A STUDY ON THE REAL-TIME RAMP CONTROL SYSTEM IN URBAN HIGHWAY WITH GENETIC ALGORITHM

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abstract : The objective of this paper is to construct a real-time ramp control system with genetic algorithm in order to use the existing highway network effectively and to reduce traffic congestion. Control options such as entrance control, peak load pricing are considered in this system. The usefulness of this system is confirmed by application to the urban highway network of a metropolitan area in Japan, and finally, the applicability to Asian countries is also discussed.

1. INTRODUCTION

In Japan, the road congestion problem has not been solved yet in spite of many efforts and there are still no effective method which can improve such situation. This resulted from the unbalanced investment compared with demand, which means that the increase of the travel opportunity was much larger than that of the network length. So far, the main measure to improve such situation has been mainly focusing on the extension of road network, but in metropolitan areas, the network could not be extended easily because of financial and spatial constraints. In this background, there is a need to understand how to use the existing network effectively.

This paper is aiming at ramp control of the highway network in order to use highway network effectively. Previous studies about ramp control method such as Linear Programming (LP) control were done in the past 25 years in Japan, but most of them were based on the static model which could not describe the real-time change of traffic flow very well, and these later became inapplicable due to the extension of the highway network. In terms of implementation, the Metropolitan Expressway Authority (MEX) has a method, in which some ramps are closed when heavy congestion occurs in order to improve such situation. But this method needs the close cooperation between MEX and the police which controls the arterial road network and cannot cope with real-time phenomena of traffic flow. Therefore, the method which uses the specific part of highway network such as on-ramp should be considered. This means that each on-ramp section of the highway network acts as a buffer, and during congestion, it becomes a waiting space and some vehicles can be contained there at that moment. The objective of this study is to construct a real-time ramp control system (RRCS) based on the consideration mentioned above.

In the construction of the RRCS, main problem was that it took a very long time to evaluate the result of ramp controls, or in other words, the computation time was much larger than the unit control time such that the system becomes meaningless. This situation was caused by the aspects of not only hardware but software, specifically, the poor performance of computer and the lack of algorithm which can solve optimization problems fast. Recently, there has been a rapid improvement in the performance of computers. Genetic algorithm (GA) was developed about 10 years ago in control engineering field, which improved the solution time of optimization problems dramatically. These advances enable the construction of the RRCS. The other main advantage of the GA is that the combination of many ramp control options can be evaluated. For example, not only entrance control but also peak load pricing can be evaluated in the RRCS.

In this paper, the concept and structure of the RRCS are discussed in Chapter 2. The formulation of each model is made in Chapter 3. In Chapter 4, the RRCS is applied to a part of the Tokyo Metropolitan Expressway (MEX) to confirm the effectiveness of this system. The possibility of applying the RRCS to freeway networks in Asian countries are discussed in Chapter 5.

2. CONCEPT AND STRUCTURE OF REAL-TIME RAMP CONTROL SYSTEM

Presently, MEX only uses entrance control as a traffic control method, but it seems that this doesn't work well because there are two operational constraints. First one is that this is operated unsystematically, in which when heavy congestion once occurs at a certain section, some on-ramps in the vicinity are closed by manual control. Second one is the difference in the control administration between freeways and arterial roads in Japan. While MEX has its own traffic control method, arterial road network is controlled by the police, but they are not coordinated with each other. This shows that it is difficult to cope with traffic flow changes such as the growth of congestion in real-time, therefore the method which uses the specific part of the highway network should be considered.

On-ramp is focused on as the specific part in this study. In the case of MEX, most of on-ramps have few booths at the junction between freeway and arterial road (Figure1), and some vehicles can be contained in the waiting space if congestion of both highway and arterial road becomes severe. Each booth can select the "optimal" option in order to improve the "bad" state of the highway network. Entrance control or booth control was considered as a ramp control option in previous studies, but in addition to this, many other options can be introduced if there is a system which can evaluate their effect. For example, peak load pricing can be regarded as a ramp control option. In this study, it is not assumed that automated toll collection system is installed at the ramps. Each vehicle is charged peak toll at the booth directly if network is congested.

An important point when constructing RRCS is the presence of data collection system of traffic flow parameters. Fortunately, MEX has a system which measures some parameters of traffic flow such as travel speed and traffic volume with censors set at intervals of about 300 meters on the whole network and at every ramp. Presently, this system is used only for information service, but this can also be applied to traffic control system.

From the background above, it can be said that the RRCS is a system which optimizes the future state of traffic flow under adequate ramp control options with real-time traffic data. It was already mentioned that previous studies about ramp control could not evaluate real-time

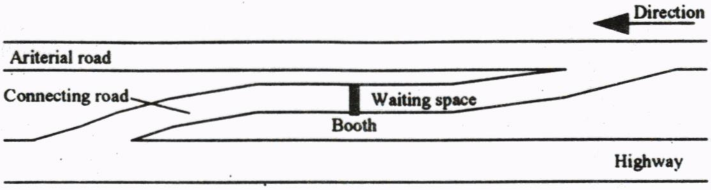


Figure 1. Ramp structure of MEX

phenomena of traffic flow because of the constraint about computer and algorithm. But this situation has been improved dramatically by the development of GA. The GA can solve the optimization problems with adequate parameter setting in accordance with their property. In this study, GA is applied to RRCS focusing on the speed of convergence.

RRCS have a hierarchical structure which consists of main model and two sub-models (Figure 2). The main model solves the optimization problem of the traffic flow state using GA. One sub-model is the traffic simulation model which simulates the future traffic flow state in terms of travel speed and traffic volume using the present traffic flow state. Another is the division rate model which expresses the probability of driver's choice of using a freeway in accordance with generalized cost. These models will be formulated in the next chapter.

3. MODEL FORMULATION

3.1 Traffic Simulation Model

Before the traffic simulation model is formulated, its characteristic should be considered. There are macroscopic and microscopic approaches to construct traffic simulation model and it must be decided which is suitable for the construction of model. In the macroscopic model, the network is divided into segment and the values of traffic flow state are described by aggregate data. On the other hand, the microscopic model focuses on the movement of each vehicle. The choice depends on the data collection system. If the road network and vehicles are integrated, vehicle travel data can be collected directly, and to formulate the microscopic model is meaningful. In this study, traffic flow data are collected by censors, therefore to choose the macroscopic model is very advantageous. Many previous studies about the macroscopic model were done, but these could not describe traffic flow phenomena clearly especially in congested state. RRCS should work well especially in congested state because it is in congested state that traffic control method is needed. Therefore the model's repeatability in congested state should be confirmed in this study.

Figure 3 shows a segment without on-ramp or off ramp, where segment length is l_i and n_i^t is the number of lanes. Each segment has at least one censor, and traffic volume and average travel speed at some time intervals can be known. At this time, density of segment i at time t d_i^t is

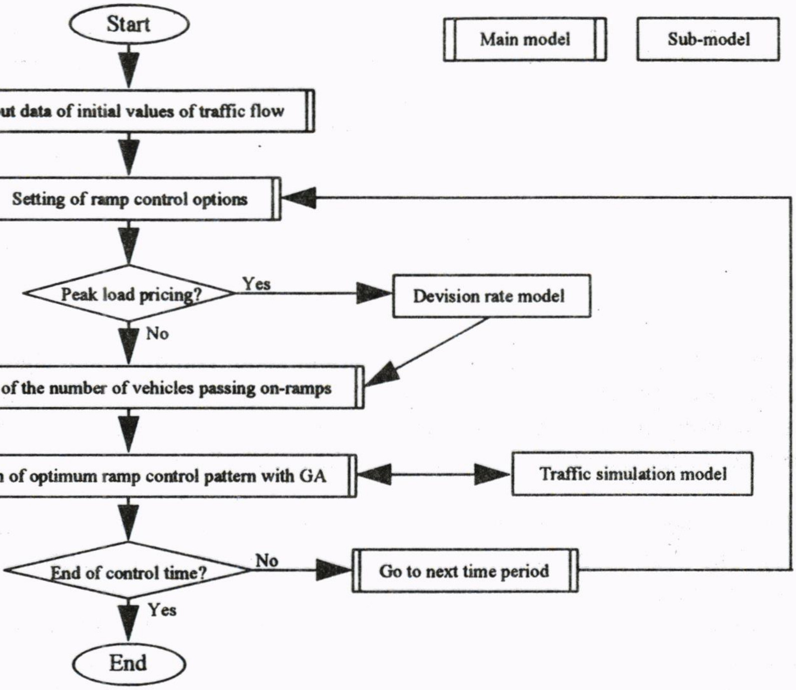


Figure 2. Structure of RRCS

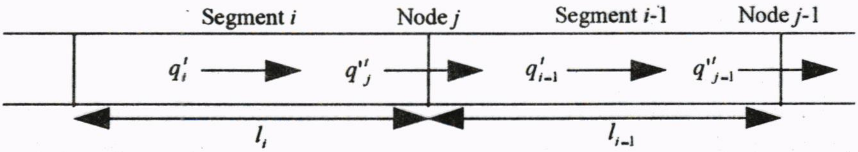


Figure 3. Segment without ramps

$$d_i^t = q_i^t / v_i^t , \tag{1}$$

where q_i^t is traffic volume, v_i^t is average travel speed of segment i at time t. The number of vehicles in segment i at time t Q_i^t is estimated as follows:

$$Q_i^t = n_i^t l_i d_i^t . \tag{2}$$

At dt time intervals, the number of vehicles in segment i will change. We must decide the number of vehicles q''^{t+dt}_j which pass through node j at time interval dt as follows:

$$q''^{t+dt}_j = \min\left(\frac{q_i^t l_{i-1} + q_{i-1}^t l_i}{l_{i-1} + l_i}, Q_{i-1}^{\max} - Q_{i-1}^t + q''^{t+dt}_{j-1} \right), \tag{3}$$

where $Q_{i-1}^{\max}$ is the maximum number of vehicles which can exist in segment i-1. Thus, the number of vehicles in segment i at time $t+dt$ Q_i^{t+dt} is determined by the equation of continuity as follows:

$$Q_i^{t+dt} = Q_i^t + q'^{t+dt}_{j+1} - q'^{t+dt}_j . \tag{4}$$

Therefore density, traffic volume, and average travel speed of segment i at time $t+dt$ d_i^{t+dt} q_i^{t+dt}, v_i^{t+dt} is expressed as follows:

$$d_i^{t+1} = Q_i^{t+1} / n_i^{t+1} l_i , \tag{5}$$

$$q_i^{t+dt} = f\left(d_i^{t+dt}\right), \tag{6}$$

$$v_i^{t+dt} = g\left(d_i^{t+dt}\right), \tag{7}$$

where $f(d)$ is volume-density function and $g(d)$ is speed-density function. Using (3)~(7) repeatedly, the future value of traffic flow state at time $t+2dt$, $t+3dt$, ··· can be solved.

Figure 4 shows a segment with on-ramp m and off-ramp n. When the number of vehicles which pass through the toll booths at time $t+dt$ u_m^{t+dt}, u_n^{t+dt} can be known, equation (4) is substituted as follows:

$$Q_i^{t+dt} = Q_i^t + q'^{t+dt}_{j+1} - q'^{t+dt}_j + u_m^{t+dt} - u_n^{t+dt} , \tag{4'}$$

The most important point when executing traffic simulation model is that we must do these calculations above mentioned upstream. This is why traffic state of each segment depends on that of its downstream one.

3.2 Division Rate Model

In this study, peak load pricing is considered as a ramp control option, therefore a model which can express division rate by toll of the highway network is needed, but there are two problems. It can be considered first that each driver generally chooses his route by comparing generalized cost of freeway with that of arterial road, but the problem is that there are no traffic data for arterial roads and a model which is a function of both generalized costs cannot be constructed. Another problem is that the uniformity of toll does not allow the model to be calibrated with a toll value. Therefore the gravity model is assumed as the division rate model which is expressed by only generalized cost of the freeway. In the next study, the model of driver's route choice behavior will be needed. In this study, the origin is defined as the on-ramp where the driver enters and the destination is defined as the off-ramp where the driver exits in this study.

The equation of gravity model is given as follows:

$$T_{mn} = kG_m A_n \left(C_m + \alpha t_{mn}\right)^{\gamma} , \tag{8}$$

where T_{mn} is the O-D traffic volume between on-ramp m and off-ramp n, G_m is trip generation rate of on-ramp m, A_n is trip attraction rate of off-ramp n, C_m is toll of on-ramp

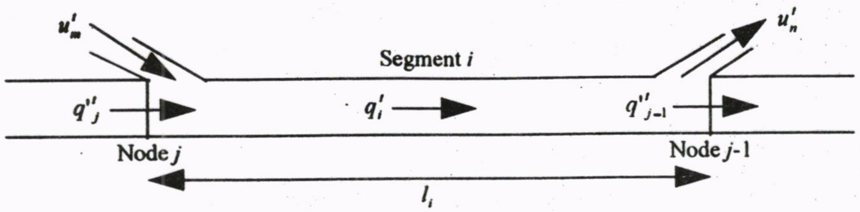


Figure 4. Segment with ramps

m, t_{mn} is travel time on highway between on-ramp m and off-ramp n, and k, α, γ are parameters. In this study, k=10, α=50(yen/min.), γ= -1.6. In practice, decreasing rate of highway utility under the change of toll is expressed as follows:

$$1 - T'_{mn}/T_{mn} = 1 - \left(D_{mn}/D'_{mn}\right)^{-\gamma} \tag{9}$$

3.3 Formulation of the Optimization Problem using GA

It has already been mentioned that the RRCS is a system which brings the highway network in some "optimum" state by solving the optimization problem. Therefore, the objective functions must be defined firstly. Four objective functions are considered in RRSC. First one is the "maximization of total vehicles which pass through the on-ramps". This standard is equivalent to the "maximization of revenue" if toll is uniform and advantageous to the road supplier.

$$\max \sum_t \sum_m u^t_m \tag{10}$$

The second objective function is the "minimization of total travel time". This standard is equivalent to the "minimization of total number of vehicles on whole network" and advantageous to road users.

$$\min \sum_t \left(\sum_i n^t_i l_i d^t_i + \sum_m w^t_m \right) \tag{11}$$

where w^t_m is the number of vehicles which are waiting at waiting space of on-ramp m at time t. The third one is "maximization of total vehicles kilometer". This standard can be regarded as "maximization of momentum"

$$\max \sum_t \sum_i n^t_i l_i d^t_i v^t_i \tag{12}$$

The fourth one is "maximization of total traffic volumes". This standard is aiming at the effective utilization of the highway network when demand is relatively large.

$$\max \sum_t \sum_i q^t_i \tag{13}$$

The constraints of the optimization problems are as follows:

$$0 \leq w_m^t \leq w_m^{\max} \quad {}^{\forall} m \in M, \tag{14}$$

$$0 \leq d_i^t \leq d_i^{\max} \quad {}^{\forall} i \in I, \tag{15}$$

where $w_m^{\max}$ is maximum number of vehicles which can be contained at waiting space of on-ramp m, M is the set of on-ramps, $d_i^{\max}$ is maximum density of segment i, and I is the set of segments. Which standard should be taken is important in accordance with the traffic situation of the highway network, but it is very difficult to decide which is the best standard without some calculation, so this will be discussed after some calculation in Chapter 4.

In this study, setting of control time interval is very important. If this interval is set large, the waiting space will be covered with vehicles at many on-ramps and this causes heavy congestion in the arterial road network. To prevent this, interval should be set short .

In the end of formulation, the method of application of the GA to RRCS is explained. In traffic engineering or transportation planning field, GA has been used in some studies, but these were applicable to the static problem. It seems that to apply GA is advantageous to dynamic optimization studies. GA is based on the principle of survived of the fittest, that is to say, "strong" living things who have ability to adjust themselves to the habitat can survive through many processes such as selection and mutation. When GA is applied to the optimization problems, ability of adjustment means the value of the objective functions. Each living is characterized by a chromosome which is composed of genes, and adequate setting of genes and chromosome is needed in accordance with the type of the optimization problem. In this study, the length of chromosome is equivalent to the number of on-ramps which are objects of ramp control on the whole applied network, and each gene is expressed by code number of ramp control option. For example, if there are 8 on-ramps and 8 ramp control options listed on Table 1, chromosome can be expressed as follows:

0 0 2 0 7 0 0 0,

This shows that if fully opened operation is done at third on-ramp, toll is 500 yen higher than usual at fifth on-ramp, and fully closed operation is done at the rest. Additionally, adequate setting of procedures and parameters is needed in order to get a good solution. In this study, setting of procedures and parameters are done like that shown in Table 2. After doing these operations, the number of vehicles which pass through booths at on-ramp m at time t can be described as follows:

$$u_m^t = h\left(b_m^t, w_m^{t-1}, r_m^t\right), \tag{16}$$

where b_m^t is the code number of ramp control option at on-ramp m at time t, and $r_m^t = \sum_n T_{mn}^t$.

4. APPLICATION OF REAL-TIME RAMP CONTROL SYSTEM

4.1 Summary of Applied Network

RRCS is applied to Kanagawa network of MEX (Figure 5) in the southern part of Tokyo Metropolitan area. Total length of the network is 40.0km (one way) in November 1994 (the new was line opened in December 1994), and 24 on-ramps and 25 off-ramps are there.

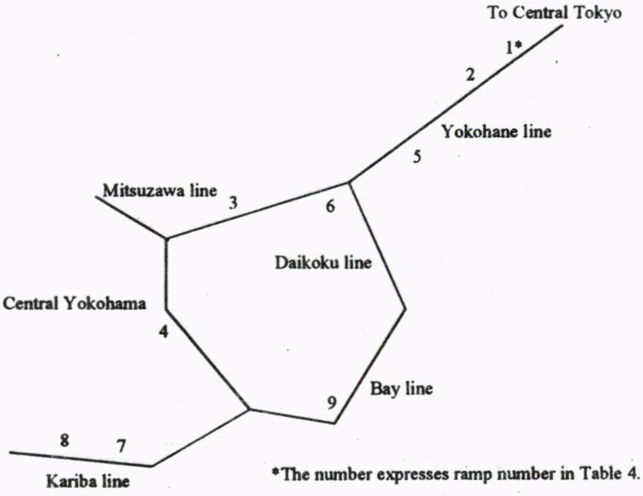
Table 1. The list of ramp control options

Code No.	Ramp Control Option	Code No.	Ramp Control Option
0	Full Closed	4	Raising 200 yen
1	One Booth Opened	5	Raising 300 yen
2	Full Opened	6	Raising 400 yen
3	Raising 100 yen	7	Raising 500 yen

Table 2. Setting of procedures and parameters

Procedures	
Strategy for selection	Rank strategy
Crossover method	One-point crossover
Mutation method	One-point mutation
Convergence condition	When best solution didn't change over 10 generations

Parameters	
Number of livings	40
Crossover rate(%)	100
Mutation rate(%)	5



*The number expresses ramp number in Table 4.

Figure 5. Kanagawa network of MEX

Uniform toll of 500 yen is charged. In peak hours, the Yokohane line is very congested especially in the direction of central Tokyo and near central Yokohama.

As Figure 5 shows, split rates at junction should be considered in the traffic simulation model. Usually, these are affected by congestion level and travel time, and varying time by time, but there is little difference of travel time between two routes through the day of survey, and there is also little difference of split rate c same day, so split rates are assumed constant in this network.

Adequate number of segments should be decided so that RRSC becomes useful in practice. It takes very long time to execute RRCS if the network divided into too many segments. Therefore the applied network is divided into 75 segments so that length of each segment is about 1,000m in this study. The simulation time interval of the traffic simulation model should be affected by length of segment, that is to say, time interval should be set such that any vehicle in each segment cannot go through the following former segment. This interval is decided as 10 seconds.

4.2 Repeatability of Traffic Simulation Model

At first, we must estimate functions about the relationship among the traffic flow variables expressed in equation (6) and (7) in order to execute RRCS. Figure 6 shows the relationships between travel speed and traffic volume (Q-V), between travel speed and average density (K-V), and between average density and traffic volume (Q-K) of the Yokohane line. In

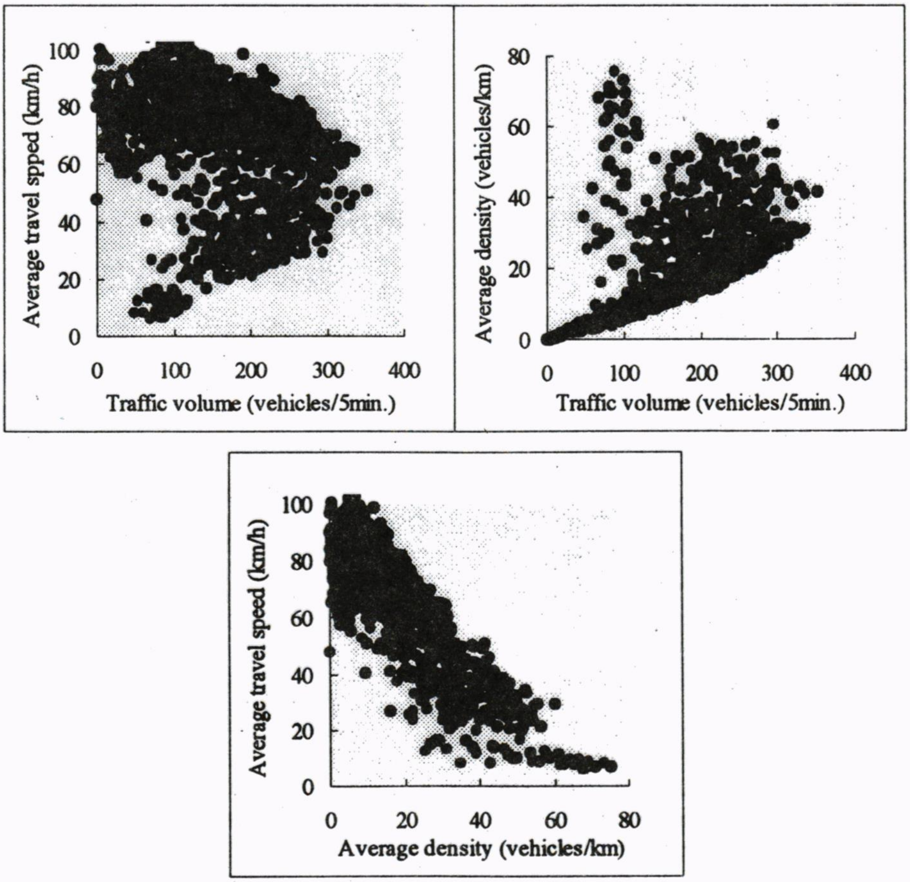


Figure 6. Relationships among the traffic flow valuables

general, these relationships are formulated by some functional forms. In this study, speed-density function is only estimated by actual censor data on weekday because this function is the most available and the easiest one. The linear function is assumed as follows:

$$v = v_{\max}\left(1 - d/d_{\max}\right), \tag{17}$$

where $v_{\max}$ is maximum speed, $d_{\max}$ is maximum density, d is observed density, and v is estimated speed. The results of estimation are as follows: $v_{\max}$ is 93.2 (km/h), $d_{\max}$ is 67.5 (vehicles/km), and R^2 is 0.731.

The repeatability of traffic simulation model is very important in order to evaluate RRCS. Figure 7 shows the correlations between observed values and estimated values of travel speed and traffic volume. It can be understood that the gap becomes larger when simulation time increases and repeatability of this model is only assured during 15 minutes. This indicates that RRCS cannot evaluate long-term effects of ramp control, therefore, short-term effects of RRCS will be evaluated in this study.

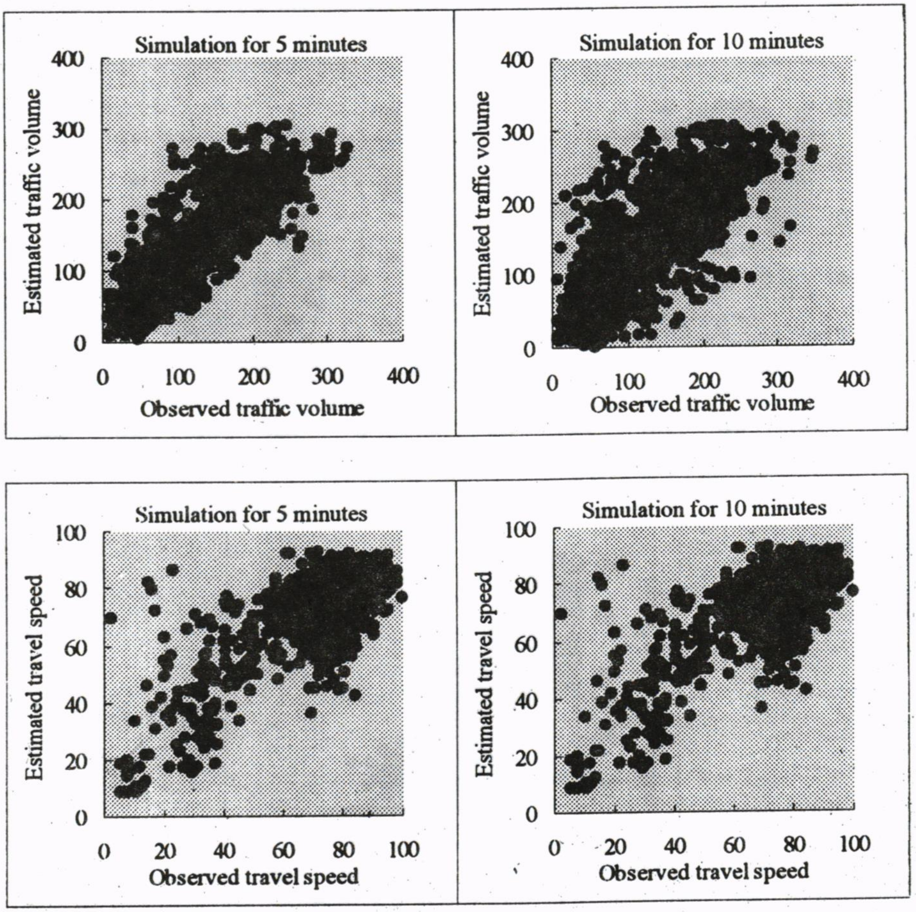


Figure 7. Correlations between observed values and estimated values

4.3 Evaluation of Real-time Ramp Control System

In this section, RRCS is evaluated by applying it to the actual highway network. There are two items of evaluation, one is its time to converge and another is the improvement between with and without control. Simulations are done from 7:00 AM to 7:15 AM under three optimization standards at 1- minute interval using actual data from sensors at 7:00 AM. The number of vehicles which arrive at ramps is decided by Poisson distribution model in which the parameter is the observed average number of arriving vehicles per 10 seconds in peak hours. RRCS is tried three times for each standard. There was no difference between traffic flow values of with control and without control in terms of the standard of the "maximization of total vehicles which pass through on-ramps", so this standard will not be considered. Additionally, the effects of with and without peak load pricing are compared. In this study, there is no comparison among optimization algorithms. The Sun SPARC Station 10 is used for the computation.

Table 3 shows the results of convergence time. It is expected that these do not exceed the unit control time which is 15 minutes, and the result meets this condition. It takes more time to execute RRCS when peak load pricing is implemented, but this is where the division rate model computes the travel time of whole O-D pairs. Table 4 shows the result of the comparison of the patterns of ramp control options in were comparatively large in the peak period. This result roughly shows that the possibility of elimination for freeway use is raised by peak load pricing if drivers tend to pay higher toll. For example, drivers who want to enter Ramp 2 cannot be permitted in the operation without peak load pricing, but if peak load pricing is implemented, they can sometimes enter when they can pay about 400 yen higher than usual. There are some differences of characteristic about the combination of ramp control options among three standards. On-ramp whose waiting space is very small (like Ramp 2) is tend to be closed or charged with high toll under "minimization of total travel time". This is why this standard is equivalent to the "minimization of total number of vehicles on whole network", that is to say, small number of vehicles can wait at such on-ramps. The aim of the "maximization of total vehicles- kilometer" is the smooth disposition of long distance trips, so on-ramps which are near the upper stream of applied network are tend to be opened under this standard. On the other hands, on-ramps which are far from congested segment are tend to be opened under "maximization of total traffic volumes", but both maximization standards are fairly similar because the upper stream of applied network is an uncongested point. Table 5 shows improvement rates under three standards expressed as follows:

$$IR = \frac{O_{with} - O_{without}}{O_{without}} \times 100 \qquad \text{if maximization problem,}$$

$$= \frac{O_{withoout} - O_{with}}{O_{without}} \times 100 \qquad \text{otherwise,} \tag{18}$$

where IR is improvement rate, O_{with} is the value of objective function with ramp control, and $O_{without}$ is the value without ramp control. If this index is positive, it can be said that RRCS is effective. Though high improvement rate can be achieved under "minimization of total travel time", the rate tends to go negative as control time passes under other two standards. This

Table 3. Convergence time of RRCS

*min:sec.msec

Standard	Without peak load pricing 1	2	3	With peak load pricing 1	2	3
Min. of travel time	2:03.56	2:08.25	2:38.41	12:07.12	9:01.61	8:50.42
Max. of vehicles kilometer	2:16.00	2:05.56	2:42.46	7:20.08	8:16.56	11:01.02
Max. of traffic volume	1:50.89	2:29.04	2:41.72	9:06.65	8:10.15	6:37.19

Table 4. The result of ramp control options

Standard		Min. of travel time		Max. of vehicles km		Max. of traffic volume	
Pricing		Without	With	Without	With	Without	With
Ramp No.		1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9	1 2 3 4 5 6 7 8 9
Set	Time						
1	7:01	1 0 1 0 0 0 2 2 0	5 7 7 5 3 2 4 4 5	0 0 1 2 2 2 2 2 1	6 0 0 6 3 2 1 6 6	0 0 0 1 1 2 1 2 1	6 7 3 4 2 2 0 0 5
	7:02	0 0 0 0 2 1 2 2 1	7 5 1 0 6 0 7 6 1	0 0 0 2 1 2 2 1 0	3 0 4 5 3 1 7 1 3	0 0 2 2 2 2 1 2 0	0 0 4 4 2 3 2 1 1
	7:03	2 0 1 0 0 2 1 2 1	3 7 5 0 5 3 3 6 0	0 0 1 2 2 2 2 0 1	6 0 7 4 2 2 4 5 3	0 0 1 2 2 2 2 1 2	0 0 2 6 5 1 4 4 0
	7:04	2 0 0 0 0 2 0 1 2	0 6 3 0 4 0 7 0 3	0 0 1 0 2 2 1 2 0	4 0 0 5 1 1 5 1 3	0 0 1 2 1 1 2 1 1	0 5 7 4 4 1 4 7 5
	7:05	1 0 0 0 1 1 0 2 2	6 7 3 0 7 6 6 7 3	0 0 0 0 2 1 0 2 2	6 0 2 6 0 6 3 0 6	0 0 0 1 1 0 1 2 1	0 5 2 2 1 4 6 3 4
	7:06	2 1 0 0 2 2 0 0 1	3 7 3 0 0 3 7 7 7	1 0 0 2 2 1 2 2 0	0 0 5 1 3 0 4 4 5	0 0 0 2 0 2 2 2 2	0 0 6 6 6 6 4 5 4
	7:07	2 1 0 0 1 0 0 2 1	4 2 2 0 6 0 5 5 0	0 0 0 1 1 1 1 1 1	4 2 0 6 2 2 2 6 4	0 0 2 2 2 2 1 0 1	1 0 1 4 3 0 7 4 3
	7:08	2 0 0 0 1 2 0 2 2	7 1 6 0 6 0 7 5 2	0 0 1 0 1 2 2 2 0	7 5 1 1 3 1 3 2 7	0 0 2 2 2 0 2 1 2	6 0 5 3 5 6 2 3 1
	7:09	1 0 0 0 1 1 0 0 2	4 1 5 0 2 6 5 2 3	0 0 2 1 1 2 2 2 2	2 2 2 2 2 2 2 2 2	0 0 2 0 1 2 2 1 1	4 0 4 7 1 2 3 1 3
	7:10	2 0 0 1 0 1 0 0 1	6 5 6 7 1 5 2 7 5	1 0 2 2 1 1 2 1 1	4 1 0 2 1 4 7 6 2	0 0 1 0 2 1 0 2 2	0 1 4 7 2 5 2 6 1
	7:11	0 0 0 0 1 0 0 2 2	6 5 6 6 5 7 6 1 4	0 0 0 2 2 0 2 0 2	0 4 0 0 4 6 7 1 1	0 0 2 0 1 0 2 2 1	1 0 1 5 1 3 3 4 6
	7:12	1 1 0 0 0 0 0 2 0	7 6 7 7 4 1 4 6 6	0 0 0 1 2 2 2 1 1	0 3 4 4 1 5 2 2 3	0 1 0 2 1 2 1 2 0	6 0 7 5 5 2 3 0 1
	7:13	1 0 2 0 2 2 0 0 0	7 6 7 5 7 7 6 7 4	0 2 0 0 2 2 0 2 0	1 3 2 1 2 7 1 0 6	1 0 1 1 1 0 1 0 1	3 0 1 2 4 1 2 5 3
	7:14	2 0 1 0 1 2 2 0 2	1 5 5 0 4 7 6 6 2	1 1 0 0 1 0 2 2 1	0 0 2 7 4 6 1 6 5	0 0 0 1 2 2 2 1 1	5 0 1 6 3 6 5 0 7
2	7:01	2 1 1 0 1 1 0 0 0	4 6 6 7 5 3 5 7 1	0 1 2 0 1 1 1 2 1	5 0 3 5 1 6 3 3 2	0 0 1 2 1 2 1 1 2	5 7 6 5 1 2 4 3 7
	7:02	1 2 2 0 1 0 2 2 1	7 6 7 1 6 1 6 7 2	0 0 0 0 2 0 2 1 2	0 4 0 7 2 5 6 2 6	0 0 1 2 2 2 1 1 0	6 0 6 0 5 1 7 1 2
	7:03	1 0 0 0 2 1 1 1 1	0 7 7 7 1 4 2 7 4	0 0 2 1 1 2 1 2 2	0 7 6 4 5 6 3 2 0	0 0 0 0 1 2 1 1 0	6 0 0 0 2 2 2 5 2
	7:04	1 0 1 0 2 2 0 0 2	5 7 6 0 7 7 2 0 7	0 0 0 0 1 2 2 2 1	0 4 7 7 1 7 5 1 5	1 0 2 1 1 0 2 2 1	6 0 0 0 3 5 2 0 4
	7:05	2 0 0 0 2 2 2 1 1	6 6 3 0 7 1 6 3 7	0 0 0 2 1 1 1 1 1	0 7 0 2 2 3 6 3 0	0 0 2 2 1 1 1 1 2	0 0 0 2 7 6 5 1 3
	7:06	2 0 1 0 1 0 0 2 2	3 0 0 0 6 5 5 3 6	1 1 2 2 1 1 1 1 0	0 7 0 6 1 4 4 0 0	0 1 2 1 1 2 1 1 2	2 2 2 2 2 2 2 2 2
	7:07	1 0 2 0 1 0 0 0 1	5 0 6 0 2 1 5 7 6	0 0 1 2 1 0 2 0 1	1 0 1 3 4 5 6 6 7	0 1 0 0 1 1 1 1 1	5 1 0 7 5 1 7 6 7
	7:08	2 0 0 0 1 0 1 2 0	5 0 6 7 3 5 0 3 4	0 0 2 0 1 2 1 2 1	1 0 0 6 5 2 7 3 4	0 1 0 2 2 1 2 2 0	2 1 0 3 6 6 1 6 2
	7:09	1 0 2 0 2 1 1 1 1	4 0 7 7 6 4 7 6 3	0 0 1 0 1 2 0 1 1	6 0 1 4 1 0 7 4 4	0 1 1 2 1 1 1 2 1	5 7 0 4 5 6 3 7 4
	7:10	0 0 1 0 0 2 2 1 2	4 0 5 0 4 5 5 2 0	1 0 1 0 1 0 2 1 1	5 0 0 0 5 5 6 4 4	0 2 1 0 2 2 2 2 2	2 2 2 2 2 2 2 2 2
	7:11	2 0 2 0 0 2 2 2 2	3 0 1 0 6 3 4 3 7	0 0 2 2 1 1 2 2 1	1 0 0 1 3 2 2 3 5	0 1 2 0 1 1 2 2 1	0 5 0 4 2 5 5 1 7
	7:12	2 1 0 0 0 2 2 2 1	6 0 6 0 6 1 7 7 2	1 0 1 2 0 1 1 1 1	2 0 4 5 2 2 3 4 3	0 0 1 0 1 2 1 1 0	0 1 1 1 3 2 3 3 2
	7:13	1 2 2 0 0 0 1 2 0	7 7 7 0 7 6 4 2 2	0 0 0 0 2 0 0 0 1	2 0 4 3 6 3 3 6 3	1 0 0 2 2 2 2 0 2	0 4 5 0 2 1 2 6 5
	7:14	1 0 0 0 0 2 1 1 2	7 6 7 0 5 1 1 0 4	0 0 2 0 1 1 2 2 2	1 0 0 0 3 1 0 4 6	0 0 0 1 1 2 2 0 2	0 0 0 6 2 3 5 1 7
3	7:01	2 0 1 0 2 2 0 2 1	4 1 7 5 5 5 7 1 7	0 1 1 1 2 1 2 2 0	2 2 2 2 2 2 2 2 2	2 0 0 2 2 2 2 1 0	2 2 2 2 2 2 2 2 2
	7:02	0 0 2 0 0 0 0 0 2	7 0 0 0 4 2 7 5 4	0 0 1 1 2 0 1 1 1	4 4 4 2 1 5 2 2 4	1 0 2 1 2 2 1 0 1	0 1 0 2 2 6 7 5 2
	7:03	2 0 1 0 0 1 0 2 2	4 0 4 0 7 5 7 5 2	0 0 1 0 1 1 2 1 0	7 0 7 7 1 3 1 3 4	0 0 2 1 1 1 2 1 1	0 5 7 0 4 1 4 2 5
	7:04	2 0 0 0 0 1 1 1 2	6 2 7 0 7 5 2 4 2	0 0 0 0 2 2 2 1 0	0 0 6 7 4 5 6 1 3	0 0 0 0 2 1 2 0 1	2 0 4 4 3 3 4 4 1
	7:05	0 0 0 0 2 0 2 1 0	5 0 6 6 0 6 3 2 1	1 0 0 1 1 1 1 2 1	1 1 2 0 5 1 2 1 4	0 1 0 0 0 2 2 1 0	7 0 1 7 3 0 3 0 0
	7:06	2 0 0 0 2 0 0 1 1	3 5 3 7 5 6 6 4 1	0 0 1 2 2 2 0 2 0	0 7 7 3 2 5 2 4 2	0 0 0 2 2 2 1 1 2	7 0 4 5 7 6 2 7 2
	7:07	2 0 0 0 0 1 0 2 2	1 6 7 6 7 4 7 6 5	0 0 0 2 1 1 2 2 0	0 6 2 4 1 1 2 2 3	0 0 1 2 2 1 2 2 1	0 0 5 6 4 7 3 7 2
	7:08	1 0 0 0 0 0 0 2 1	5 7 3 7 5 2 4 6 5	0 0 1 1 1 2 1 2 2	0 2 7 6 3 2 2 2 0	0 0 2 0 1 1 1 2 2	0 0 0 5 1 1 2 7 1
	7:09	2 0 0 0 0 1 2 2 0	5 7 7 7 4 7 0 1 4	0 0 0 2 2 1 1 1 2	0 0 3 2 1 1 5 7 5	0 0 1 2 2 0 2 1 0	0 1 5 3 6 2 4 7 0
	7:10	2 0 0 0 1 1 0 1 0	5 7 7 6 7 5 0 2 0	0 0 2 0 2 0 2 1 1	0 7 1 2 3 2 1 2 2	0 1 1 2 1 1 1 2 1	0 0 2 2 3 7 2 0 4
	7:11	1 0 1 1 2 0 0 1 1	7 7 5 7 6 1 7 2 4	0 0 2 0 2 2 2 1 1	0 1 4 3 1 1 2 1 7	1 0 1 0 1 0 2 2 2	0 0 1 2 6 7 3 2 3
	7:12	0 0 2 0 0 2 0 0 0	3 4 6 7 6 5 3 1 3	0 0 0 0 1 0 0 2 1	1 2 4 6 2 1 1 2 3	0 0 2 1 1 1 2 2 0	0 6 0 5 1 4 5 3 4
	7:13	2 0 1 1 0 2 0 1 0	5 6 5 5 7 5 7 0 2	0 2 0 0 2 0 2 2 2	1 2 3 7 5 6 3 4 3	0 0 2 0 2 2 2 2 2	1 3 4 2 2 5 4 5 1
	7:14	1 0 0 1 1 0 0 1 0	6 5 6 6 6 6 7 3 6	1 1 0 1 1 1 2 1 1	6 4 7 6 4 4 7 4 0	0 0 2 2 1 2 1 0 1	0 7 1 7 4 3 7 7 7

Table 5. Improvement rate of RRCS

(%)

Standard Pricing		Min. of time		Max. of Veh. km		Max. of volume	
		Without	With	Without	With	Without	With
Set	Time						
1	7:05	1.68	2.88	0.91	0.40	1.32	0.54
	7:10	8.09	9.72	3.75	0.88	4.11	0.67
	7:15	11.84	12.58	1.50	-3.81	6.48	-0.51
2	7:05	2.12	2.35	1.94	0.18	1.02	0.44
	7:10	8.73	8.03	4.47	1.42	1.93	-0.10
	7:15	11.62	12.33	5.61	-3.25	-0.43	-3.87
3	7:05	6.38	2.43	1.19	0.38	0.63	0.10
	7:10	6.93	9.00	3.75	1.15	2.37	-0.88
	7:15	12.61	10.57	0.86	-4.18	2.38	-3.63

results from short time intervals of ramp control, but long time intervals cannot be chosen because the concept of this control method does not permit the selection of long time intervals. But it is insufficient to use the objective function which only uses the traffic variables of freeway, so a new objective function which uses not only the traffic variables of freeway but that of arterial roads may be considered.

It could be considered that the effectiveness of RRCS using GA is partially confirmed by the results of some calculation. Also, it was confirmed that the possibility of elimination was mitigated by the implementation of peak load pricing. But if algorithm is improved, other options can be implemented. For example, there is a possibility that each booth can choose different options at same on-ramp. When there are two booths at some on-ramp, and peak load pricing is implemented at one of booths and the other is closed, drivers who don't want to pay high toll can wait until it becomes more advantageous for them. It will be possible to construct such system by applying GA.

5. CONCLUSION OF THIS STUDY AND THE POSSIBILITY TO APPLY REAL-TIME RAMP CONTROL SYSTEM IN ASIAN COUNTRIES

In this study, a real-time ramp control system which evaluates the effects of various ramp control options are constructed by the application of GA, and its effectiveness is confirmed in spite of the insufficient repeatability of traffic simulation model. Peak load pricing is applied as ramp control option and its role, mitigation of the possibility of elimination of freeway use, is confirmed. But there are still things which are improved as follows.

(1)In terms of modeling, repeatability of traffic simulation model in long periods in congested situation should be improved in order to evaluate the effects of ramp control in period longer than 1 hour.

(2)In this study, K-V, Q-V and Q-K curve are considered uniform in each line. But these may depend on geometric condition such as lane width, so segments should have different curves.

(3)The objective of this study is to construct new ramp control system, in which on-ramps get as a buffer in order to mitigate congestion in arterial roads, but there is no objective function which is described by some variables of arterial road.

(4)In this study, segments are not divided into lanes. But the characteristics of traffic flow are different among lanes, so traffic simulation model should be constructed not by segment level but by lane level.

(5)In this study, control option is uniform among toll booths, but these may have different strategies in order to help drivers decide their attributes, waiting or entering with high fare. It is easy to consider such situation if using GA.

Finally, the possibility that such RRCS is applied to the freeway network in developing countries in Eastern Asia will become important in the future. The reasons are expressed as follows:

(1)Total stock of road infrastructure is limited and congestion problem becomes serious in these countries. In this background, the need of effective utilization of urban expressway is essential in order to maintain economic growth. Therefore, ramp control of the urban expressway becomes very important.

(2)In these countries, the implementation of the toll policy as demand control has large effect on driver's expressway use because the demand for expressway use may be very sensitive to the change of toll level such as peak load pricing. But people are against its implementation, so this should be combined with the implementation of usual ramp control method.

There are some considerations in order to apply RRCS in these countries. Firstly, the difference in driver's behavior may be very large because of the gap of income level, and also, the behavior of passenger car is quite different from that of heavier vehicles or buses, such that the segmentation of drivers and analysis of behavior for each segmentation are needed. Finally, real-time traffic data collection system is needed in order to apply RRCS and the installation of many traffic counters will be very important and its needs will become urgent.

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