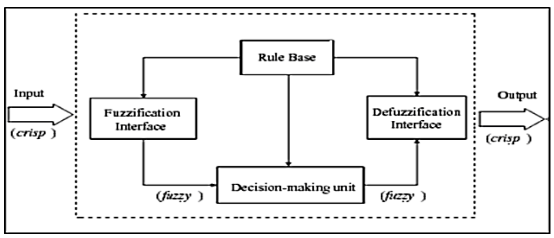

Figure 1: Basic Configuration of a Fuzzy Logic System

Trial and error method can determine number of fuzzy partitions for input and output variables. The linguistic variable for membership functions for input data and output data are (Low, Medium, High, Very High) and (Very Very Low, Very Low, Low, Medium, High, Very High, Very Very High), respectively. Figure 2 shows the graphical representation of the membership functions.

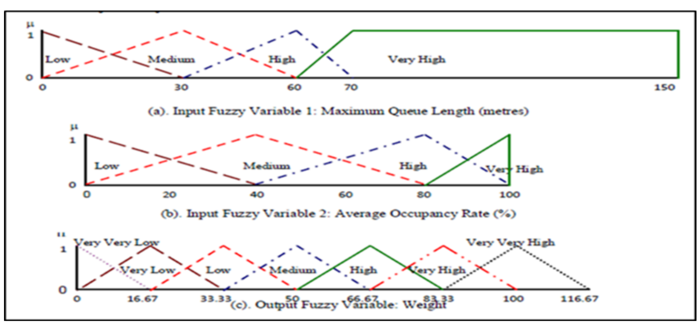

Figure 2: Graphical representation of membership functions of the FLSC
Source: Budi Yulianto and Setiono (2012)

Figure 3 shows how the fuzzification of car speed value with $x_0 = 70$ km/h has a membership function of μ_A and μ_B and characteristics low and medium, respectively. Thus, a car speed of 70 km/h produces degree of membership function $\mu_A(x_0) = 0.75$ with low to fuzzy set and $\mu_B(x_0) = 0.25$ with medium to fuzzy set.

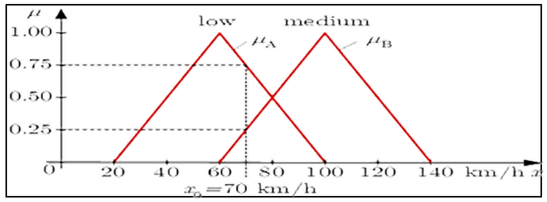

Figure 3: Fuzzification of car speed
Source: Schmid (2005)

Process 2: Fuzzy Rule Base

The fuzzy inference system (FIS) is the most important unit of a fuzzy logic system whose main function is decision making. It uses the "IF…THEN" rules along with connectors "OR" or "AND" for drawing essential decision rules. For example, IF traffic from the north many AND traffic from the west is short THEN allow movement of traffic from the north side (Arora & Banga, 2012). FLSC states that each input consists of four membership functions, thus two inputs will produce sixteen (4^2) fuzzy rule bases. The input fuzzy variable maximum queue length is more sensitive to the performance of the controller if compared to the average occupancy rate when the fuzzy rule base is adjusted based on the trial and error method. Figure 4 represents the configuration of the fuzzy rules in the matrix structure of the FLSC.

		Maximum Queue Length			
		L	M	H	VH
Average Occupancy Rate	L	VVL	L	M	H
	M	VL	L	H	VH
	H	L	M	H	VVH
	VH	M	H	VH	VVH

Note: VVL = Very Very Low; VL = Very Low; L = Low; M = Medium; H = High; VH = Very High; VVH = Very Very High

Figure 4: Fuzzy rule base in matrix structure to derive a weight value for each signal group
Source: Budi Yulianto and Setiono (2012)

Process 3: Fuzzy Inference Engine and Defuzzification

A fuzzy rule-based system evaluates linguistic if-then rules to produce a fuzzified output. Defuzzification is a process that converts this output into a single crisp value to define the action to be taken in controlling the process. Known methods of defuzzification include mathematical methods like centre of sums, centroid of area, bisector of area, weighted average and maxima (see Figure 5). The current study has used the centroid method. It defines the centre for the area under the graph of a membership function. In addition, it has displayed better performance in terms of continuity, counting and computer complexity (Madhavi Arora & Banga, 2012). All fuzzy logic calculations in the current study were run using the MATLAB software.

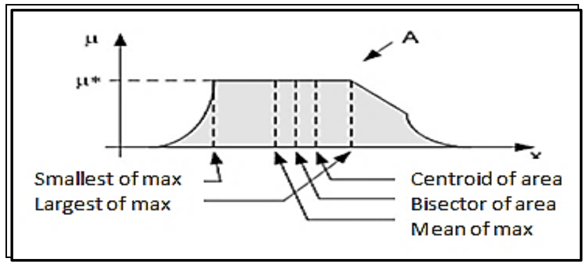

Figure 5: Graphical demonstration of defuzzification methods
Source: Kozlowska (2012)

METHODOLOGY

The study was carried out at a four-way junction around Jalan Kerinchi (see **Error! Reference source not found.**), namely Jalan Kerinchi East junction (JKE), Jalan Kerinchi from West junction (JKW), Jalan Kerinchi Kiri from South junction (JKS) and Jalan 112h from North junction (J112h). Two types of TSCs were used here: FTSC and VATC. Fuzzy logic was applied to VATC. TC always occurs during peak hours on weekdays, thus raw data needed for this study was run in the evenings from 4.30 p.m. to 7.30 p.m. for six days. Data was collected from the cycle of TSC about three hours per day, producing a total of 354 complete cycles of traffic light.

Figure 6: Location for data collection

Model Development

Model development will be discussed with respect to all three main processes in FLSC.

Fuzzification and Membership function

Two input variables were number of vehicles that arrive at traffic signal (Arrival) and number of vehicles queuing in the lane (Queue). The output was the time period for green light (Green Light). The crisp inputs like the number of vehicles detected by the sensor were sent for fuzzification. A membership function then defined how each of these numbers was mapped to a membership value between 0 and 1. Three membership functions were generated for the input and output variables in this study as shown in **Error! Reference source not found.**.

Table 2: Abbreviations for Fuzzy Set

Variable	Short Term	Fuzzy subset
Number of vehicles that arrive at traffic signal	Arrival	- Too few - Few - Medium - Many - Too many
Number of vehicles queuing in the lane	Queue	- Too short - Short - Medium - Long - Too Long
The period time for green light	Green Light	- Low - High - Very High

The inference rule for this study is a conditional statement expressed as the following:

$$IF\langle \textit{fuzzy proposition}\rangle, THEN\langle \textit{fuzzy proposition}\rangle \quad \text{OR} \quad IF\langle FP_1\rangle, THEN\langle FP_2\rangle \tag{1}$$

where FP_1 and FP_2 are fuzzy propositions

Fuzzy Inference Base Rule

This project has two input variables with five linguistic variables each. 5^2 = 25 possible outcome rules were generated using MATLAB toolbox. The following lists out the first three rules. Table 3 summarizes these rules.

Rule 1 = If queue is too short and arrival is too few then green light is low.
Rule 2 = If queue is too short and arrival is few then green light is low.
Rule 3 = If queue is too short and arrival is medium then green light is low.

Table 3: Fuzzy control rule for inputs and output

		Arrival				
		Too Few	Few	Medium	Many	Too Many
QUEUE	Too Short	Low	Low	Low	Low	High
	Short	Low	Low	Low	High	High
	Medium	Low	Low	Low	High	High
	Long	Low	High	High	Very High	Very High
	Too Long	High	High	Very High	Very High	Very High

In addition, Mamdani Implementation was used to obtain the membership function for the IF-THEN rule:

Mamdani Min $\mu_{QMM}(x,y) = \min[\mu_{FP_1}(x), \mu_{FP_2}(y)]$ (2)

Mamdani Algebraic Product $\mu_{QMP}(x,y) = \mu_{FP_1}(x,y)\cdot\mu_{FP_2}(y)$ (3)

Defuzzification

Some membership functions have a higher demand on computation. The formula for the centroid method is expressed by the following equation:

$$z = \frac{\int x \cdot \mu(x)}{\int \mu(x)} \tag{4}$$

where z is the fuzzified output and $\mu(x)$ is the membership function and x is output variable.

The defuzzification procedure used here allocated a fuzzy output value (period time variable) for fuzzy decision making. Thus, period time was converted into numerical value in seconds.

RESULT AND DISCUSSION

The findings are presented according to Fuzzification and Membership Functions, Fuzzy Inference Base Rule, Defuzzification and The Validation of Result.

Fuzzification and Membership Functions

Each junction had their own membership functions. Figure 7, Figure 8 and Figure 9 display the transformation of crisp values into membership function for all variables. The range for membership functions was found to be similar for every junction except for J112h. There were fewer vehicles using this junction. The higher ranges of membership function were JKE and JKW. Since the range and linguistic variable of membership function were determined based on the observation of the system and TC environment on Jalan Kerinchi, the range of membership function can be changed based on the condition of the traffic junction.

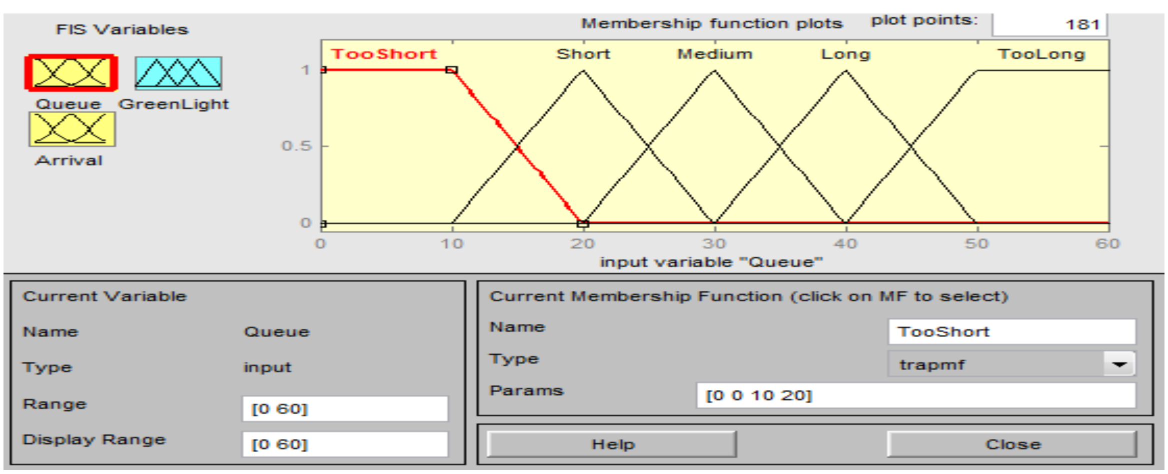

Figure 7: Membership functions of the number of vehicles in the queue

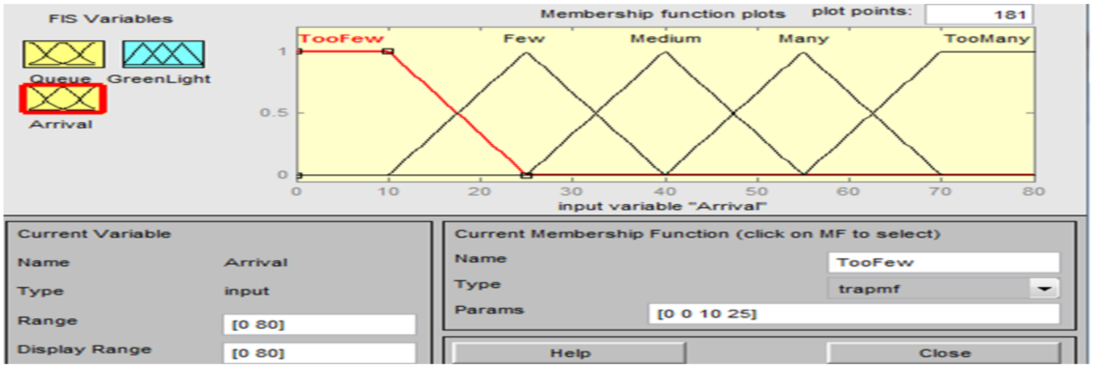

Figure 8: Membership function of number of vehicles that reach arrival side

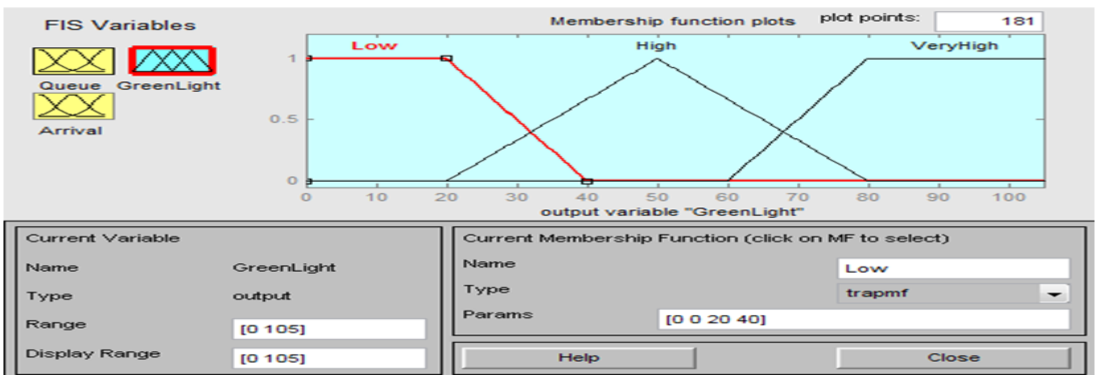

Figure 9: Membership function of the period time for green light

Fuzzy Inference Rule

A sample result after application of the if-then rule is given in Figure 10.

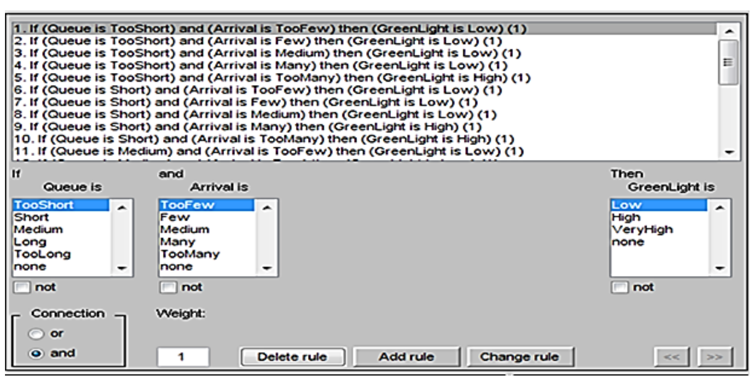

Figure 10: Sample result after application of if-then rule

Defuzzification

Defuzzification is a process that transforms fuzzy output value into the crisp value. To generate the result, MATLAB software is used to evaluate the value based on inference rule. The results from 354 complete cycle data were compiled in MATLAB. Figure 11 shows defuzzification results for data from the junction on JKE. It shows the average value for the input and output variable. For the number [30 40], 30 denoted the average number on queuing in the lane while 40 was the number of vehicles that arrive at the traffic signal. The result for the output variable (as stated at the top of the rightest column) was 15.3 seconds. Consequently, the fuzzy logic results can be stated as: IF 30 number of vehicle queuing in the lane AND 40 number of vehicles that arrive at traffic signal THEN the period for Green Light is 15.3 seconds. The output indicated that the timing was based on the longer queue or many vehicles in the junction.

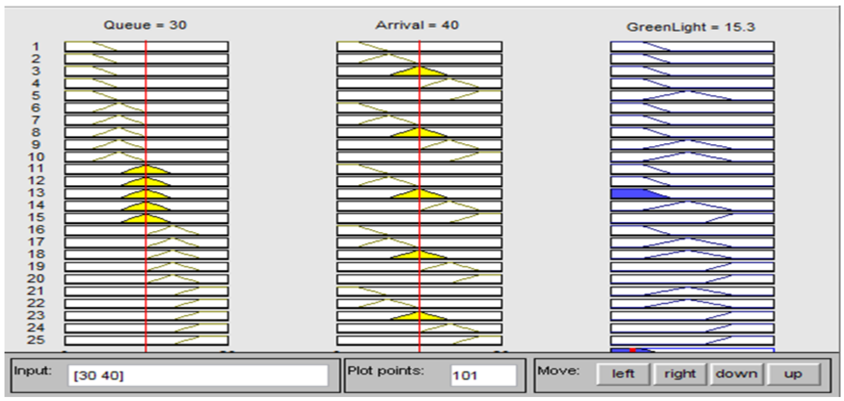

Figure 11: Result after defuzzification for JKE

Average number of input variables and output variable for each junction were calculated. Table 4 shows the results from comparing fuzzy logic use to current data.

Table 4: Comparative data analysis between current and fuzzy logic data

Junction	**Average Value (second)**		**Differences Time(second)**
	Current Period Time for Green Light	Fuzzy Logic Period Time for Green Light	
JKE	91.81	15.30	76.51
JKW	92.74	55.00	37.74
JKS	31.58	20.00	11.58
J112h	13.88	10.00	3.88

Current period time for green light was observed to be higher for fuzzy logic period time for green light. This can be attributed to the fact that the timing for green light at the junctions was fixed. More important to observe is that the average value for green light period time from current data did not cater for the number of vehicles that queued in the lane and vehicles that arrived at the traffic signal. For example, junction JKE with average number of vehicles queuing and arriving in lane as 36.51 and 48.55 produced a period time for green light of 91.81 seconds. Where there was longer period of green time for any junction, other junctions would experience TC. However, results for fuzzy logic green light showed lower values at all junctions. Therefore, the fuzzy logic application has produced optimal results for traffic control at these junctions because timing settings for the signal controllers considered number of vehicles which queued and arrived at the junctions as variables.

CONCLUSION

Comparative analysis between durations for current green time and fuzzy logic green time showed large differences between them, namely 76.51 seconds, 37.74 seconds, 11.58 seconds and 3.88 seconds for JKE, JKW, JKS and J112h. Therefore, fuzzy logic application has minimized TC at all junctions. This study considered only two input variables, thus MATLAB generated 25 inference rules for the study. Effectiveness of this adaptive system can be further improved by adding more input variables. In addition, actions like automatic change to yellow can be considered under stricter conditions.

REFERENCES

Almselati, A. S. I., Rahmat, R. A. O. K., Jaafar, O., 2011. An Overview of Urban Transport in Malaysia. The Social Sciences 6, p. 24.

Budi Yulianto, Setiono, 2012. Traffic Signal Controller for Mixed Traffic Conditions. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 4, p.19.

Ho, C. S., 2008. Urban governance and rapid urbanization issues in Malaysia. Jurnal Alam Bina 13, p. 1.

Homaei, H., Hejazi, S., Dehghan, S. A. M., 2015. A new traffic light controller using fuzzy logic for a full single junction involving emergency vehicle preemption. Journal of Uncertain Systems 9, p. 49.

I.N.Askerzade (Askerbeyli), M. M., (2010). Control the Extension Time of Traffic Light in Single Junction by Using Fuzzy Logic. International Journal of Electrical & Computer Sciences IJECS-IJENS 10, p. 48.

Kozlowska, E., 2012. Basic Principles of fuzzy logic. Czech Technical University in Prague, Faculty of Electrical Engineering, 1-6.

Kulkarni, G. H., Waingankar, P. G., 2007. Fuzzy logic based traffic light controller. Paper presented at the 2007 International Conference on Industrial and Information Systems.

Madhavi Arora, Banga, D. V. K., 2012. Application of Morphological Method of Edge Detectionand Fuzzy Logic Technique for Traffic Light Control. International Journal for Science and Emerging Technologies with Latest Trends 1, p. 31.

Mehan, S., 2011. Introduction of Traffic Light Controller with Fuzzy Control System. International Journal of Electronics & Communication Technology 2, p. 119.

Murat, Y. S., Gedizlioglu, E., 2005. A fuzzy logic multi-phased signal control model for isolated junctions. Transportation Research Part C: Emerging Technologies 13, p. 19.

Niittymäki, J., Pursula, M., 2000. Signal control using fuzzy logic. Fuzzy sets and systems 116, p 11.

Rahman, S. M., Ratrout, N. T., 2009. Review of the fuzzy logic based approach in traffic signal control: prospects in Saudi Arabia. Journal of transportation Systems engineering and information Technology 9, p. 58.

Salehi, M., Sepahvand, I., Yarahmadi, M., 2014. TLCSBFL: A Traffic Lights Control System Based on Fuzzy Logic. International Journal of u-and e-Service, Science and Technology 7, p. 27.

Schmid, C., 2005. Fuzzification. Retrieved from http://virtual.cvut.cz/course/syscontrol/node122.html

Tencer, D., 2013. Number of Cars Worldwide Surpasses 1 Billion. Huffpost Business Canada. Retrieved from http://www.huffingtonpost.ca/2011/08/23/car-population_n_934291.html