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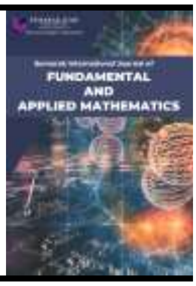

Prediction and Traffic Light Control Performance Using Fuzzy Logic at Intersections of Road

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ABSTRACT

The rapid expansion in the number of vehicles in Malaysia has resulted in a high traffic density on the country's roadways, which has become a significant challenge for Malaysia's road traffic planners. In its current configuration, the traffic light system in Malaysia makes use of a fixed timer system, which is comprised of timing signal controllers and adaptive signal controllers. It is calculated based on the statistics of the peak hour and the time is kept consistent even during the non-peak hours. Number of how many cars are on the road or how wide the road is, this one standard green time that had been used at each intersection throughout the day. This strategy was result in a significant amount of time spent waiting at junctions since the green traffic light will be on for an extended period of time even though there are just a few vehicles on the road. Therefore, the purpose of this research is to study traffic signal control problems with the fuzzy logic control method according to number of vehicles as to investigate the traffic signal control performance at intersections and analyze queue length and congestion at intersections and throughout the road network by improving intersection quality. The classification of the number of cars, road width, and amount of time it takes for vehicles to move at crossings that was recommended in an earlier work had been accomplished by using fuzzy logic rules. A numerical example from a case study had been used to highlight the ability and feasibility of the method. The amount of time spent waiting at intersections on each road was determined with the help of fuzzy logic and a traffic controller formula. The new schedule has times that are proportional to the number of cars and the width of the road. Comparisons were made, and the results demonstrate that the timing of the green light that was achieved is suitable for the two elements that were taken into consideration. Additionally, the amount of time spent waiting for vehicles during each traffic cycle was cut down.

1. Introduction

The rapid expansion of metropolitan areas has led to an increase in traffic congestion in most modern cities. There is a growing consensus that a rise in the global automobile population is a key

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contributor to urban congestion. This circumstance has been a contributing factor in the rise in the number of cars on the road, which has led to an increase in both pollution and traffic congestion.

According to the data statistics from the Malaysia Automotive Association, the number of new passenger and commercial vehicles registered in Malaysia for the year 2010 to Year to Date (YTD) September 2022 is increasing day by day [1]. This trend is expected to continue until the end of the period, which is September 2022 [1]. Congestion in our country is only going to get worse if the number of people using our roads continues to grow at its current rate. Therefore, to prevent this scenario from occurring, the government needs to think about the best solution, which is an optimal traffic signal control strategy.

Currently, the traffic light system in Malaysia makes use of a fixed timer system, which are timing signal controllers and adaptive signal controllers. The system function depending on the time that was expected to operate be the fixed timer system. There is not much variation in the timing of the green and red phases. This method is not fit for usage since it produced congestion at every intersection if there is even a slight shift in the flow of traffic or an increase in the number of vehicles. This occurs because the timer on the system does not relate to the flow of traffic.

A varied pattern of traffic can be expected throughout the day outside of these peak hours as well as on weekends. Because of this, the amount of time spent waiting at crossroads with fewer vehicles will be significantly increased. As a result, it is envisaged that by adjusting the length of the green light in accordance with the number of vehicles, the amount of time spent waiting will be substantially decreased.

In order to increase comfort and safety of the driving experience as well as reducing fuel consumption and emissions to mitigate the environmental impact, some researcher developed intelligent traffic light system using traffic-light-to-vehicle communication (TLVC) [2]. While another researchers are using hardware such as IR and ultrasonic sensor [3], wireless communication [4], and microcontroller [5] to detect and compute amount of traffic. Meanwhile others are developing special algorithm to tuning and optimize the traffic light timing [6-9]. Since traffic problem is a real world problem and are based on ambiguity, uncertainty and impression, fuzzy logic is more beneficial to reduce and solve road traffic problems [10].

In this study, fuzzy logic and a traffic controller formula had been used to establish the timing of the traffic lights at each junction, which be one standard time that is utilized throughout the day. This help prevent problems like the one described above from occurring. The volume of traffic on the road fluctuates throughout the day, with the highest volume occurring in the morning as office workers make their way to work, followed by business traffic in the middle of the morning, lunch traffic, and finally traffic made up of people heading home from work.

This research aims to study traffic signal control problems with the fuzzy logic control method, to investigate the traffic signal control performance at intersections and to analysis queue length and congestion at intersections and throughout the road network by improving intersection quality.

The choice of fuzzy logic output depends on its input which is the number of vehicle and the road width. The linguistic variable for each input is divided into 3 groups which is few, moderate many and wide, medium, narrow and therefore the duration time for green light will be divided into 4 groups which is very short, short, long ang very long. This approach discussed and applied via a case study. This paper ends with concluding remarks based on the findings of the case study.

2. Literature Review

Preliminaries: In this section, some basic definitions and a brief description related to the theoretical concept in the proposed methodology are reviewed and were utilized in the rest of the paper.

2.1 Development of the Road

The development of roads in Malaysia dates to well before the country's independence. Prior to the year 1957, there was a road network that connected Johor Bahru in the south with Kangar in the north and Kota Bharu on the East Coast. This road network served the purpose of connecting the major cities of the country. Following the nation's attainment of its independence in 1957, efforts have been made to effectively enhance the road system. This has been accomplished by fast development planning, most notably the Malaysia Plan every five years, which has been initiated by the Federal Government [11].

2.2 Traffic Light Background

Wagons and pedestrians were the initial users of traffic lights when they were first invented, therefore the original aim of traffic lights was to regulate their movements. In today's world, a single traffic light can serve numerous purposes, including as a pedestrian crossing signal, an intersection crossing signal, and so on. Before the advent of traffic lights that used electric light, the first traffic light was a gas lantern that displayed the colours red and green on opposite sides of the lantern [12].

J.P. Knight, a railroad engineer, is the one who comes up with the idea for the first traffic signal. J.P. Knight was the inventor of the first gas lantern-powered traffic light, which he named after himself. This traffic light is operated manually by a law enforcement officer using a lantern that is attached to a lever located at the foot of the post. The lever will be triggered by a member of the police department to manage the flow of traffic. The type of lantern that was utilised during that period was red and green, and it was quite like the traffic light that we use now. When you saw the colour red, it indicated "stop," and when you saw the colour green, it meant "go." These days, there are three colours for the traffic light: green for "go," red for "stop," and yellow for "ready to stop or ready to go." Green means "go," red means "stop," and yellow means "ready to halt or ready to go" [12].

The contemporary traffic light system has several different electrical components, which has allowed it to become more flexible in terms of timing signals, as well as in terms of adjusting the phase duration and sequence. In a contemporary traffic light system, the controller can operate in one of three different modes: pre-timed, semi-actuated, or fully actuated. These modes are described below. When a traffic signal is pre-timed, the timing of the light is set in stone, and the timer does not move in response to changes in the flow of traffic. When the system is in semi-actuated mode, the timing of the traffic signals will impact when a vehicle is identified in some approaches, but not all of them. When in fully actuated mode, the timing of the traffic signal is totally controlled by the flow of traffic, as determined by the detection of vehicles, on all of the approaches.

During the years 1977 and 1978 in Malaysia, advancements in traffic light technology allowed Kuala Lumpur to be managed by a Philips traffic controller. This allowed for significant improvements in the city. Pre-timed mode and semi-actuated mode are the two kinds of traffic signal controller modes that are utilised the most frequently in Malaysia.

2.3 Fuzzy Logic

Fuzzy logic has developed into a valuable extension and necessary supplement of the traditional bi-valued logic of Aristotle, and its applications now cover almost the entire spectrum of human activities. This is because fuzzy logic was originally developed as an extension of traditional logic, which was based on two values. The idea of fuzzy sets was first presented by Zadeh in 1965, and since then, this new logic of infinite values has been rapidly developing. Its foundation is the fuzzy set concept [13].

The concept of fuzzy logic was first proposed in 1965 by Zadeh [14]. Fuzzy logic was not, however, recognized in academic circles since part of the mathematics that underlies it had not yet been investigated. However, fuzzy logic was used or implemented in Japan's product, which led to a resurgence of interest in the concept of fuzzy logic in the United States because of Japan's product. The reasoning process of humans is modelled after the process of fuzzy logic. Problems that arise in everyday life may be solved with the help of fuzzy logic technology, which employs reasoning methods that are analogous to human thought [13]. Since, the traffic congestion is based on ambiguity, impression & uncertainty and these parameters may be dealt with fuzzy logic. Moreover, this problem can be characterized by Linguistic variables proposed by Zadeh [15].

2.4 Linguistic Variable and Fuzzy If-Then

According to Zadeh [15], a linguistic variable is defined as a variable whose values are words or sentences in a natural or artificial language. This definition applies whether the language in question is human-created or not. For example, the number of cars is a linguistic variable since its values can be interpreted in a variety of ways, including few, moderate, many and so on in addition to the numbers 19, 35, and 55.

Like sets, but with constituents that might have varying degrees of membership, fuzzy sets also exist. Zadeh wrote, with reference to Zimmermann, that the concept of a fuzzy set provides a convenient point of departure for the development of a conceptual framework that parallels in many respects the framework employed in the case of ordinary sets but in a more general way and, hopefully, can influence a wider scope of applicability, within the fields of pattern classification and knowledge processing. Zadeh's writing was based on Zimmermann's research [16].

Linguistic variables are variables whose values are words or phrases in a natural or artificial language. Linguistic variables can be used with both natural and artificial languages. Each of these linguistic variables can be associated with one or more linguistic values; alternatively, they can be related to a numeric value by way of the membership function mechanism. It can also be understood in accordance with the alternative definition, which describes it as a variable whose values can be words derived from natural language. The fuzzy sets that have been defined within the universe of speech in which the variable has been established serve to characterize the words.

There are two types of fuzzy proposition which is atomic fuzzy proposition and compound fuzzy proposition. An atomic proposition is a single statement which is $x\ is\ A$, where x is a linguistic variable, and A is a linguistic value of x while A compound fuzzy proposition is a composition of atomic fuzzy proposition using the connectives ”and”, ”or”, and ”not” which represent fuzzy intersection, fuzzy union, and fuzzy complement, respectively.

2.5 Mamdani-Fuzzy Logic

In Mamdani fuzzy logic system, crisp input is converted into crisp output through the application of fuzzy logic and other reasoning processes. Figure 1 illustrates the primary components of the Mamdani fuzzy logic system, which include a "fuzzification" component, a "inference engine" component, and a "defuzzification" component. The decision-making process in a Mamdani-fuzzy logic system is known as rule-based since it uses an IF-THEN structure [17].

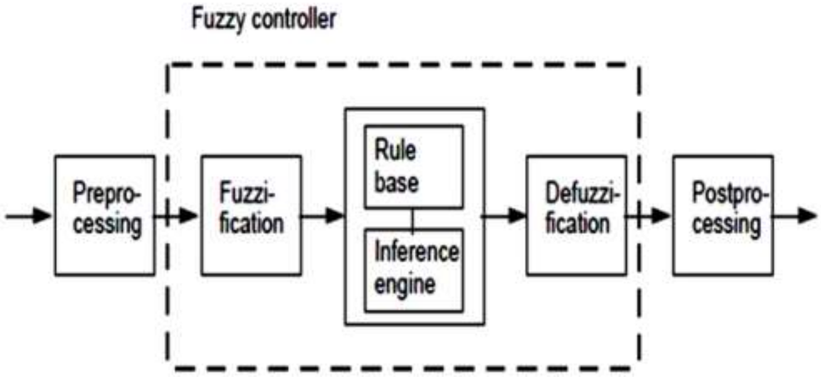


Fig 1. Fuzzy structure logic system

The fuzzy set output is created by the fuzzification step, which takes the crisp input and makes it fuzzy. The method of fuzzification known as singleton fuzzification is the one that is employed most frequently in strategy. After that, the role of the inference section is to establish the extent to which each rule in the rule base applies in the current scenario and to construct a corresponding implied fuzzy set for each rule. This is done by forming a corresponding fuzzy set for each rule. In addition, an implied fuzzy set is computed for every rule using the results of this calculation. Last but not least, the function of the defuzzification phase is to combine the inferred fuzzy sets of all of the rules in order to provide a clear result [18].

2. Methodology

2.1 Research Design and Procedure

When conducting this research, it is essential to determine the steps that need to be taken in order to accomplish the goals. In the beginning, the definitions, fundamental concepts, and theory regarding fuzzy logic, the rule of fuzzy logic, traffic lights, and intersections are investigated in order to acquire a deeper comprehension of the research topic. In spite of that, the site must be situated at a four-way intersection, with roads leading in from all four cardinal directions (north, west, south, and east). In addition, the input and output criteria for fuzzy logic, such as the number of vehicles, road width, and green time, need to be determined. Following this step, the fuzzy rule recommendations for the green light was figured out after the fuzzy logic and output criteria have been established. The formula is then used to calculate the amount of time until the green light turns on. In this study, MATLAB were used to develop fuzzy logic system based on Mamdani-Type Fuzzy Interference. Fuzzy logic controllers were used to find the green light time. Below shown is the step for the work:

Step 1: Determine the fuzzy logic Input and Output for each Data.

Step 2: Isolated four-way junction with traffic coming from the north, west, south, and east directions.

Step 3: Define the linguistic variable for each Input and Output.

Step 4: Obtain the degree of membership function namely road width and number of vehicles using MATLAB (refer Table 1 until Table 3).

Table 1
Linguistic variable for each function

Functions	Criterion	Fuzzy construction
Input	Number of vehicles	Few
		Moderate
		Many
	Road width	Wide
		Medium
		Narrow
Output	Duration time for green light	Very short
		Short
		Long
		Very Long

Table 2
Fuzzy logic input for Number of vehicles

No	Linguistic variable	Number of vehicles (units)
1.	Many	40 – 70
2.	Moderate	20 - 39
3.	Few	0 – 19

Table 3
Fuzzy logic input for Road width coefficient factor

No	Linguistic variable	Road width coefficient factor
1.	Wide (1m - 4m)	1
2.	Medium (3m – 8m)	2
3.	Narrow (7m-15m)	3

Step 5: Determine green time using fuzzy rules and vehicle movement time (refer Table 4).

Table 4
Fuzzy logic input for vehicle movement time

No	Linguistic variable	Vehicle movement time
1.	Car	1.86s
2.	Bus	2.58s
3.	Lorry & Truck	3.77s

Step 6: Collect the data for green time at study case.

The "IF-THEN" circumstances act as a framework for the construction of the fuzzy logic rule. The "IF-AND-THEN" expression is used to determine each one of the adaptable rules that are used for controlling the system. The fuzzy logic design rule for the duration time for green phase is specified in Table 5. The possible rules have been established for the purpose of effectively implementing fuzzy logic in the green branch module.

For example:

IF number of vehicles on Branch is Few AND
road width on Branch is Wide.
THEN green time for branch is Very Short.

Table 5
The Fuzzy Rule Recommendations for the green light

IF	Number of vehicles in branch	AND	The road width	THEN	Green time
IF	Few	AND	Wide	THEN	Very short
IF	Few	AND	Wide	THEN	Short
IF	Few	AND	Wide	THEN	Long
IF	Few	AND	Wide	THEN	Very long
IF	Few	AND	Medium	THEN	Very short
IF	Few	AND	Medium	THEN	Short
IF	Few	AND	Medium	THEN	Long
IF	Few	AND	Medium	THEN	Very long
IF	Few	AND	Narrow	THEN	Very short
IF	Few	AND	Narrow	THEN	Short
IF	Few	AND	Narrow	THEN	Long
IF	Few	AND	Narrow	THEN	Very long

Step 7: Calculate green time for the road based on traffic controller. To calculate the green light time signal, traffic controller calculations need to be considered:

$$\gamma = \frac{NV}{Road\ width\ coefficient\ factor} \times NWHS \tag{1}$$

where, $\gamma = Green\ Time\ in\ seconds$, $NV = Total\ numbers\ of\ vehicles$, $NWHS = average\ movement\ of\ vehicle$

Step 8: Calculate the comparison between collected data with traffic controller formula for green times.

Step 9: Repeat the process.
Figure 2 below shows the flow of methodology for this study.

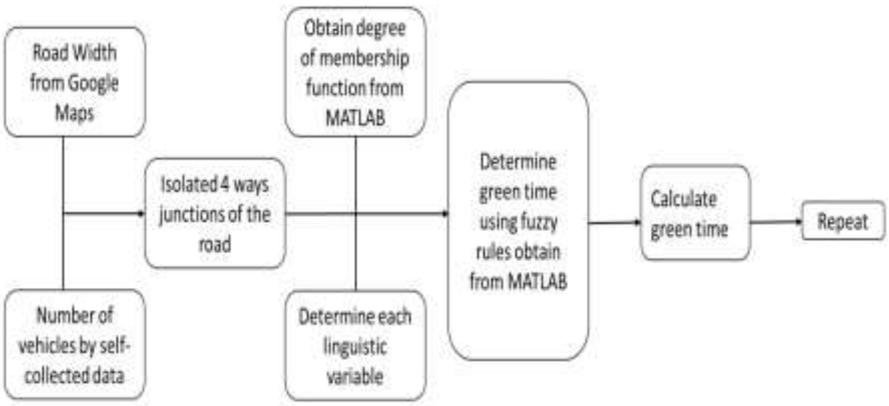


Fig 2. Research framework

3. Results

The collected data at two different places which is Kuala Terengganu, Terengganu and Marang, Terengganu were evaluated. Data collected from Kuala Terengganu intersection are tabulated in the tables below. The number of vehicles that pass through and the length of time that the green lights are on are both recorded, and the width of the road is determined using Google Maps. The findings of the calculation of the number of vehicles at the intersection were recorded during morning and afternoon.

3.1 Inspection Conducted at the Kuala Terengganu Intersection

The Kuala Terengganu has four branches, and the road width on branch 1 is 12.46 meters, branch 2 is 7.69 meters, branch 3 is 7.21 meters and branch 4 measures 11.43 meters. These measurements were taken from Google Maps. According to Table 3, each of the four distinct paths has a road width coefficient factor of 3 and 2. The data collection took place in the morning and afternoon, as shown in Table 6 and Table 7 below.

Table 6
Data at Kuala Terengganu Intersection in the morning

No.	Details	Branch 1	Branch 2	Branch 3	Branch 4
	Road width with coefficient factors	12.46 (3)	7.69 (2)	7.21 (2)	11.43 (3)
1	No. of vehicles	27	25	31	34
	Green time	60	57	82	83
2	No. of vehicles	42	43	37	25
	Green time	93	90	77	63
3	No. of vehicles	36	27	21	25
	Green time	73	57	56	53

Table 7
Data at Kuala Terengganu Intersection in the afternoon

No.	Details	Branch 1	Branch 2	Branch 3	Branch 4
	Road width with coefficient factors	12.46 (3)	7.69 (2)	7.21 (2)	11.43 (3)
1	No. of vehicles	47	36	35	41
	Green time	63	52	53	63
2	No. of vehicles	42	43	32	33
	Green time	67	67	53	50
3	No. of vehicles	23	23	37	25
	Green time	48	48	73	53

3.2 Inspection Conducted at the Marang Intersection

The Marang intersections are divided into four branches; the road width on branch 1 is 10.72 meters, the road width on branch 2 is 6.86 meters, the road width on branch 3 is 10.02 meters, and the road width on branch 4 is 7.29 meters. These distances of all four widths were calculated by using Google Maps. According to Table 3, each of the four separate routes has a road width coefficient factor that falls somewhere between 3 and 2 which is branch 1 is 3, branch 2 is 2, branch 3 is 3 and branch 4 is 2. As can be seen in Table 8 and Table 9 below, the data collection took place first is in the morning and then again in the afternoon.

Table 8
Data at Marang Intersection in the morning

No.	Details	Branch 1	Branch 2	Branch 3	Branch 4
	Road width with coefficient factors	10.72 (3)	6.86 (2)	10.02 (3)	7.29 (2)
1	No. of vehicles	43	37	51	31
	Green time	90	80	90	62
2	No. of vehicles	45	38	44	29
	Green time	90	80	90	62
3	No. of vehicles	41	31	45	20
	Green time	90	80	90	62

Table 9
Data at Marang Intersection in the afternoon

No.	Details	Branch 1	Branch 2	Branch 3	Branch 4
	Road width with coefficient factors	10.72 (3)	6.86 (2)	10.02 (3)	7.29 (2)
1	No. of vehicles	32	32	27	23
	Green time	90	80	90	62
2	No. of vehicles	45	37	45	13
	Green time	90	80	90	62
3	No. of vehicles	43	25	47	13
	Green time	90	80	90	62

Once the data was collected, then the Equation from step 7 was used to compute the amount of time spent in the green state for each branch based on table below. The variation in the amount of time spent in the green time utilizing in “Kuala Terengganu and Traffic Controller” and “Marang and Traffic Controller” in the morning and afternoon were presented in Table 10 until Table 13. It was also showed how long the waiting time difference for all branches during each cycle.

According to the findings presented in the tables above, the fuzzy traffic controller achieves better results than the pre-timed controller does in terms of cycle length. The length of one cycle in the fuzzy logic controller's changing process is determined by the volume of traffic. The length of the cycle will be shorter if there is a low traffic flow rate and will rely on the traffic flow regardless. Considering these findings, the amount of time that cars spend waiting in in the morning will be cut by a range of -67% to +37% while in the afternoon will be reduced by between -6% and -68% in comparison to the time that they spent waiting under the pre-timed system.

Table 10
Comparison at Kuala Terengganu during morning

No.	Branch	Green time		% Difference in green time	Waiting time	
		KT	TC		KT	TC
1	1	60	24.57	-59	0	0
	2	57	34.13	-40	60	24.57
	3	82	42.32	-48	117	58.70
	4	83	30.94	-63	199	101.01
2	1	93	38.22	-59	0	0
	2	90	58.70	-35	93	38.22
	3	77	50.51	-34	183	96.92
	4	63	22.75	-64	260	147.42
3	1	73	32.76	-55	0	0
	2	57	36.86	-35	73	32.76
	3	56	28.67	-49	130	69.62
	4	53	22.75	-57	186	98.28

Table 11
Comparison at Kuala Terengganu during afternoon

No.	Branch	Green time		% Difference in green time	Waiting time	
		KT	TC		KT	TC
1	1	63	42.77	-32	0	0
	2	52	49.14	-6	63	42.77
	3	53	47.78	-10	115	91.91
	4	63	37.31	-41	168	139.69
2	1	67	38.22	-43	0	0
	2	67	58.70	-12	67	38.22
	3	53	43.68	-18	134	96.92
	4	50	30.03	-40	187	140.60
3	1	48	20.93	-56	0	0
	2	48	31.40	-35	48	20.93
	3	73	50.51	-31	96	52.33
	4	53	22.75	-57	169	102.83

Table 12
Comparison at Marang during morning

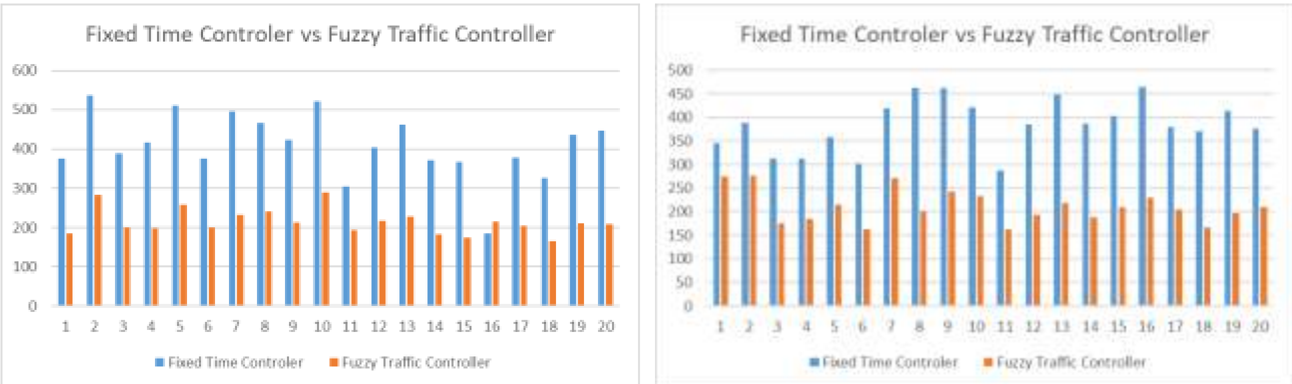
No.	Branch	Green time		% Difference in green time	Waiting time	
		KT	TC		KT	TC
1	1	90	39.13	-57	0	0
	2	80	50.51	-37	90	39.13
	3	90	46.41	-48	170	89.64
	4	62	42.32	-32	260	136.05
2	1	90	40.95	-55	0	0
	2	80	51.87	-35	90	40.95
	3	90	40.04	-56	170	92.82
	4	62	39.59	-36	260	132.86
3	1	90	37.31	-59	0	0
	2	80	42.32	-47	90	37.31
	3	90	40.95	-55	170	79.63
	4	62	27.30	-56	260	120.58

Table 13
Comparison at Marang during afternoon

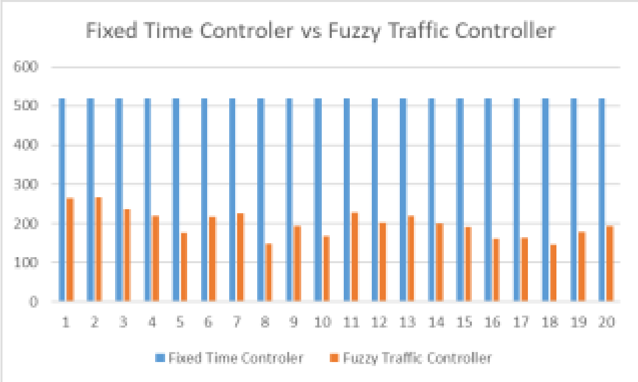
No.	Branch	Green time		% Difference in green time	Waiting time	
		KT	TC		KT	TC
1	1	90	29.12	-68	0	0
	2	80	43.68	-45	90	29.12
	3	90	24.57	-73	170	72.80
	4	62	31.40	-49	260	97.37
2	1	90	40.95	-55	0	0
	2	80	50.51	-37	90	40.95
	3	90	40.95	-55	170	91.46
	4	62	17.75	-71	260	132.41
3	1	90	39.13	-57	0	0
	2	80	34.13	-57	90	39.13
	3	90	42.77	-52	170	73.26
	4	62	17.75	-71	260	116.03

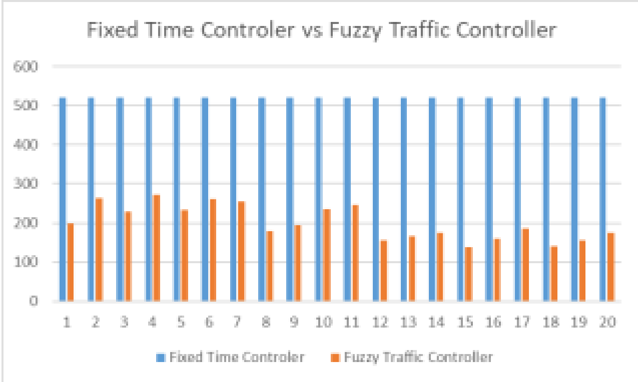
The tables indicate that the fuzzy traffic controller outperforms the pre-timed controller when measuring performance in terms of cycle length. Fuzzy logic controllers have a variable cycle time that is proportional to the volume of traffic. The cycle time will be shorter when the volume of traffic is low, and vice versa. As a result, this will cut vehicle waiting times in each branch by -32% and -87% in the morning while in the afternoon will be reduced by between 37% to 87% percent, relative to the time spent waiting in the pre-timed system.

According to the all Figure 3 below, the results of the comparison between a controller that uses a fuzzy logic system and a fixed-timed controller indicate that the performance of the fuzzy traffic controller is better to that of the fixed-timed controller. The fuzzy traffic controller has the potential to give reduced waiting times and deliver large capacities per lane.



(a)





(b)

Fig. 3. Fixed time controller vs fuzzy traffic controller for (a) Kuala Terengganu, (b) Marang during morning (left) and afternoon (right)

4. Conclusions

The results from the collecting data were implementation with the fuzzy logic controller to compare the performance of the system with pre-timed system. The results were collected at different places to see the different traffic conditions. The traffic light system with a fuzzy logic controller, performs better than the traditional method which is pre-timed system or fixed timer system based on the flexibility of the system. The system is able to adapt to real time traffic conditions and can change the timing for traffic signal based on traffic conditions and reduce the waiting time of green light based on whatever traffic condition at the junction. From the results, it can be observed that the fuzzy logic controller has better performance in terms of cycle length, waiting time and at once can increase the capacity per lane. The system with fuzzy logic controller can minimize waiting time and delay time while increasing the capacity of vehicle pass through the intersection. The developed system can benefit local municipalities in providing a traffic light system that can ensure smooth and efficient traffic flow at road intersections. It also can reduce fuel consumption and reduce air and noise pollution with less waiting time.

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