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Traffic Signal Control Using Fuzzy Logic

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***Abstract*— Bangkok has been mentioned as a city that is growing rapidly which has caused changes in the social structure extensively. The expansion area of the city has been extended fragmentally based on basic infrastructure, the transportation infrastructure cannot support the growth of the economy and the rapid increase in population. The rapid changing environment of traffic has impacted and lead to the problem of traffic congestion. Due to the problem of traffic congestion, this research has conducted a model of traffic intersection for traffic congested areas using the micro-level modeling program (VISSIM). This is achieved by applying a casual predictive fuzzy logic model which has automatic comparison ability depending on the changing environment. The results of this research may lead to revised guidelines of the appropriated traffic light control which should reduce traffic congestion in Bangkok.**

Keywords—traffic; signal control; fuzzy logic; Takagi Sugeno and Kang (TSK).

I. INTRODUCTION

Concept of the application of fuzzy logic has been very active in the field of computer research. It has been applied in various applications such as military, medical, industrial, etc., which are unique. It has abilities to compare the system and automate the environment changes. Fuzzy logic has been distinguished in the computer industry as similar logic to that of humans. It can be seen that the fuzzy logic has led to applications such as traffic management [1,2], The technique was used to develop a system for monitoring and blocking traffic (Land-Blocking) to solve the problem of traffic congestion which prepares one to handle the situation of blocking traffic lanes for 1, 2 and 3 lanes by lane modeling AIMSUN programs that are suitable for small spaces. It forms a path that is not complicated. The indicators are normal or abnormal traffic lanes. The calculation of the average time spent in verification and validation. The testing showed that the fuzzy logic evaluates traffic conditions correctly. By the use of such techniques, there are researchers that have used this to choose the right path in traffic [3], and adopted it to tackle traffic congestion. In choosing the right path for traffic, by selecting a path created by MATSIM (Multi Agent Transport Simulation) is comparable to the AHP-Fuzzy (Analysis Hierarchy Process-Fuzzy) that uses software MITSIMlab software of the Massachusetts Institute of Technology to simulate traffic on a computer. The results of the study showed that AHP-Fuzzy is traveling at more speed than MATSIM. The research shows it can select the right path and can help to reduce traffic. Some researchers have adopted a technique to evaluate the congestion of traffic on the road which [4] has been applied to the main artery of the city with appropriate consideration of several factors such as time of the day, day of the week, water on the road, and capacity of the street and the levels of traffic jams (red, yellow and green). Fuzzy Logic and CDT (Cell Dwell Time) where also applied to assess the level of congestion. It is valid up to 86% compared to a simple technical evaluation criterion (Simple Threshold).

Not only the task of forecasting is able to reduce traffic congestion, researches have also recognized the importance of increasing safety on the road [5], making travel more efficient and reducing the environmental lead TSC (Traffic Signal Control) to the artificial intelligence (CI: Computational Intelligence). Artificial Neural Networks (Neural Network) Fuzzy Logic (Fuzzy Logic) and evolutionary computation (Evolutionary Computation Algorithms), have been widely regarded as a way to help resolve the problem in terms of traffic as well as the introduction of traffic that occurs both on the streets and freeways. It can reduce traffic congestion, for example, a researcher from Algeria has developed a system to predict traffic accidents [6] to increase safety on the road. By simulation using MATLAB implementation on the basis of fuzzy logic can be use in traffic management systems effectively and can identify risk factors associated with the appearance of the street.

Fuzzy Logic is applied to forecast due to the fact that there is no logic for reason like a human brain and relies on experience more than theoretical. It also supports dynamic behavior (Dynamic Behaviors), including uncertainties too. Many researches have introduced fuzzy logic to control the traffic signals intelligence [8,9] using fuzzy logic in a separate analysis of the complex and application of graph theory to use in conjunction with a separate analysis of normal traffic. It can find a number of vehicles of each traffic channel through the sensor. The data will be processed by MATLAB to show if the traffic signal control is satisfactory. Without regard to geographical limitations, researches in Indonesia used artificial neural network techniques to help organize the transportation of traffic [10], controlling the traffic in real-time, adjusting traffic light system to improve the accuracy of

the traffic by the application of Neural Network (NN), Fuzzy Learning Vector Quantization (FLVQ) and Fuzzy Learning Quantization Particle Swarm Optimization (FLVQ-PSO). technique applied to assess the accuracy of the performance were on average, FLVQ 90.71% and 99.51%, followed by FLVQ-PSO 74.76%. Research in the USA are expected to change the flow of traffic in California [11] by setting the parameters to be estimated such as average speed, density and flow rate which can be used for processing Hybrid Fuzzy TSK Model consists of Fuzzy Logic and Neuro-Fuzzy Network Recurrent Algorithm. The results will be used to predict the flow of traffic in California in the future.

II. NOMENCLATURE

The notations addressed in this paper are listed as follows:

K	The ratio of the volume of traffic that occurs daily on the hour with the highest traffic volume.
D	The ratio of the volume of traffic in the peak hour of traffic volume traveling in the direction of maximum occurrences.
n	The amount of information on travel time observed.
d	Distance moving in miles (mi) kilometers (km) or feet (f).
t_i	Time spent on the road in hours (h) or second (s).

III. ENGINEERING THEORIES

A. *Highway Engineering*

Roads are factor of traffic and are associated with the engineering of the (Highway Engineering) significantly since the design, the type of construction, and quality control according to the traffic engineering. The network of roads and network of traffic on roads are constructed to support the travel of the vehicles. The construction of the road will be designed with geometry, which consisted of placing the road, designing the curve, diopter and junction designs. The size and weight of the car, the motion of the car and the impact of the movement of the car must be taken into account. Types of road traffic engineering have 4 categories as follows.

- Expressway or Freeway is a road built specifically to facilitate the journey to be more efficient. It is different from other types of road traffic which is able to accommodate a large number. There are special requirements different from normal road to limit the amount of cars. It does not allow people or animals to walk or cross and no separate cross-sectional.
- Arterial street serves the route for a long distance between one area to another area. The intersection is the amount of traffic from other roads connecting. The physical characteristics of the main road to a high standard, including the width of the surface should be at least 4 channels and a center island. The max speed of cars should be between 50-60 km/h. The length of the main road, there should be no less than 4 km.
- Collector road serves as an avenue to collect and distribute traffic from congested areas within any one floor to enter into the main street. It should be standard physical medium is the width of the pavement 2-4 channels depends on the density of the area. There should be no island and should have a moderate speed at 40-50 km/h. The distance of roads linking the main line should be between 2-4 km.
- Local road is a road connection type in alley or street that looks out of the single track roads and connects directly. The road should have a distance of no more than 2 km of road and it should have a 2 lane channel with speeds of up to 30-35 km/h.

B. *Traffic Engineering*

Traffic engineering is the application of principles of engineering applications to manage the movement of traffic flow to be effective and safe. The implementation of traffic engineering is pertinent to study the flow of traffic, designed to control the flow of traffic, and traffic management using various mathematical models for traffic simulations Analysis Principles Applied Statistics, and the introduction of modern technology, the Intelligent Transportation Systems (Intelligent Transportation System, ITS) applications.

Traffic volumes and flow rates are the amount of traffic that passes through the reference position on the road or lane-way traffic in a given period. In general, there are Units per unit of time, such as cars or cars per hour per day, for a flow rate typically is measured. Vehicles per hour calculate the peak hour factor (Peak hour factor, PHF) by the following equation (1):

$$PHF = \frac{Hourly \;\; volume}{Max.rate \;\; of \;\; flow} \tag{1}$$

In designing the traffic peak hour (Peak-hour volumes) can be estimated from the AADT by considering the direction of the traffic volume, the highest such value, including the amount of traffic you for designing seamless direction (Directional design hour volume, DDHV) which can be obtained from the following equation (2):

$$DDHV = AADT \times K \times D \tag{2}$$

Time mean speed (TMS) is the average speed of all vehicles passing on a road or lane position in any given period. It is calculated by the following equation (3):

$$TMS = \frac{\sum_i \frac{d}{t_i}}{n} \tag{3}$$

Space mean speed (SMS) is the average speed of all vehicles on the road to tenure in a given period. It is calculated by the following equation (4):

$$SMS = \frac{d}{\frac{\sum_i t_i}{n}} = \frac{nd}{\sum_i t_i} \quad (4)$$

IV. FUZZY LOGIC CONTROLLER DESIGN

This section discusses the design of FLS used in traffic signal control. Fig. 1 demonstrates the block diagram for regulation of the intersection traffic lights.

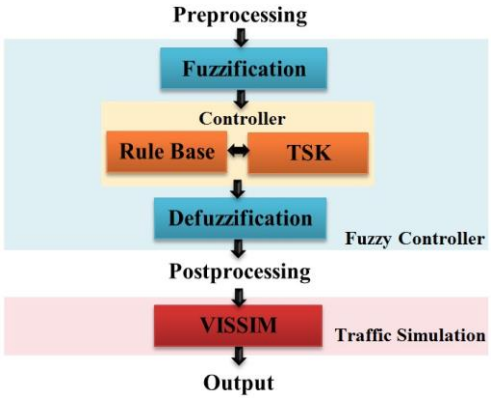


Fig. 1. Block diagram of the intersection traffic lights based on FL scheme.

A. *Fuzzification*

First, it is necessary to convert the input data into suitable, real fuzzy variables. A process known as fuzzification is then used to establish the membership degrees for the different fuzzy partitions of the fuzzy variables. Fuzzification consists in attributing a numerical value to each fuzzy quantifier represented by membership functions which are qualitative descriptions of the behavior of the fuzzy system. Such a set is characterized by a membership function which attributes to each object a degree of membership between zero and one. A fuzzy set is defined by a membership function $\mu_A(x)$, which describes the degree to which the element belongs to x and A such that (5):

$$\mu_A(x) : U \mapsto [0,1] \quad (5)$$

Generally, one uses membership functions of triangular, trapezoidal. Complex shapes making the creation of a computer system are complicated too. One can simulate a simple relation to the scope of a member of the set (6), (7):

$$A = \{(x_1, \mu_A(x_1)\}, \{(x_2, \mu_A(x_2)\}, ..., \{(x_N, \mu_A(x_N)\} \quad (6)$$

Or in a format easily understood as follows.

$$A = \{\mu_A(x_1)/(x_1), \mu_A(x_2)/(x_2), ..., \mu_A(x_N)/(x_N)\} \quad (7)$$

Fuzzy sets for linguistic variable system traffic signal control. The most often used are Error and Rate of Error Change in the control system. Thus, in this system there are two inputs and one output variable which is detailed in TableI.

TABLE I. Linguistic Variable

System	Variable Name	Variable	Meaning
Input 1	Number of cars on driving lane (NDL)	FC RC EC	Few Cars Regular Cars Extreme Cars
Input 2	Number of cars on going lane (NGL)	FC RC EC	Few Cars Regular Cars Extreme Cars
Output	Time	30 60 120 180 240	Thirty seconds Sixty Seconds One hundred twenty seconds One hundred and eighty seconds Two hundred and forty seconds

B. *Fuzzy Inference Rules*

The fuzzy inference rules are the essential operation of the fuzzy inference system and include a number of inference rules connecting the input fuzzy variables to the output fuzzy variables. These relationships then provide the basis of rules on which decisions can be made.

Considering the traffic signal control system with two inputs (variables) is NDL and NGL, one output is Time, so the design rules of fuzzy variables and 3 are as follows.

IF	NDL = FC	AND	NGL = FC	THEN	Time = 120
IF	NDL = RC	AND	NGL = FC	THEN	Time = 180
IF	NDL = EC	AND	NGL = FC	THEN	Time = 240
IF	NDL = FC	AND	NGL = RC	THEN	Time = 60
IF	NDL = RC	AND	NGL = RC	THEN	Time = 120
IF	NDL = EC	AND	NGL = RC	THEN	Time = 180
IF	NDL = FC	AND	NGL = EC	THEN	Time = 30
IF	NDL = RC	AND	NGL = EC	THEN	Time = 60
IF	NDL = EC	AND	NGL= EC	THEN	Time = 120

From the Fuzzy Rules, 2 inputs and 1 output size 3 × 3 matrix. This can be represented in the Fig. 2 shows the format of a fuzzy matrix is Fuzzy Associative Memory or FAM.

Number of cars on driving lane

Number of cars on going lane	**FC**	**RC**	**EC**
FC	120	180	240
RC	60	120	180
EC	30	60	120

Fig. 2. Fuzzy Associative Memory or FAM

C. *Takagi Sugeno and Kang Using MATLAB®*

1) Membership Function Editor: The first step in designing fuzzy variables, which are both the input and output variables. The system has an input of 2 variables and 1 output variable. The number of variables and variable names as required, preferably named to convey the functions of variables that (default MATLAB requires adding variables Input1 or Output1). When adding variables in MATLAB, a new window will pop up called membership Function Editor, as shown in Figure 3, which is used to determine the detailed function of variables such as in table II which shows the set list. Learn member function of the input variables NDL NGL and output variable Time on membership Function Editor is then conducted.

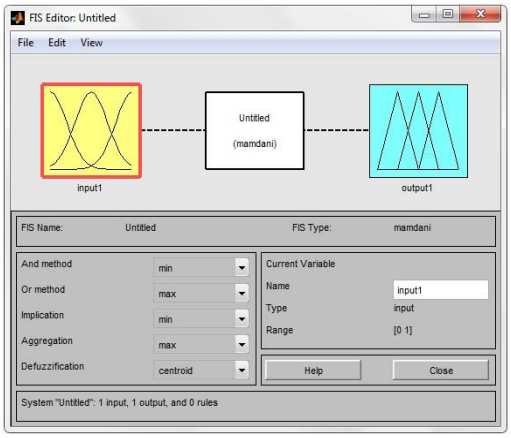
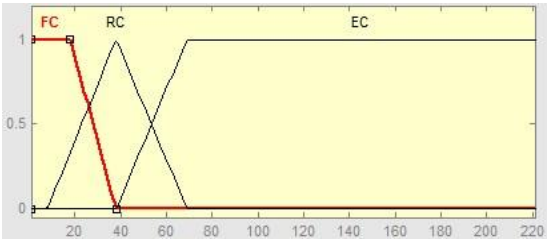
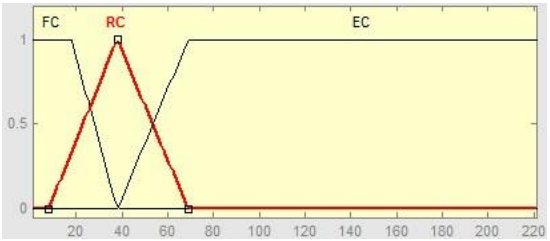
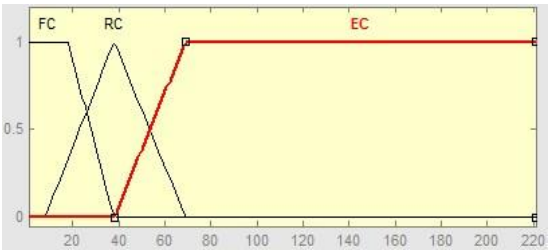
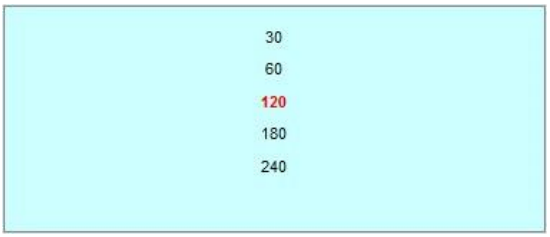


Fig. 3. Shows Membership Function Editor Takagi Sugeno and Kang

Considering the member functions between sets and fuzzy sets. Set clear boundaries between the set is separated by a vertical line. Thus, the membership of any variable is separated by boundary lines clearly. In contrast, for fuzzy sets. Boundaries between sets are the disparity between sets. Represented by a straight line with a slope which makes the value of the variable the value of a disparity between the two sets. This member function is essential to the fuzzy logic system as it can simulate the expert knowledge into the system because of its design elements to consider the shape of the various functions such as height (usually to the norm of 1.0), width (expressed as a range of sets that), the slope of the border, (Representing a fuzzy) center and the overlap of functions of each set. Each of these elements is derived from experts who can identify the authenticity of the variables within the system.

The statistical analysis of data traffic by 2013, selected two types of main roads and secondary roads of the total, 174 Route and 366 intersection in Bangkok. The road traffic in each direction with a minimal number of cars is 1 unit / min at most 221 units / min and the average traffic is 38 units / min.

TABLE II.Specifies the membership functions of input and output variables.

Fuzzy Input (NDL, NGL)	The language of the member functions: FC Type of member functions: Trapmf Shape parameters of member functions: [1 1 18 221]  The language of the member functions: RC Type of member functions: Trimf Shape parameters of member functions: [18 38 69]  The language of the member functions: EC Type of member functions: Trapmf Shape parameters of member functions: [38 69 221 221] 
Fuzzy Output (Time)	The language of the function: 30 parameters: 30 The language of the function: 60 parameters: 60 The language of the function: 120 parameters: 120 The language of the function: 180 parameters: 180 The language of the function: 240 parameters: 240 

2) Rule Editor: Rule Editor is used to determine the details of the fuzzy inference, which is usually set for Mamdani inference, one can choose a Sugeno inference in the initial stages of creating a new file as shown in Figure 4. Learn the rules of the fuzzy traffic signal control system by selecting Add Rule to add a rule with the details of the variables were selected. If the input variable conditions with more than one condition, it can choose to include conditions (or or and) as well as the ability to add the condition "no" (not) to facilitate the creation of fuzzy rules even more.

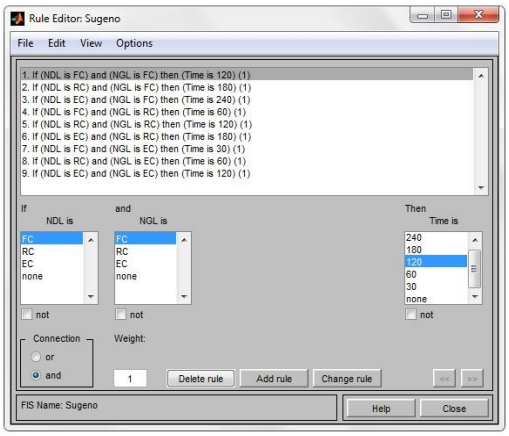


Fig. 4. Shows Rule Editor Takagi Sugeno and Kang

3) Rule Viewer: Rule Viewer is a tool to analyze the results of the Rule Viewer to display the output of the system. The rules of the system results show that the rule would affect the Rule Viewer input set to make a good impression to get the fuzzy output. One can select the input to the output, as shown in Figure 5.

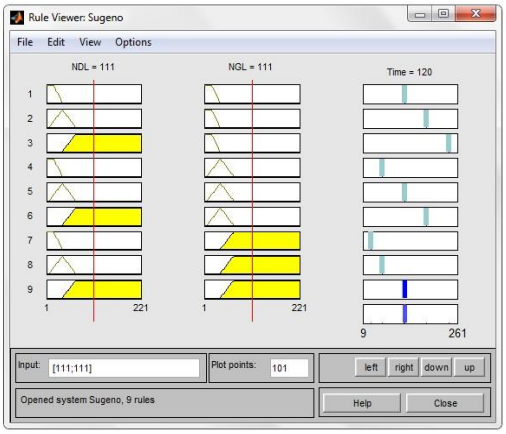


Fig. 5. Shows Rule Viewer Takagi Sugeno and Kang

4) Surface Viewer: Surface Viewer is a surface analysis of the relationship between input and output variables. Such surfaces can browse to analyze system performance. It will search based on fuzzy rules defined in the system as shown in Figure 6.

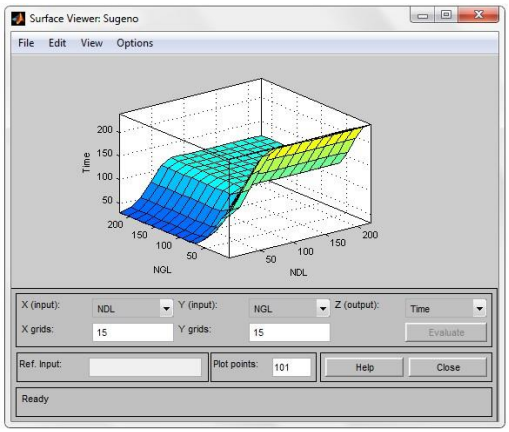


Fig. 6. Shows Surface Viewer Takagi Sugeno and Kang

V. VISSIM TRAFFIC CONTROLLER

Selecting program used in this study, the author has considered the suitability and capability of the application for the traffic of Bangkok. From the analysis, the researchers selected advanced applications in VISSIM modeling such traffic.

A. Traffic analysis programs are being used in Thailand.

- Advanced Program to simulate large scale network and sophisticated as well as PARAMICS and VISSIM.
- Intermediate Program is suitable for small spaces and patterns to choose a path that is not complex as CUBE DYNASIM and AIMSUN.
- Basic programs ideal for small networks. Procedure is quite simple but there are limits.

TABLE III. Compare Traffic Simulation Program

List	S-PARAMICS	VISSIM	CORSIM
The difficulty of use.	relatively easy	rather difficult	moderate
price	moderate	expensive	Cheap
Traffic channel selection	very well	very well	A problem if the short road
The circuit / combined traffic.	very well	very well	Poor
Handles Traffic Beginning - the end	have	have	can not
3D display	have	have	can not
Route selection for Real-time	very well	good	can not
Special event simulation	very well	good	can not
Difficulty in calibration.	moderate	rather difficult	difficult
The display of traffic Index	very well	Good	good
MCA Animation	moderate	relatively easy	relatively easy

Source: Micro-Simulation Guidance Note of Transport for London.

B. The strength of the program that was used to develop a model for the traffic.

- AIMSUN modeling gap acceptance behavior of drivers on the basis of the delay which other models cannot.
- VISSIM modeling driving the junction of the complex as well. Including the ability to simulate the behavior of off-street parking and parking on both sides.
- PARAMICS can be modeled with high reliability due to the number of trips from origin to destination directly.
- DYNASIM a model with maximum efficiency and speed of processing. It has the ability to display three-dimensional animation is excellent.
- S-PARAMICS simulation fits in a wider area and has the ability to simulate the public transport system as well.
- CUBE DYNASIM can track the movement of vehicles, each vehicle and simulated driving behavior based on the information from the survey was realistic.

Program AIMSUN, CORSIM and VISSIM are suitable for areas with traffic management, traffic jams on the main roads and expressways. The program AIMSUN is appropriate to create a network of large cities, while models of the PARAMICS, INTEGRATION and CORSIM effective in intelligent transportation systems. However, the PARAMICS has disadvantages and limitations that cannot be replicated, motorcycles and bicycles. Currently the only program which can achieve this is VISSIM as shown in figure 7.

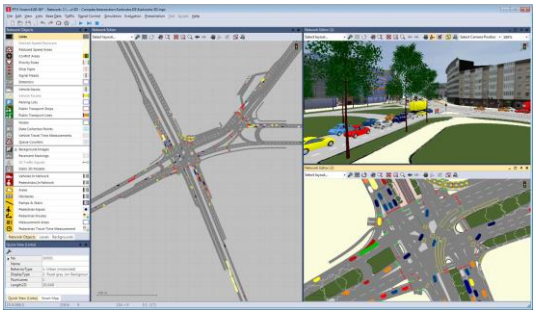


Fig. 7. Sample Screenshot VISSIM

VI. CONCLUSION AND FUTURE WORKS

This research demonstrates the network design of traffic. The selection of the road under the Highway Engineering road used in the study are divided into two types: Arterial street and Collector road, which is the next step towards including the application of Fuzzy Logic in judgment on the traffic light, according to the number of channels. Each type of road traffic application VISSIM and the host by the total delay of the simulation.

The results of the simulation with VISSIM program will be entitled to alter the type of discharge lights and for the appropriate model for each road type to alleviate the traffic congestion in Bangkok.

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