A CASE STUDY ON SUN-YAT-SEN FREEWAY ON-RAMP CONTROL USING FUZZY THEORY

Hsiang-Chen Lin
Assistant Professor
National Peng-Hu Insititute of Marine and Management Technology
Department of Shipping and Transportation Management
Address: 300, Liu-Ho Rd., MA-KUNG, PENGHU, TAIWAN
FAX: 886-6-9265760
E-mail: hclin@bbs.ph.edu.tw

Abstract : Recurrent congestion often occurs day after day from 7:00 A.M. to 8:00 P.M. on Sun-Yat-Sen Freeway near some important metropolis in Taiwan. Recently, pre-timed on-ramp metering control is taken to improve the traffic condition since 1 September 1998. No effect shown when the significant difference between real flow and predicted flow occurred. Therefore, it is important that metering rate must change according to the real flow.

Traffic responsive ramp control is used in this study to avoid the shortage of pre-timed control mentioned above. Both volumes of ramp and upstream main lane are considered when metering rate is decided anytime. Mamdani method is used to infer green time.

The data used in this study is peak day's volume collected 24 hours per day from 26 January to 1 February 1998 which is the most important holiday of Chinese. Some interesting results are acquired.

1.INTRODUCTION

Recurrent congestion occurs while there are heavy traffics that many short distance daily trip drivers near the metropolitan on Sun-Yat-Sen freeway. On-ramp control and substitute routes are adopted to avoid congestion since 1998. Pre-timed ramp control is principally applied Sun-Yat-Sen freeway. This control system type suits in low and steady flow rather than high and rapid changed flow. It is no effect when traffic volume approach capacity in some special festival in Taiwan.

Average car speed is dropped to less than 40 km/hr when all drivers who work far from their hometown want go home on importance continuous holidays. It seems more suitable to utilize traffic responsive ramp control in heavy traffic because traffic responsive ramp control will adjust green time according to real time volume.

The study area is shown in figure 1. There are two lanes in freeway which both will effect level of service according to HCM 1994 and one lane in ramp. Total on-ramp's length is 360 m. Three types' flow is used to analysis their different effect under pretimed and adaptive control. Flow from 29 to 31 Jan is very high which total flow equal to 130218 vehicles/day in main lanes. Flow in 24 Jan, 28 Jan and 1 Feb is middle. The others are low which total flow less than 12000 vehicles/day.

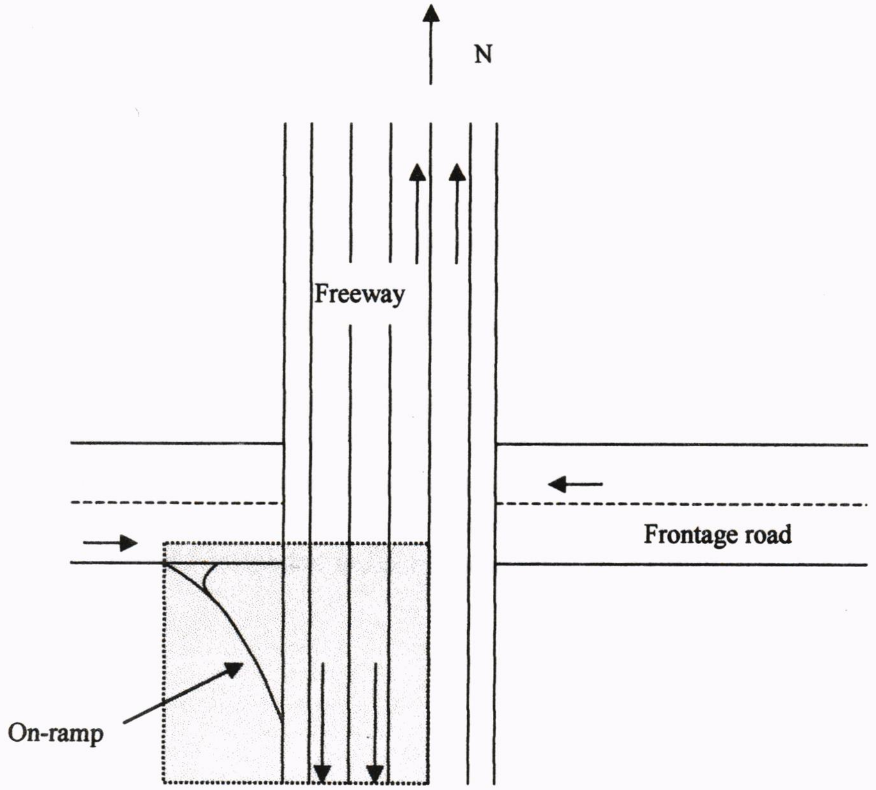

Figure 1 study area

The methods being used include fuzzy theory and simulation. Fuzzy theory is used to construct microscope adaptive ramp control model. Main-lane's vehicle arrival and vehicles waiting behind ramp's stop line are two input variables. Next second's Green time is the output variable. Fuzzy set's styles are continuing shoulder and triangle. Direct inference method and geometry centroid method are used to deal with implicating and defuzzy problem.

2.LITERATURE REVIEW

General freeway control method is on-ramp control which includes ramp close, pretimed ramp control, traffic responsive ramp control, merging control and integrated ramp control (Lin, 1980). Only traffic responsive ramp control can real time reflect volume change among then.

In general, it is called adaptive signal control if green time can change according to volume in a few seconds (Lee, 1993). Some famous adaptive signal control systems for urban intersection are developed including SCOOT, SCATS, TOL, Miller's algorithm, OPAC, SAST, SCII-2 and COMDYCS-III.

Papageorgiou (1984) proposed a multi-layer control method. Adaptation layer stores historical data and predicts next control period's traffic condition according to historical data. Optimization layer calculates integrated optimum metering rate. Direct layer modifies every ramp according to ramp's real condition.

Jacobson(1989) proposed a bottleneck algorithm. Every ramp's basic metering rate is calculated independently. Upstream metering rate must gradually reduce from basic metering rate according distance when a bottleneck occurs.

Papageorgiou et al. (1990) proposed a nonlinear method tried to acquire dynamic traffic model's optimum metering rate. This method is lack of generality because different flow characteristic exists everywhere.

Papageorgiou (1991) proposed a steady, simple and effective control method. The metering rate is calculated according to formula (1).

$$R(k)=R(k-1)+Vc(Oc-Oo) \qquad (1)$$

Where R(k) is metering rate of k^{th} control period
Oc is occupancy of metering object
Oo is occupancy of downstream main lane
Vc is Oo's speed in volume-occupancy

Wei and Wu(1996) apply an time-space neural network model to training data and construct an adaptive ramp metering control system. This system has good performance in low volume but congestion will occur in high volume situation.

Traditional model's construction becomes more complicated and cannot handle the relations among all events when information is incomplete or cannot use mathematics model to precisely describe all events. This information can be easily constructed by fuzzy theory measuring information's degree of fuzzy.

Fuzzy concept is people's subjective reflection to objective matters and popularly accepted by the public. The origin of fuzzy is an objective thing can be described more than one meaning. Membership function contain some kind of psychology process (Wuang, 1991) because there are strict relations between stimuli and mankind's feeling shown in the results of many psychology tests. We cannot arbitrarily measure fuzzy concept because of these tight relations.

Some characteristics are required if we want the membership function can match real world. At first, membership function must satisfy basic fuzzy theory. Membership function must match problem's definition and is easily calculated. Variable's number must reduce as many as possible. Variables must have explanatory and actual meanings.

3.MODEL CONSTRUCTION

Metering rate of adaptive ramp control is calculated according to predicted traffic flows which are based on historical traffic flow and changed immediately when traffic situation changes. Main advantages appearing in adaptive ramp control include minimizing the effect in traffic demand rapid change and reducing the effect of accident causing capacity reduction.

Detectors are installed in freeway main lane, merging area, behind stop line and conjunction between ramp and frontage road shown in figure 2. These detectors can obtain vehicle's speed or number to understand relationship between traffic demand and capacity.

Main lane vehicles must go first if detectors show high volume both in main lane and on-ramp. Queue length will grow rapidly when numerous vehicles arrive for a long time because they can not enter freeway under the pre-timed ramp control system. Red time will be cut in the same circumstance under adaptive control system and queue length will grow temperate.

Some assumptions stated below are made before model construction. In the first, proposed model will decision whether to change phase next second because the facilities are fast enough to translate and process data within one second. In the second, there is only one lane in the ramp that allows one vehicle entering merging area every second. Maximum metering rate is 900 vehicles/hour (Lin, 1990). Vehicle arrival is Poisson distribution (Lee,

1993) both in freeway and ramp. Maximum flow is 2400 vehicles/hour/lane in main lane. Maximum queue length is 14 at ramp. In the last, the unit of green or red time is one second.

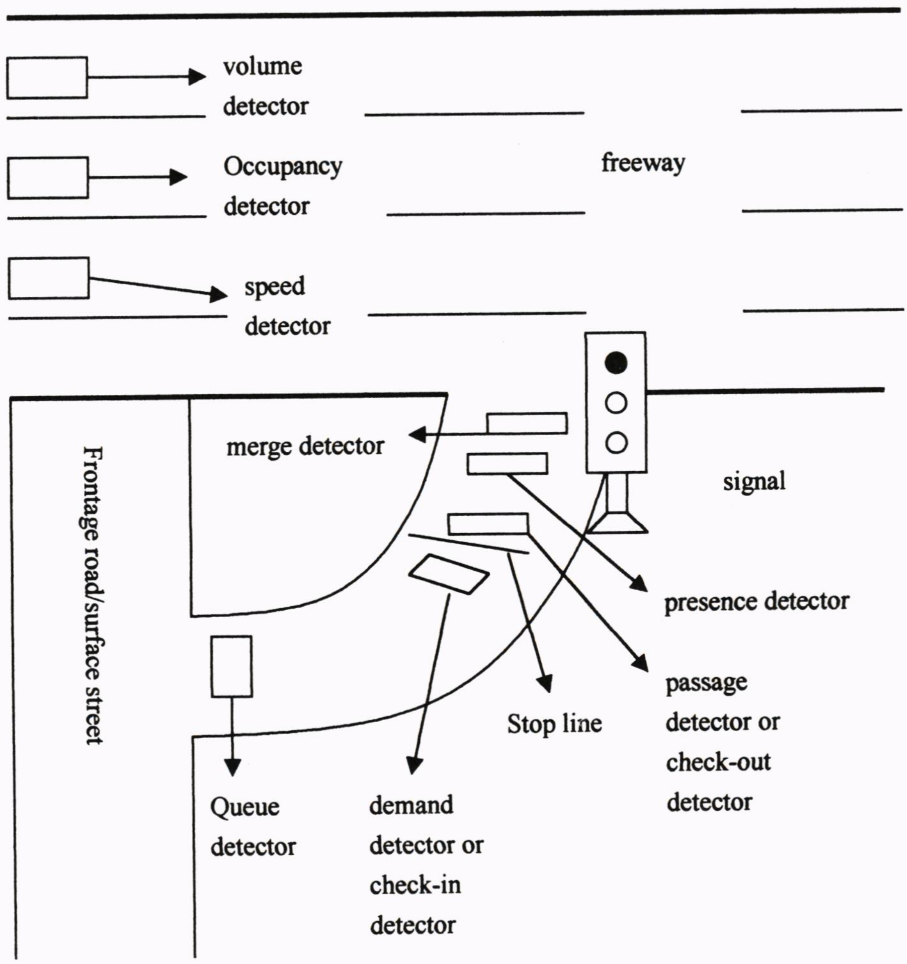

Figure 2 the layout of adaptive ramp control

Figure 3 shows the membership function of vehicle arrival per second in main lane. Five situations including very low arrival, low arrival, middle arrival, high arrival and very high arrival are considered.

Figure 4 shows queue length's membership function. Queue length can be classified five types to acquire its membership function value although queue length is integer. Very short means queue length less than 4.67 vehicles. Short means queue length greater than 2.33 and less than 7 vehicles. Middle means queue length greater than 4.67 and less than 9.33

vehicles. Long means queue length greater than 7 and less than 11.67 vehicles. Very long means queue length greater than 9.33 vehicles.

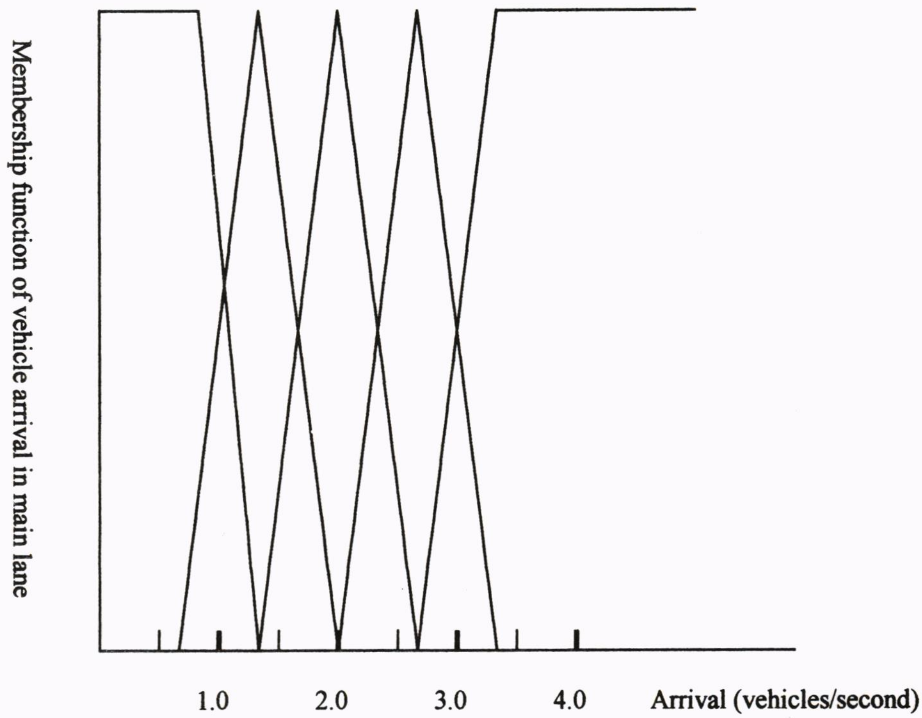

Figure 3 Membership function of vehicle arrival in main lane

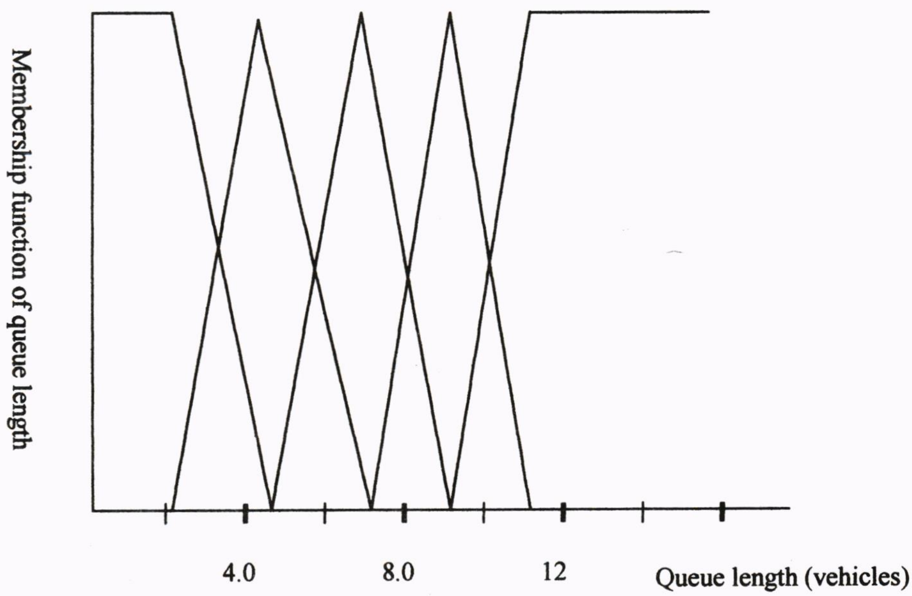

Figure 4 Membership function of queue length at ramp

Figure 5 shows green time's membership function containing three conditions that are very short, short and long. Red phase will appear at next second if inference result is very short.

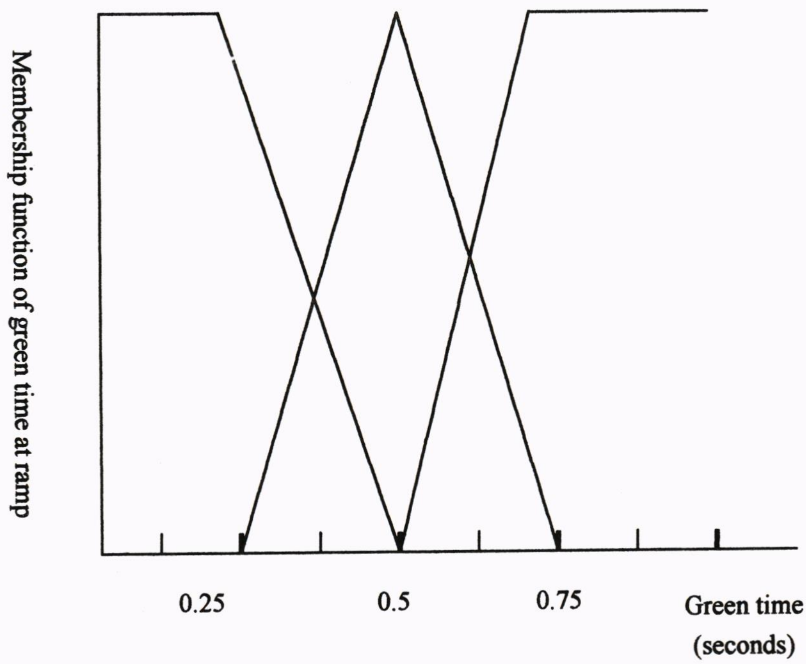

Figure 5 Membership function of green time at ramp

Table 1 shows the criteria of inference rules. Green time is decided under particular situation of main lane's arrival and ramp's queue length. For example, green time is short if flow is middle both in main lane and ramp.

Table 1 database of inference

		Vehicle arrival in main lane				
		Very low	Low	Middle	High	Very high
Ramp's queue length	Very short	short	Very short	Very short	Very short	Very short
	Short	short	short	short	Very short	Very short
	Middle	short	short	short	short	Very short
	Long	long	long	long	short	short
	Very long	long	long	long	long	long

Mamdani method, the most popular one among direct inference, is applied in this study. For example, vehicle arrival equals to 3 and queue length equals to 3. There are two rules to infer green time.

Rule 1. IF main lane's arrival is A1 and ramp's queue length is B1 THEN green time is C1.

Rule 2. IF main lane's arrival is A2 and ramp's queue length is B2 THEN green time is C2.

The fitness W_1 equals to 0.5 according to equation (2) because arrival is very high and queue length is very short. The fitness W_2 equals to 0.29 according to equation (3) because arrival is high and queue length is short.

$$W_1 = \mu_{A1} \wedge \mu_{B1} = 0.5 \quad (2)$$
$$W_2 = \mu_{A2} \wedge \mu_{B2} = 0.29 \quad (3)$$

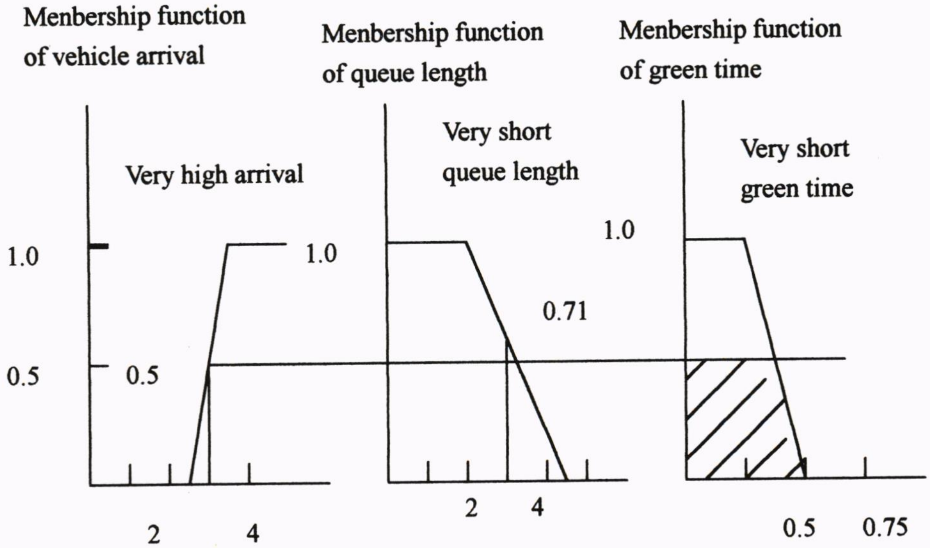

Figure 6 infer result of rule 1

Figure 6 and figure 7 show the result of rule 1 and rule 2. These results can also obtained by equation (4) and equation (5).

$$\mu_{C1} = W_1 \wedge \mu_{C1} \quad (4)$$
$$\mu_{C2} = W_2 \wedge \mu_{C2} \quad (5)$$

Centroid method is used to defuzzy. The result of inference is 0.31 obtained by equation (6) and shown in figure 8. Zero value is final output because one second is minimum unit in this example.

$$\mu_C = \mu_{C2} \wedge \mu_{C1} \quad (6)$$

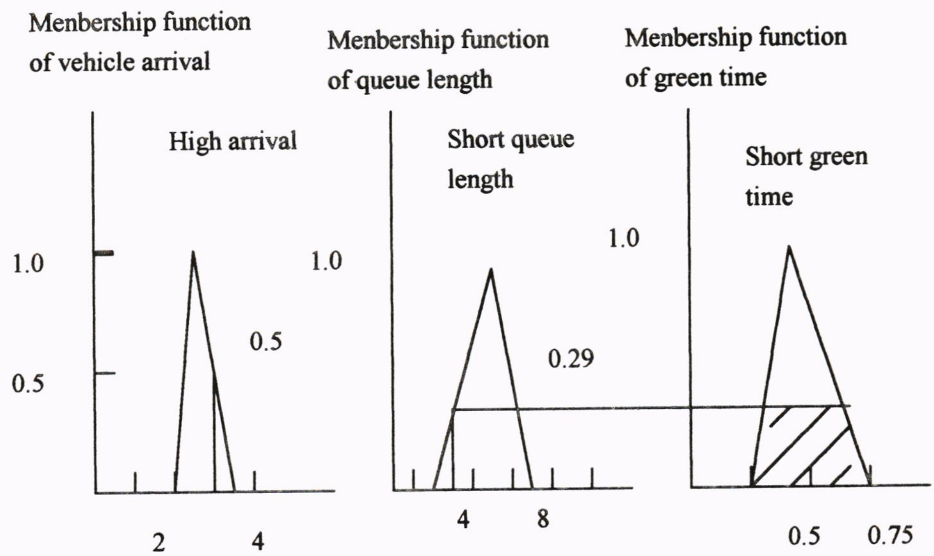

Figure 7 infer result of rule 2

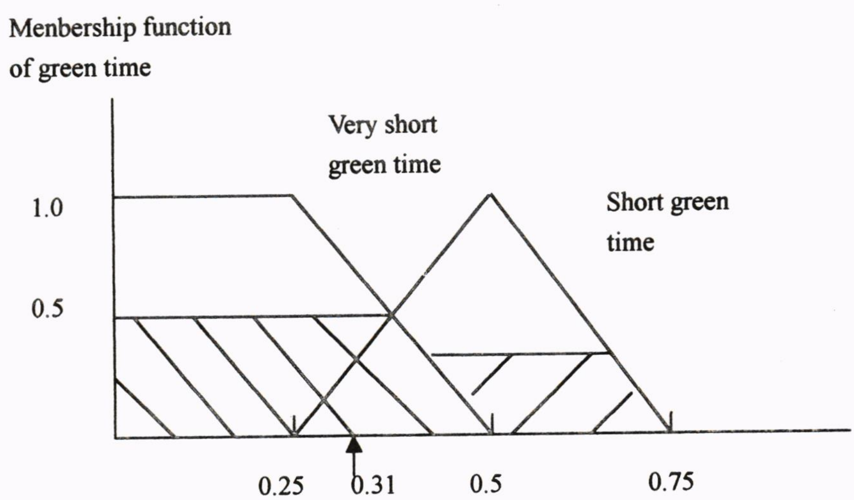

Figure 8 Defuzzy result

The flow chart of simulation is shown in figure 9. We obtain metering rate and on-ramp's actual arrival rate to calculate queue length at time t-1. Then predicted arrival rate and queue length are acquired. Metering rate is obtained according to fuzzy system's operation. Finally, we can calculate the delay and number of stops using metering rate and arrival rate in on-ramp.

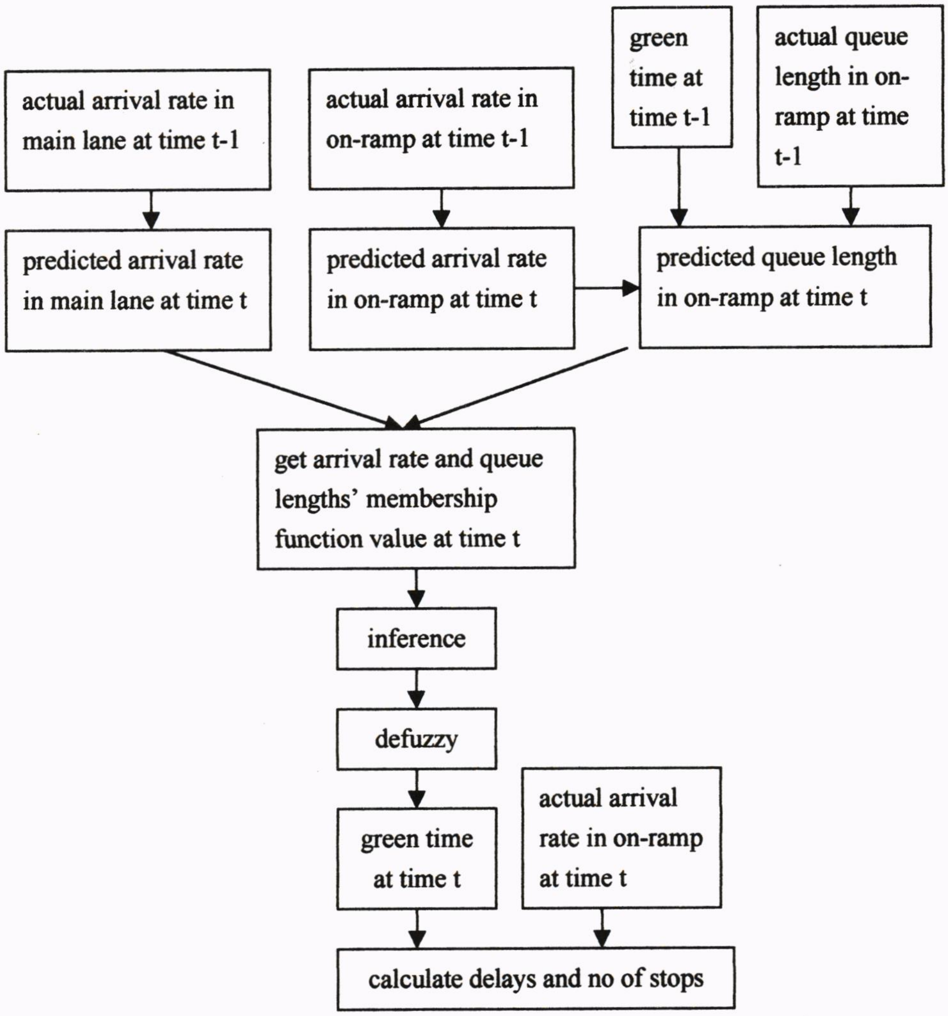

Figure 9 the procedure of simulation

4. DATA ANALYSIS AND RESULTS ANALYSIS

Table 2 shows neigh input data's scenarios classified by main lane and ramp flow. Three flow conditions are considered both in main lane and ramp. The high flow data used in this study is average volume collected 24 hours at 31 January 1998 during the most important vacation of Chinese.

Table 2 scenarios of input data

		Flow in main lane		
		High(2400veh/hr)	middle(1800veh/hr)	low(1440veh/hr)
Flow in ramp	high(2160veh/hr)	Scenario 1	Scenario 2	Scenario 3
	middle(1800veh/hr)	Scenario 4	Scenario 5	Scenario 6
	low(1440veh/hr)	Scenario 7	Scenario 8	Scenario 9

An hour simulation is made for comparing pretimed and adaptive ramp control system. Table 3 shows adaptive control is superior to pretimed control according to total delays at ramp and the number of vehicles giving up entering freeway.

Table 3 scenarios of input data

Scenario	Pretimed control (metering rate equals to 900 vehicles/hour)			Adaptive control			Improvement at delay =[(1)-(2)]/(1)
	Maximum queue length	Vehicles do not enter freeway	Total delays at ramp (1)	Maximum queue length	Vehicles do not enter freeway	Total delays at ramp (2)	
1	14	667	36785	12	0	10020	72.76%
2	14	667	36785	12	0	9003	75.53%
3	14	667	36785	11	0	8646	76.50%
4	14	421	30782	9	0	9425	69.38%
5	14	421	30782	7	0	6664	78.35%
6	14	421	30782	7	0	6187	79.90%
7	12	189	19388	4	0	2823	85.44%
8	12	189	19388	4	0	2588	86.65%
9	12	189	19388	4	0	1809	90.67%

5. CONCLUSION

Adaptive ramp control is superior to pretimed ramp control under the assumption of poisson distribution's arrival. The performance improves at least 69.38% using adaptive control system. Another benefit is all vehicles can enter freeway under adaptive control model. However, adaptive ramp control system is more expensive than pretimed system in facilities. Hence, it is a trade-off problem between government's finance and social cost.

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