Asian Journal of Business and Management (ISSN: 2321 – 2802)
Volume 05– Issue 01, February 2017

An Integrated Model to Control Traffic Lights: Controlling of Traffic Lights in Multiple Intersections using Fuzzy Logic and Genetic Algorithm

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ABSTRACT— ***In this paper we propose an integrated model combines Fuzzy Logic (FL) and Genetic Algorithm (GA), utilizing their applications in order to minimize the traffic congestion and traffic delay, through controlling traffic light system in three proposed traffic intersections. The proposed model in this paper will adjust the timing and phasing of the green traffic lights according to the current situation in the proposed traffic intersections; each intersection is supposed to be controlled by traffic signals that will apply the model. The green light interval time length shall provide at an intersection will be decided by FL. the outputs of FL will be optimized by GA, in order to obtain a higher performance. This performance can be measured considering the reduction in the waiting time and the total amount of vehicles that arrived to the Queue of the three intersections. The proposed model expected to provide a significant improvement to the traffic light system performance which might be very important to be applied in the metropolitan areas in Malaysia.***

Keywords— Traffic Light, Fuzzy Logic, Genetic Algorithm, Congestion, Malaysia.

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1. INTRODUCTION

Many developing Asian cities are finding it is difficult to cope with the growth of urbanization and increased car ownership. Traffic congestion is a growing problem in many metropolitan areas in Malaysia. Congestion increases travel time, air pollution, carbon dioxide (CO2) emissions and fuel use because cars cannot run efficiently. Studies by economists at the World Bank have shown that in 2014, economic losses due to traffic congestion in Greater Kuala Lumpur was estimated at 1.1 - 2.2% of GDP in 2014[1], The majority of this cost is associated with lost productivity, followed by wasted fuel costs and environmental damage caused by the tailpipe exhaust fumes from wasted fuel.

One of the best ways to eliminate traffic congestion is to control traffic flow through controlling traffic lights, in order to eliminate the conflicting traffic flows between the consecutive traffic intersections, and using intelligent traffic light system, Since an intelligent traffic light system is a major part of an intelligent transportation system, it is a challenge to increase the work efficiency of these traffic signals in order to reduce traffic jams and congestions as well as vehicle emissions in the metropolitan areas.

The current system of traffic light in many traffic intersection in Malaysia still using a conventional system which have been providing a fixed traffic control plan, this system is called "Preset Cycle Time (PCT) Controller" the setting for this kind of traffic lights is almost be done based on prior traffic counts, and mostly the setting can be manually changed, the disadvantage of this method that if there is a congestion in any roadway, the green light will not be extended, and the next phase will continue on time without considering the traffic density in any other junction [2].

Another common conventional traffic light system nowadays called Vehicle Actuated (VA) Controllers, in this method every road is built with only one magnetic sensor placed at the road end before the junction. The sensor is usually visible as a black rectangular line next to the traffic light in each road. This method works with three parameters: Initial Interval, Extension Unit and Extension Limit [3], if the phase turned to green light, the green phase will be expended by the extension unit while there are a cars crossing the junction, ones the extension limit is reached the traffic light will turned to red phase. This method also doesn't consider the traffic density in any other junctions, and doesn't give priority to the most congested road.

As the number of vehicles in Malaysia is increasing while the road system doesn't be improved well, therefore, the current traffic light system is not capable of solving the problem of congestion by using the same efficiency. Therefore it is very necessary to apply an intelligent traffic light system that overcomes the congestion and traffic jam. The traffic light system should be able to interact with congestion and thus help passengers, drivers, and products to reach their destinations quickly and safely. Which might save time, effort, and, minimize the transportation costs.

In this paper we propose an integrated model including a genetic algorithm (GA), and Fuzzy Logic (FL); in order to adjust the timing and the green phase of traffic light according to the current situation in multiple intersections; every intersection will be controlled by traffic signals. Thus, the model will decide how long the green light interval time shall be provided in each road at an intersection; in order to decrease the traffic congestion.

2. STATEMENT OF THE PROBLEM

The rapid population growth in Malaysia with depending on private cars for transportation has its impact on traffic congestion in the metropolitan areas; in the shade of using the current conversional traffic light system the traffic congestion problem get worst. The big challenge we face now is how to minimize the traffic congestion in the road system and to reach to smooth and safe traffic flow.

In order to elicit a fundamental diagnosis about traffic congestion problem in Malaysia, a cluster random sample has been selected using google forms technique. In this regard a survey has been conducted on 1360 respondents in Malaysia [[4]], the survey has revealed that 50.5% of the respondents in KL reported that the main problem in the traffic system that causes the high level of traffic congestion is "Inadequate green time in traffic lights" (table1), while 22.1% of them reported that traffic accidents in the road way what cause the high level of traffic congestion

These findings may support our idea to find the best way to manage the time in the traffic light system in order to minimize the waiting time.

Table 2: The most critical causes of traffic congestion problem in Malaysia

The most critical Transportation Problem	Kuala Lumper		Other		Grand Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Inadequate green time in traffic lights	301	50.5%	395	51.7%	696	51.2%
Road utility work	64	10.7%	80	10.5%	144	10.6%
The attitude of the driver on the road	99	16.6%	135	17.7%	234	17.2%
Traffic incidents	132	22.1%	154	20.2%	286	21.0%
Grand Total	596	100.0%	764	100.0%	1360	100.0%

Source: Filed survey

It is clear from (Table 2) that the majority of the population in Malaysia depends on privet cars as the main transportation method, where 53.6% of total respondents and 50.5% of those who live in KL revealed that they usually use private care for transportation, while only 29.5% of the respondents in KL reported that they use train for transportation.

In this sense the big number of private car users may minimize the capacity of the road system; this may also increase the level of congestion. so that this is very important to find good methods to manage the traffic flow density and to minimize the waiting time in the traffic lights.

Table 2: The Most Common Transportation Method Used

Kind of Vehicle Used	Kuala Lumper		Other		Grand Total	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Motorbike	52	8.7%	67	8.8%	119	8.8%
Private Car	301	50.5%	428	56.0%	729	53.6%
Public Bus	33	5.5%	42	5.5%	75	5.5%
Taxi	34	5.7%	31	4.1%	65	4.8%
Train	176	29.5%	196	25.7%	372	27.4%
Grand Total	596	100.0%	764	100.0%	1360	100.0%

Source: *Filed survey*

The aim of this study is to develop an integrated model to control traffic light System as an application for the management of traffic congestion which might be good method to be applied in the metropolitan areas in Malaysia.

3. OBJECTIVES

The objectives of this research are to introduce a proposed integrated model to achieve the following objectives:

1. Providing an efficient method for traffic flow management.
2. Organizing and optimize the green time interval for traffic light system.
3. Smoothing the traffic flow and eliminating the conflict between multiple consecutive traffic intersections.
4. Minimizing the traffic congestion in multiple consecutive intersections.

4. SCOPE OF THE WORK

Kuala Lumpur city is selected as a study area for assessing the traffic congestion. Kuala Lumpur is considered as the most affected area by traffic congestion (Figure 1-3) is depicting the road net-work of Kuala Lumpur, which provides data about real time road congestion right on the map. Red color shows block way, yellow color shows slow moving, and green color shows smooth flowing.

Figure 1: The road net-work in Kuala Lumpur (Source: Google Maps)

We will construct our model and assess the results on simulated data, and then the parameters of the model will be revised to adopt real situation in KL.

5. REVIEW OF RELATED WORK

Many researchers recently have focused on finding a new methods to control signals that adjust the timing and phasing of lights in order to minimize traffic congestion, some of these studies used one method like FL or GA, and few studies used hybrid model including these two methods; some studies focus on an isolated traffic intersection, and others focus on multiple intersection. Here we present some of these studies.

A two stage traffic light system for real-time traffic monitoring has been proposed by [5] to dynamically manage both the phase and green time of traffic lights for an isolated signalized intersection with the objective of minimizing the average vehicle delay in different traffic flow rate. There are two different modules namely traffic urgency decision module (TUDM) and extension time decision module (ETDM). A mathematical model representing the traffic control stochastic environment has been developed by [6]. The optimum/near optimum traffic signal timing values have been determined through the application of a genetic algorithm that feeds these values into a developed simulation model to obtain the corresponding queuing parameters. The generated signal timings significantly enhance the traffic performance and alleviate the choke points over a multiple-junction urban network. Optimization results show that the proposed model can improve the parameters of the vehicular flow. The chromosomes which represents the cycle time and the green split, is generated randomly in this model which might include some mistakes. A fuzzy logic for multi-agent based autonomous traffic lights control system was applied for to intersections by[7].The real time parameters such as traffic density and queue length are obtained by using image-processing techniques. [8] used a genetic algorithm and traffic emulator, developed in JAVA, to represent dynamic traffic conditions the high proportion of motorcycles. [9] proposed an optimal control of traffic lights using genetic algorithm (GA), in a four-way, two-lane junction with a pedestrian crossing to provide intelligent green interval responses based on dynamic traffic load inputs, they compared the performance between the genetic algorithms controller and a conventional fixed time controller and the results showed that the genetic algorithms controller performs better than the fixed-time controller..

6. METHODOLOGY

6.1 Introduction:

This study propose an integrated model including a genetic algorithm (GA), and Fuzzy Logic (FL); in order to adjust the timing and the green phase of traffic light according to the current situation in multiple intersections; the data about traffic density will be captured and collected using a placed observing camera to be used in our model. Every intersection will be controlled by traffic signals. Thus, the model will decide how long the green light interval time shall be provided in each road at an intersection; in order to decrease the traffic congestion. The proposed model expected to provide a good contribution to the current knowledge in this field.

In this study, both analytical and quantitative approaches are utilized. The analytical approach is utilized to analyze the performance of the Malaysian traffic system. The quantitative approach is used within an integrated transportation model framework utilizing Genetic Algorithm (GA) and Fuzzy Logic (FL) Methods.

Here we present the research methodology that was developed and followed in conducting this paper. We present also the methods that we use to construct our model, how we structured the model. We also present the model structure and the methods that we follow to collect the data

6.2 Traffic Flow Phases

Our proposed model will be applied for two bunches of traffic phases as it shown in Figure 2 in order to decide which bunch of traffic phases should be applied for the model to give optimal results.

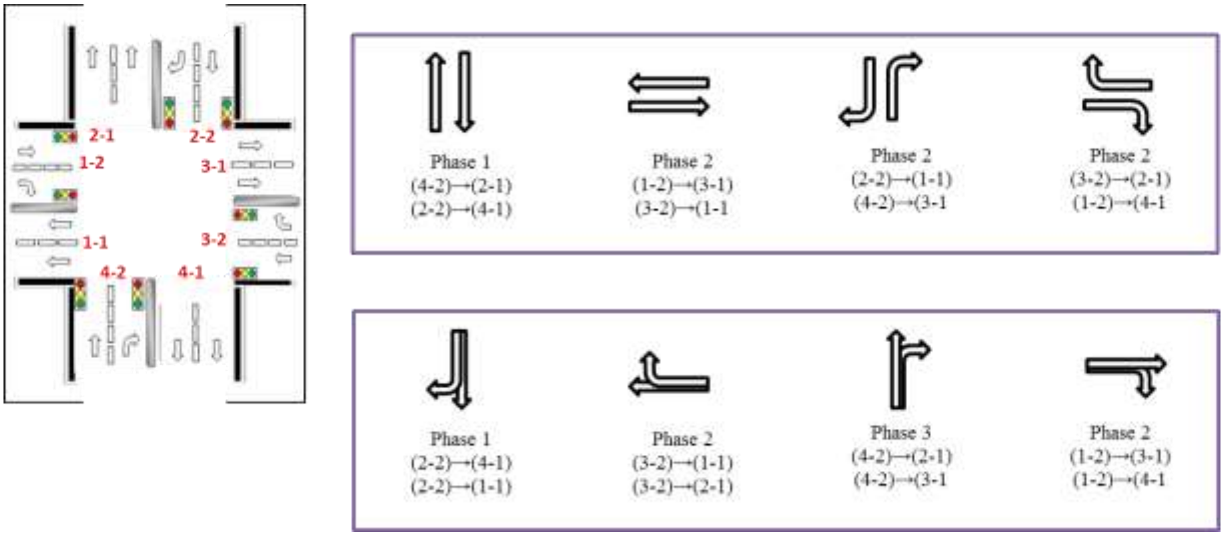

Figure 2: The typical intersection with Two Bunches of traffic Phases

6.3 Video image detection system:

The objects in the road will be defined by the Video image detection system as vehicles moving or stopping on the roads. The different sizes of the vehicles that use the road can be observed and counted. The basic algorithm starts with a pre-image processing step, consisting of digitization and segmentation. The next step is called video segmentation which can be defined as the following: given a scene of the road without any object captures this frame as a reference frame, which will be considered as background to our video segmentations that may contain one or more objects. The algorithm has four major functions, the first one is convert the video segmentation into frames and select the last frame and will call it current image, the second function is convert the current image to black and white in order to prepare for boundary tracing and remove the noise by using morphology functions. The third function subtracts the background from the current frame. The last function counts all distinct objects in the image [1].

The model will be applied to manage three intersections, A, B, and C, with distance 200 m between each two intersections; each intersection is controlled by a smart traffic light, each intersection consists of four roads, and each road consists of three directions (Straight, Left, and Right). The model is assumed to be used in the most congested areas so we assume that for all directions in all intersections there should be a number of vehicles that will travel in the same speed 40 km/h.

6.4 Fuzzy Logic FL

In this proposed model, the input data of the number of vehicles on each lane of the road in each intersection will be taken from a video object detection system. The data will be treated by fuzzy logic that is characterized by a set of rules which defined antecedent.

There are two inputs representing the number of vehicles in the same lane and the number of vehicles in the affected lane. For example, the number of vehicles at lane 2 on intersection B Figure 1 will affect the number of vehicles on lane 4 in intersection A. However, in other cases, there will be three inputs because of the existence of two affected lanes, such as (C1) the number of vehicles at lane 1 of the intersection C which will have an effect on (B1) the number of vehicles at lane 1 in intersection B and also (A4) the number of vehicles at lane 4 in intersection A. In this case the fuzzy logic system will work in two stages: Fuzzy Logic Controller FLC1 will be done for the first two inputs; then the output of this (FLC1) will be considered as an input for the second stage of FLC2 including the third input.

Figure 3 shows the structure of the system composed of FLC1 and FLC2; FLC1 has two inputs that represent C1 and B1, respectively, and FLC2 has also two inputs In (A4) and the output of FLC1 that represent the green light time interval for the signal at C1. The output of FLC2 represents the final decision of green light time interval for a signal B1.

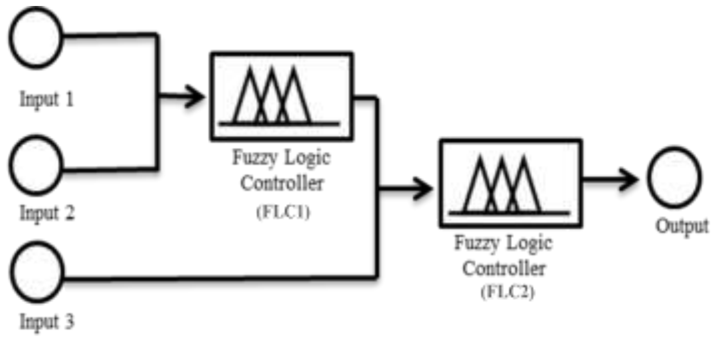

Figure 3: Structure of fuzzy Logic controllers FL

Fuzzy logic rules include all possible scenarios for each traffic jam in every intersection; finally we can get two outputs from fuzzy logic model, the cycle time and green light time for each lane in each intersection. Then GA is applied to optimize the best performance of FLC.

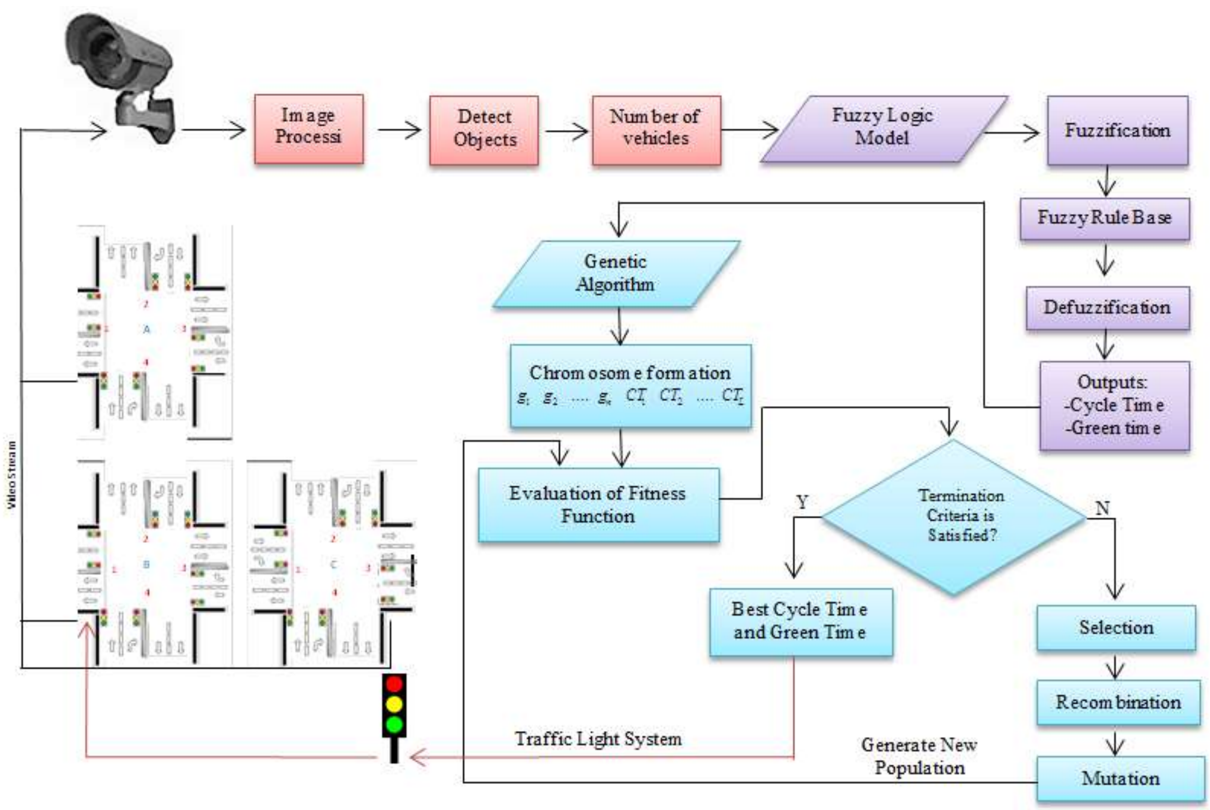

Figure 4: Flow Chart of the Model

6.5 Genetic Algorithm GA

Each chromosome is composed of (n) genes representing (i+k) decision variables. These are the green splits and the cycle times of the junctions in the road network which have been generated in fuzzy logic model. The chromosome size depends on the number of feasible states (i) and the number of intersections in the road network (k) which we assume three as three intersections in our paper. The fitness function of each chromosome, the same as the objective function in the mathematical model (Equation 1), is evaluated. The chromosomes are then ranked according to their normalized fitness values. As stated earlier, the chromosome size depends on the size of the road network under study. then the model check, if termination criteria is satisfied, which means either the predefined maximum number of generation have reached or fitness function is not satisfied, If the termination criteria are not satisfied; selection is performed from the given population to obtain fitter parents, which can lead to fitter sons. These parents, thus selected are mated to produce fitter children and this phenomenon is called crossover or recombination. Some mutation is performed for example some bits of children are altered from the above result. After mutation we have a new set of generation, now go back to evaluating the fitness function. If the termination criteria are satisfied, get the solution.

The result is received from GA is the green extension times for all roads. These extension times are added with predefined fixed green times and applied to the traffic light system.

6.6 Mathematical Model

We use the structure of [[10]] model, The characteristic of objective function, as shown in Equation 1, is non-linear function which includes two performance metrics: Queue Length and vehicular waiting time. Queue Length and Waiting time Equations 5 and 6 compute the maximum values of Queue Length and Waiting time occurring for each control point (j) in junction (k) at period (p). The maximum value in this array is considered as the objective function to be minimized.

The decision variables are the green splits of each state (i) and the cycle time of each junction (k) in the network at different periods, denoted by g_{ikp} which represent the proportion of state (i) from the total cycle time of the junction (k), and CT_{kp} which can be counted as the sum of all the state timings occurring at that junction, which also must equal the green and red signal timings for control point (j) in the network, as shown in Equation 4. Equation 7 and 8 determine the average of the maximum queue length and waiting time over a specified period (p); the rest model equations 9-11 are set of hard constraints.

Objective **Minimize:** $$Z = Max\{LQ_{\max jkp} * WQ_{\max jkp}\} \qquad \forall j,k,p$$ **Equation 1**

Z

$LQ_{\max jkp}$ Maximum Vehicular Queue Length for control point (j) in junction (k) at period (p)

$WQ_{\max jkp}$ Maximum Vehicular waiting time for control point (j) in junction (k) at period (p)

Subject to $$T_{ikp} = g_{ikp} * CT_{kp} \qquad \forall i,k,p$$ **Equation 2**

T_{ikp} State timing interval of state (i) in junction (k) at period (p)

g_{ikp} Green Split of state (i) in junction (k) at period (p) $0 \le g_{ikp} \ge 1$

CT_{kp} Cycle Time of junction (k) at period (p)

$$CT_{kp} = \sum_{i=1}^{N} T_{ikp} \qquad \forall k,p$$ **Equation 3**

CT_{kp} Cycle Time of junction (k) at period (p)

$$CT_{kp} = \sum_{i=1}^{N} S_{ijkp} \qquad \forall i,k,p$$ **Equation 4**

CT_{kp} Cycle Time of junction (k) at period (p)

S_{ijkp} Current Signalization Setting (Green/Red) within a state (i) for a control point (j) in junction (k) at period (p)

$$LQ_{\max jkp} = Max\{\ Max(\ A_{jkp} - D_{jkp}\ ),0\ \} \qquad \forall i,k,p \qquad \textbf{Equation 5}$$

$LQ_{\max jkp}$	Maximum Vehicular Queue Length for control point (j) in junction (k) at period (p)
A_{jkp}	Dynamic Arrival inflow at control point (j) in junction (k) at period (p)
D_{jkp}	Dynamic Dissipation outflow at control point (j) in junction (k) at period (p)

$$WQ_{\max jkp} = Max\{\ Max(\ TD_{vjkp} - TA_{vjkp}\ ),0\ \} \quad \forall i,k,p \qquad \textbf{Equation 6}$$

$WQ_{\max jkp}$	Maximum Vehicular waiting time for control point (j) in junction (k) at period (p)
TA_{vjkp}	Arrival time of vehicle (v) at control point (j) in junction (k) at period (p)
TD_{vjkp}	Departure time of vehicle (v) at control point (j) in junction (k) at period (p)

$$\overline{LQ_P} = \frac{1}{\sum_{K=1}^{L} jkp} * \sum_{k=1}^{L}\sum_{j=1}^{M} LQ_{\max jkp} \qquad \forall p \qquad \textbf{Equation 7}$$

$\overline{LQ_P}$	Average of Maximum queue lengths for a period (p)
j	Control Point index, where $1 \le j \le M$
k	Junction index, where $1 \le k \le L$
p	Period index, where $1 \le p \le H$

$$\overline{WQ_P} = \frac{1}{\sum_{K=1}^{L} jkp} * \sum_{k=1}^{L}\sum_{j=1}^{M} WQ_{\max jkp} \qquad \forall p \qquad \textbf{Equation 8}$$

$\overline{WQ_P}$	Average of Maximum vehicular waiting times for a period (p)

$$T_{\min} \le T_{ikp} \le T_{\max} \qquad \forall i,k,p \qquad \textbf{Equation 9}$$

$T_{\min}$	Lower bounds for a state timing.
T_{ikp}	State timing interval of state (i) in junction (k) at period (p)
$T_{\max}$	upper bounds for a state timing.

$$CT_{\min} \le CT_{kp} \le CT_{\max} \qquad \forall k,p \qquad \textbf{Equation 10}$$

$CT_{\min}$	Lower bounds for a junction’s cycle time.
CT_{kp}	Cycle Time of junction (k) at period (p)
$CT_{\max}$	upper bounds for a junction’s cycle time.

$$\sum_{i=1}^{N} g_{ikp} = 1 \qquad \forall i,k,p \qquad \textbf{Equation 11}$$

g_{ikp} Green Split of state (i) in junction (k) at period (p)

7. EXPECTED RESULTS

We intend to expand our proposed model, so Neural Network NN method, and simulation model will be added in order to make it more robust; The validity of the model will be checked at the first using simulation model that it will be applied in MATLAB code; finally we can apply our model in Kuala Lumpur city, using the real time data using the observing camera and strategically placed ultra-sonic sensors.

With applying and testing this proposed model we expect to get the following outcomes:

- Optimal traffic lights' timing control at the targeted traffic intersections.

- Eliminated conflict between multiple consecutive traffic intersections

- Eliminated Traffic congestion with Smooth traffic flow of vehicles.

- Applying an accurate model for traffic is close to reality, using a real time data captured by the observing camera system; which might be adjustable to be applied in Malaysian traffic light system.

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