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# OPTIMIZING GREEN_TIME OF A TRAFFIC SIGNAL CONTROLLER

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**Abstract**

Traffic congestion is a major concern throughout the world especially in urban cities. It takes place following the rapid increase in automobile use in cities. Traffic signals play an important role at coordinating efficient movement of people and vehicles in the transport system. However, most conventional traffic signal controllers with pre-computed constant signal timing parameters or vehicle actuated control do not respond well to real-time traffic demand. The current study aimed to determine the optimal duration of green light (Green_Time) for installing a fuzzy logic signal controller (FLSC) at a three-way junction. Fuzzy logic incorporates qualitative values into the system, thus FLSC is widely proven to be efficient. The decision on Green_Time for this study was taken by importing the input variables (the number of vehicles on Arrival and on Queue) into a Matrix Laboratory (MATLAB) software. Comparative analysis between manually calculated results from the centroid method and MATLAB simulated results were found to be the same for all three intersections.

**Keywords:** centroid method, congestion, fuzzy logic, Green_Time, signal controller

## 1.0 INTRODUCTION

Current densely populated urban areas undergo rapid development. An immediate consequence that takes place will be a sudden rise in traffic flow on the roads in the area. Rapid increasing number of vehicles on a road may result in bottlenecks at road intersections. In particular, greater traffic in-flow than traffic out-flow at an intersection during congestion will increase traffic queue size (Yau et al., 2017). Besides congestions and accidents, other problems that may arise include abundant delays, increase in environmental pollution and personal matter hiccups or glitches.

Previous works have suggested many methods to solve the problem of traffic congestion such as system of linear equation (Adu et al., 2014), queueing theory (Anokye et al., 2013), simulation model (Salimifard & Ansari, 2013), particle swarm optimization (García-Nieto et al., 2012), and image processing (Darshan et al., 2017). On the other hand, traffic congestion problem can also be attributed to the in-efficient Green_Time in traffic control signals.

Conventional traffic signal controls are implemented with fixed-timed controls or an actuated control. A fixed-timed signal controller (FTSC) has a simple operating system (i.e. the green or red phase is set as a constant) and usually performs well in normal traffic conditions (Mehan, 2011). The Green_Time in a vehicle actuated signal controller (VASC) is calculated based on the density of road traffic. A VASC performs better than an FTSC, but it is still unable to accommodate the randomness and uncertainty of traffic flow. However, both conventional traffic signal controllers have not exhibited good performance at optimizing vehicles' travel time in heavy traffic conditions (Homaei et al., 2015; Mehan, 2011; Yulianto, 2003; Zarandi & Rezapour, 2009).

Unlike an FTSC, a fuzzy logic signal controller (FLSC) can incorporate qualitative values into the system. It can also flexibly define a new time range for the current green time based on size of traffic flow on the road (Askerzade & Mahmood, 2010; Kulkarni & Waingankar, 2007). There is no necessity to spend money for building new roads or widening existing roads. A more intelligent adaptive traffic signal controller like an FLSC should be able to improve efficiency of the current roadway system.

FTSCs that are located at current existing intersections in some urban areas in Malaysia may not be able to cater for the severe congestion that occurs. Due to its flexibility, an FLSC can perform generally better than an FTSC (Askerzade & Mahmood, 2010; Kulkarni & Waingankar, 2007). This article shares the findings from a study conducted to determine the optimal Green_Time for installing an FLSC at a three-way junction in a congested area.

## 2.0 BACKGROUND OF STUDY

The discussion here is presented in three sections: Traffic control signals, Location of study and Fuzzy Logic.

### 2.1 Traffic Control Signals

Daily activities in urban areas rest on many factors including properly functioning traffic lights. Pappis and Mamdani (1977) pioneered the first attempt to use an FLSC at an isolated intersection with two one-way roads and no turning traffic. Other early works in this area included fixed-phase signal control (Chen & Chen, 1992), traffic flow control on two adjacent intersections (Nakatsuyama et al., 1984) and fuzzy logic lights control at an isolated four-way junction with no left or right turns (Khalid, 1996). Findings from these early research works reported that FLSC has outperformed conventional traffic signal controllers under heavy traffic conditions.

The use of FLSC has also been tested on roads with different conditions such as secluded four-way intersection with mixed traffic conditions (Yulianto, 2003), full intersection with two-way streets and left-turn lanes (Zarandi & Rezapour, 2009), and single junction (Askerzade & Mahmood, 2010). Kumthekar et al. (2016) regulated the green light intervals of an FLSC using micro-controllers at a four-way junction. FLSC was also tested on a four-way junction by Eze et al. (2014).

Kuang and Xu (2012) applied a four-layer neural network to a real-time signal controller with transit-priority at an intersection. In particular, an absolute transit-priority was given to special vehicles to pass through when the sensors in the red phase detected the arrivals of special vehicles. Likewise, an FLSC has also been tested to minimize traffic flow on roads passed by three emergency vehicles: ambulance, police unit and fire brigade which came from three different directions (Salehi et al., 2014). In short, FLSC can be applied to areas of congestion under different conditions. In this study, the focus was to solve the traffic congestion at a three-way junction.

### 2.2 Location of study

This study focused on Jalan Sultan Abdul Samad, Banting. Traffic jams have been observed that often take place during peak hours from 7 am to 9 am and 5 pm to 7 pm. The site involved a road that has a three-way junction. Traffic lights have been set up at each intersection. The plan for the location of study is displayed in Figure 1.

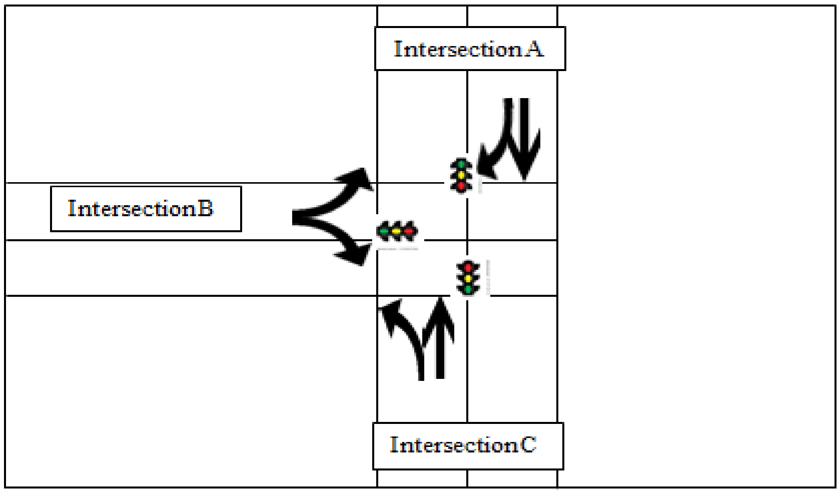


**Figure 1 Traffic layout at Jalan Abdul Samad**

### 2.3 Fuzzy logic (FL)

FL was invented by Lotfi Zadeh. It is a reasoning method that resembles the human thinking. It can also functions as a mathematical tool that deals with cases containing ambiguity (Alam, 2014). FL approach considers all possible intermediate options between two extremes including options that lie between a Yes and a No. A FL System (FLS) is made up of four major elements: fuzzification, knowledge base, inference engine and defuzzification (Singhala et al., 2014).

#### 2.3.1 Fuzzification

Fuzzification is a process that transforms system inputs in the form of crisp numbers into fuzzy sets. It involves the development of linguistic variables (LVs) and membership functions (MFs). Linguistic variables appear as input variables (IVs) and output variables (OVs) in simple forms or words. An LV is generally broken down as a set of linguistic terms.

Using the MFs, non-fuzzy IVs will be mapped onto fuzzy linguistic terms and vice versa. MFs can be represented in many different waveforms such as triangular waveform, S-curve waveform, bell-shaped waveform, trapezoidal waveform, sigmoidal waveform and Gaussian waveform. The exact waveform to be used will be determined during actual application.

#### 2.3.2 Knowledge base

The function of a fuzzy rule is to control the OV. A fuzzy rule is described by a simple if-then rule that consists of a condition and a conclusion. A single fuzzy if-then rule can be written as follows:

If *x* is *A* then *y* is Z
where
*A* = a set of circumstances that has to be fulfilled
and
*Z* = a set of implications that can occur.

Fuzzy rules can be evaluated using operations involving fuzzy sets. Most often used set operations in the fuzzy rules for *OR* (Union) and *AND* (Intersection) are Max and Min, respectively.

### 2.3.3 Inference engine

An inference process is then conducted to combine all the evaluation results. Two commonly used fuzzy inference system are Mamdani-type and Sugeno-type. Decision making using Mamdani-type is more preferred over other types because it is easier to transform Mamdani output into linguistic form (Blej & Azizi, 2016). In contrary to Sugeno-type, Mamdani-type produces output MFs (Kaur & Kaur, 2012). In the current study, Mamdani-type has been applied in the formulation of the mapping from IVs to OV.

### 2.3.4 Defuzzification

In order to obtain an overall result, fuzzy values are deffuzified to produce a final crisp output. In addition, the MF of the OV is used in the defuzzification process. Many different algorithms are utilized at this stage. They may include the centroid method, bisector method and largest, smallest as well as mean of maximum (Naaz et al., 2011). In particular, the centre of gravity of the fuzzy set is used as the basis for the calculation of the crisp value obtained from the centroid method. It can be represented as the following:

$$y = \frac{\int \mu_A(x).x dx}{\int \mu_A(x) dx} \qquad (1)$$

where $A$ = output of aggregate conclusion

## 3.0 METHODOLOGY

The discussion in this section will be divided into two parts: Criteria for design of FLSC and constraints; and Fuzzy Logic System (FLS) in this study.

### 3.1 Criteria for Design of FLSC and Constraints

The following assumptions were made in the development of the FLSC for a three-way junction:

i. All three junctions (labelled as A, B and C) were distinct from each other, with in-flow traffic from the north, south and west directions, respectively.
ii. When there was traffic flow from A, traffic flows from B and C were stationary.
iii. When traffic flowed from B, there was no traffic flow on A and C.
iv. When the traffic was flowing from C, traffic from A and B were assumed to stop.
v. The side with traffic flow was denoted as Arrival while the side with traffic queueing to stop was denoted as Queue.

vi. Several vehicles on the left-most lane at intersections B and C slide to the left from time to time, however no left turns were considered in this study.
vii. The Green_Time for the FTSC at all three junctions was pre-set at 60 seconds.

### 3.2 FLS in this study

All four major processes (fuzzification, knowledge base, inference engine and defuzzification) of the FLS were focused on intersection A. The next two sub-sections will describe the fuzzification and knowledge base processes for this study.

#### 3.2.1 Fuzzification

Fuzzification process includes the development of LVs and MFs. As stated earlier on in Section 3.1, there are two IVs, namely Arrival and Queue. On the other hand, the OV is defined as the Green_Time. Labels given to the LVs for both IVs were defined as very small, small, medium, large and very large. The labels for the OV were short, medium and long. Specifically, the following norms were followed:
i. Arrival = {*VS*, *S*, *M*, *L*, *VL*}
ii. Queue = {*VS*, *S*, *M*, *L*, *VL*}
iii. Green_Time = {*S*, *M*, *L*}

Ranges for each variable were determined by finding the minimum and maximum number of data taken. It is to be highlighted again here that the current Green_Time for each intersection was set at 60 seconds. Now, the Green_Time has been assumed to be varied from 20 to 60 seconds. As a result, the ranges of the variables for intersection A were stated as in the Table 1.

**Table 1 Ranges of variables for intersection A**

| Variable | Quantity of traffic on Arrival | Quantity of traffic on Queue | Green_Time |
|---|---|---|---|
| **Label** | A | Q | T |
| **Range** | (6,42) | (20,80) | (20,60) |

Chosen MFs for this study were triangular and trapezoidal waveforms. Possible MFs for both IVs and OV were represented as in Figure 2, 3 and 4.

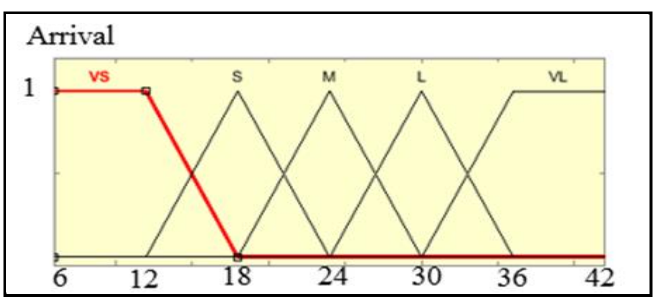


**Figure 2 MF for Arrival**

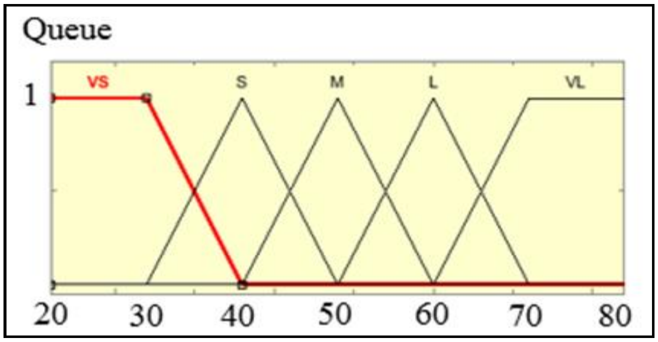


**Figure 3 MF for Queue**

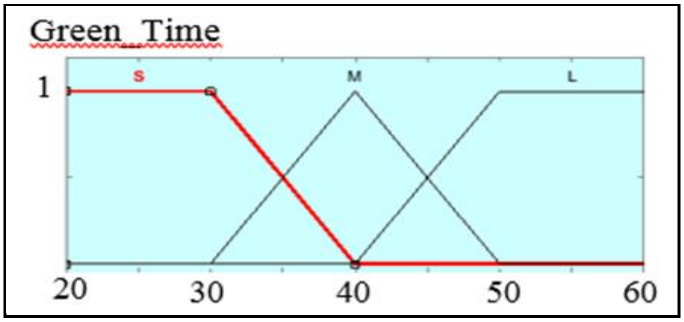


**Figure 4 MF for Green_Time**

### 3.2.2 Knowledge Base

A fuzzy rule is built to control the OV and it is a simple *if-then* rule that consists of a condition and a conclusion. There were 25 possible fuzzy rules used in this study, as displayed in Table 2.

**Table 2 Fuzzy Rules in this study**

| Q \ A | ***VS*** | ***S*** | ***M*** | ***L*** | ***VL*** |
|---|---|---|---|---|---|
| ***VS*** | *Sh* | *Sh* | *Sh* | *M* | *M* |
| ***S*** | *Sh* | *Sh* | *M* | *M* | *M* |
| ***M*** | *Sh* | *M* | *M* | *M* | *L* |
| ***L*** | *M* | *M* | *M* | *L* | *L* |
| ***VL*** | *M* | *M* | *L* | *L* | *L* |

*Note:*
*VS = very small, S = small, M = medium, L = large, VL = very large, Sh = short, M = medium* and *L = long*

The FIS and defuzzification process made use of the Mamdani type and the centroid method respectively. After completing all four processes, manual calculations were compared to simulated MATLAB results. Results were considered as True if both compared values were approximately the same.

## 4.0 RESULTS AND DISCUSSION

Centroid method was used to calculate the output. The AND operator was used to get the aggregate conclusion. For instance, the last rule has used the AND operator as follows:

> If amount of vehicles on Arrival is very large AND amount of vehicles on Queue is very large, then the time required for Green_Time is long. Based on the data taken, if Arrival is 40 AND Queue is 72, then Green_Time is 52.3 seconds.

Results obtained from manual calculations using the centroid method were compared to the simulated results in MATLAB. As expected, same results were produced. In particular, the defuzzification process in MATLAB was also based on the centroid method. Specifically, Figure 5 displays the result in the Rule Viewer of MATLAB quantity of traffic on Arrival = 40 and the quantity of vehicles on Queue = 72. As shown, the most suitable Green_Time was also 52.3 seconds. Since both solvers produced same results, they were applied to all data.

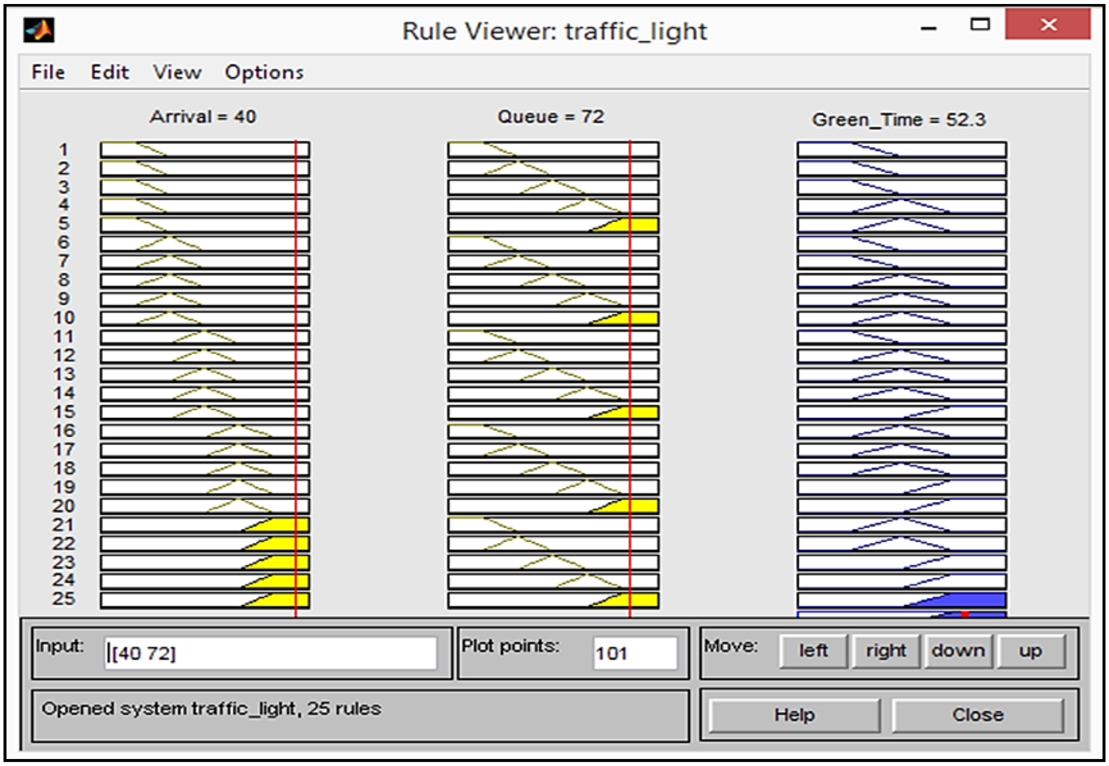


**Figure 5 Structure of the Rule Viewer**

In order to determine which type of timing was better to be used on the traffic signal controllers, an analysis was carried to compare results from the whole experiment with time from FTSC. In particular, Table 3 displays the differences between FTSC and FLSC.

**Table 3 Comparison between FTSC and FLSC**

| ITEM | FTSC | FLSC |
|---|---|---|
| **Duration of green light** | Duration of green light was fixed at 60 seconds for every intersection. | Duration of green light was computed using a set of fuzzy rules and current traffic volumes. |
| **Timing of the signal** | Repeated the pre-set constant cycle. | Controlled by the traffic demand. |
| **Example on Intersection A** | *If* Arrival is 40 AND Queue is 72, *then* Green_Time is 60 seconds. | *If* Arrival is 40 AND Queue is 72, *then* Green_Time is 52.3 seconds. |
| **Example on Intersection B** | *If* Arrival is 20 AND Queue is 50, *then* Green_Time is 60 seconds. | *If* Arrival is 20 AND Queue is 50, *then* Green_Time is 40 seconds. |
| **Example on Intersection C** | *If* Arrival is 10 AND Queue is 29, *then* Green_Time is 60 seconds. | *If* Arrival is 10 AND Queue is 29, *then* Green_Time is 27.7 seconds. |

As a conclusion, FLSC has been shown to perform better than FTSC. Particularly, the Green_Time which was varied depending on the traffic demand showed values less than 60 seconds at all three intersections.

## 5.0 CONCLUSION

In this study, an FL model was successfully constructed with the ability to optimise the best Green_Time for a traffic signal controller at a three-way junction on Jalan Sultan Abdul Samad, Banting. In addition, FLSC has shown to outperform FTSC in finding the best timing method. Results obtained were found to be more realistic since the Green_Time was computed with respect to a set of defined fuzzy rules and real-time traffic updates. More importantly, the model managed to produce all Green_Time values of less the time set for all FTSCs, namely 60 seconds.

An analysis was carried out to compare centroid method manually calculated results with MATLAB simulated results. Both techniques gave the same results. All Green_Time at all intersections were less than 60 seconds. Therefore, the main objective of this study to optimize Green_Time at all three intersections has been achieved.

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