Evaluation of On Ramp Metering on Hanshin Expressway Using Traffic Simulator(HEROINE)

Takehiko YUKIMOTO*, Masashi OKUSHIMA**,
Nobuhiro UNO** and Takehiko DAITO****

** Chief Clerk, Hanshin Expressway Public Corporation*
KyutaroCyo4-1-3, Chuo-ku, Osaka, 541-0056, JAPAN
Tel: +81-6-6252-8121, Fax: +81-6-6252-7410
*** Research Associate, Department of Civil Engineering, Gifu University*
Yanagido1-1, Gifu, 501-1193, JAPAN
Tel: +81-58-293-2446, Fax: +81-58-230-1528,
E-mail: okushima@cc.gifu-u.ac.jp
**** Associate Professor, Department of Civil Engineering, Kyoto University*
YoshidaHonmachi, Sakyo-ku, Kyoto, 606-8501, JAPAN
Tel: +81-75-753-5126, Fax: +81-75-753-5907,
E-mail: uno@urbanfac.kuciv.kyoto-u.ac.jp
***** Managing Director, Transportation System Studies Laboratory Co., Ltd.*
NishiNakajima7-1-20, Yodogawa-ku, Osaka, 532-0011, JAPAN
Tel: +81-6-6101-7001, Fax: +81-6-6101-7002,
E-mail: daito@tss-lab.com

ABSTRACT

Recently, because of progress in technologies around the road network, the needs for practical use of an on-ramp metering control model are getting higher and higher. This study attempts to propose an on-ramp control model, which is more reasonable, efficient, and available for actual application. Proposed methods such as on-ramp metering control were evaluated be using a traffic simulation model (HEROINE). As a result of evaluation, the proposed “On-Ramp Metering Control Method” was proved to be more effective than the “On-Ramp Closure and Booth Restriction Control Method” now in use, and was able to manage the traffic condition more reasonably. In the future, not only the development of the concrete on-ramp control technique but also the application as a social experiment for making social agreement is required.

INTRODUCTION

The evolution of system for traffic control makes dynamic and large traffic data on expressways more available, and traffic data on ordinary streets becomes observable. Using these data, based on real time traffic condition, appropriate traffic control measure can be adopted. With the progress of interactive communication on vehicles and collecting information by probe car, the accuracy of traffic information is improved and information service in real time can be distributed for in-vehicle units at any elective point and any timing. So, the situation of traffic control can be announced immediately and precisely. Also tollgate equipment for ETC can make inflow adjustments at even intervals, and realize traffic control according to control ratio.On the other hand, expansion of networks may supply alternative routes and ramps instead of dealing with congested sections and restricted on-ramps.

Several previous studies proposed methods for on-ramp control, which was represented by the LP control model, to cancel or reduce traffic congestion on the Hanshin Expressway. Because of the problems in the development of the facility equipment and in the way of practical use, “On-Ramp Closure and Booth Restriction Control” was adopted immediately. However, by the changes of traffic environment as above the needs for practical use of “On-Ramp Metering Control” are getting higher and higher.

In this study, it was set as a goal to put “On-Ramp Metering Control” into practical use through a quantitative evaluation. This study consists of 3 parts, 1) proposal of practical ramp metering method, 2) structure of traffic simulator with not only expressway flow model but also ordinary streets flow model and route choice model, 3) evaluation of traffic control methods with the results of estimate by HEROINE on the route of Osaka-Ikeda Line and around mainly ordinary streets.

RAMP CONTROLER METHOD

Outline of Inflow Control

In Japan, the lineal programming control model to protect against occurrence of traffic congestion in a preventative method has not already been applied. To ease and cancel congestion, the method of on-ramp control through temporary and successive closing of tollgates has been adopted.

In this study, for laying stress on the actual application, the suggested method of “On-Ramp Metering Control” is based on the frame of “On-Ramp Closure and Booth Restriction Control Method” now in use. With response to the occurrence or the expansion of traffic congestion, the proposed method control interval of vehicles flowing into tollgates above the origination point of congestion.

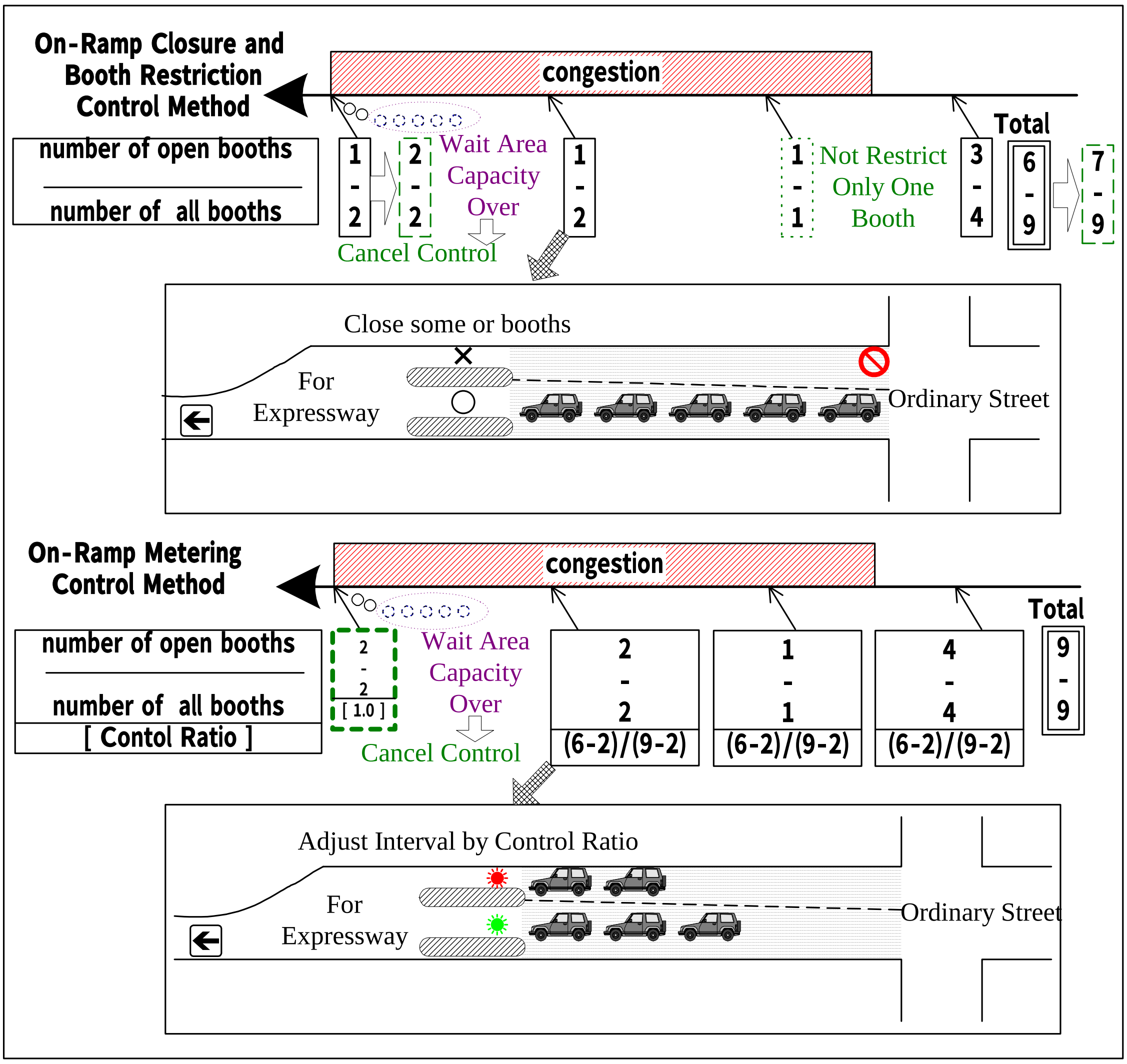


Fig.1 Ramp Control Method

On-Ramp Closure and Booth Restriction Control Method

The Traffic control method now in practical use manages to ease congestion on center loop route or up route to center loop. The congestion class is determined with 5 ranks in proportion as the length of congestion parts. According to the congestion class the number of open booths increase and decrease on the upper side on-ramps. As like the LP-control method, considering arrival rates from on-ramp to bottleneck section calculated on the static OD-matrix, the number of open booths is adjusted. Because we cannot reach social agreement for perfect closure of on-ramp in a part of the area, it is gotten away from as much as possible. So the on-ramp with only one booth cannot be restricted. When the ramp closes completely, it needs to open again in 30 minutes. Based on the “Traffic Control Manual”, which consists of the rules as such, the traffic control officer set the number of restrict booth in practical operation, and notify for toll collector to close or open booths.

Because this control method is not precautionary, it cannot reject the occurrence of traffic congestion. Of course, the LP-control method cancels it, but inflow volume into expressway is repressed, so we have a concern as the other congestion break out on the ordinary roads.

On-Ramp Metering Control

"On-Ramp Closure and Booth Restriction Control" requires closure of some or all booths. However, the equipment of the tollgate for ETC makes traffic control more flexible and dynamic. Therefore, by using "On-Ramp Metering Control" the booths do not have to be closed continuously. The inflow interval of waiting vehicles was adjusted by using control rate, which is calculated as follows.

$$R = \left(\sum_i m_i - \sum_i \delta_i M_i\right) \Big/ \left(\sum_i M_i - \sum_i \delta_i M_i\right) \qquad (1)$$

R : Control Ratio (= Inflow Rate)

M_i : Number of all booths at on-ramp [i]

m_i : Number of open booths at on-ramp [i] by "Booth Restriction Control"

δ_i : Dummy Variable (Waiting vehicles over waiting space capacity or Not)

So the on-ramp with only one booth is subject to inflow control. When on-ramp waiting queue goes over waiting space capacity, the on-ramp control could not continue to prevent the occurrence of traffic congestion on ordinary road around the on-ramp. At that time, control rate calculates again without on-ramp where the queue length of waiting vehicle has gone over more than maximum.

SIMULATION MODEL STRUCTURE AND VALIDATION

Outline of Traffic Simulation Model

The traffic simulator (HEROINE) was developed for simulating the situation on Hanshin Expressway. Fig.2 shows "HEROINE" configuration, which has 6 sub-models for estimation of traffic condition in the short term. It is based on a macro traffic flow simulation model. The traffic flow is described by moving vehicles from upper to lower block with considering density of blocks per 10 sec. For example, inflow traffic volume, traffic condition (units in block, passed volume, velocity, occupancy, density, judge of congestion) of blocks, queue length at tollgate, several kinds of characteristics could be calculated and outputted.

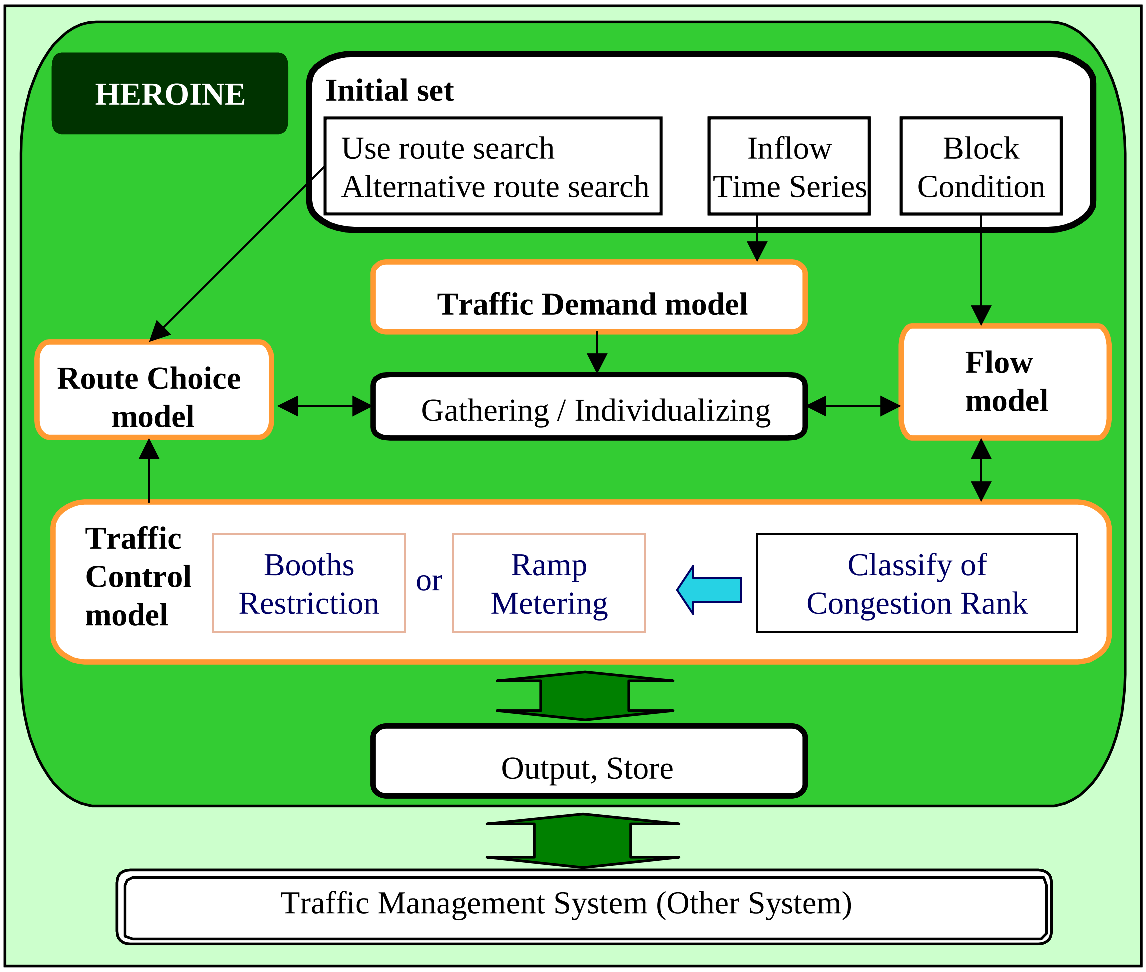


Fig.2 Traffic Simulator Configuration

Traffic Control Model

Classification of Congestion Rank

Traffic condition is observed every five minutes in practical. So the Traffic Management System reports the occurrence point and the length of congestion to the traffic control officer every 5 minutes. Then a section is judged by flow volume and occupancy whether congested or not. In the Traffic Control Manual, the congestion rank is classified to 5 ranks in proportion to the length of congestion at each potential point of occurring congestion. The number of open booths is set at each point and each rank of congestion.

Flow Interval through the Booth

When no congestion can be observed, service interval flow is 6sec per vehicle through a booth where a toll is paid to a collector. Each booth lets vehicles pass independently. At each tollgate each driver selects the booth with the shortest length of queue. Each gate counts the number of passing vehicles and reports it to the expressway flow model.

When we adopt “Booth Restriction Control” to ease congestion, service interval of open booths doesn’t change and drivers cannot select closed booths. So the closed booths let the vehicles at the queue flow into by default service interval until the queue disappears.

When we adopt “Ramp Metering Control” to ease congestion every booth in operation doesn’t close. First, service interval of the tollgates on the whole is updated by control ratio with consideration of the number of booths at the ramp with the exception of tollgates where the number of waiting vehicles overreaches waiting space. Secondly, considering the interval seconds of the tollgates on the whole the booth with the longest seconds to wait lets a vehicle flow into the expressway.

$$TG_i = TB_0 / (R \times M_i) \qquad (2)$$

TG_i : Interval Seconds of Tollgate[i] on the whole

TB_0 : Default Interval Seconds of Every Booth

R : Control Ratio (= Inflow Rate)

M_i : Number of Booths on Operation at Tollgate [i]

Consideration of Influence for Ordinary Roads

Because traffic control might cause driver’s to make detours to ordinary streets, inclusive evaluation of traffic condition on ordinary roads was required. The behavioral model was applied in addition to the traffic simulation model, for considering the driver’s route choice by traffic information and traffic control.

The two-level nested logit model is assumed for the driver’s route choice at the on-ramp. [1] On the upper side model, the driver makes a choice to use the expressway or not at first. On the lower side model, the expressway user selects to use the original ramp or detour ramp.

On the ordinary streets, the flow model structure is based on simply Input-Output model with no consideration for jammed cars at the intersection, because we have a lot of difficulty in estimation of details in real-time at the ordinary streets. A vehicle on an ordinary street moves to the next link until the end of the estimated travel time by 10-model.

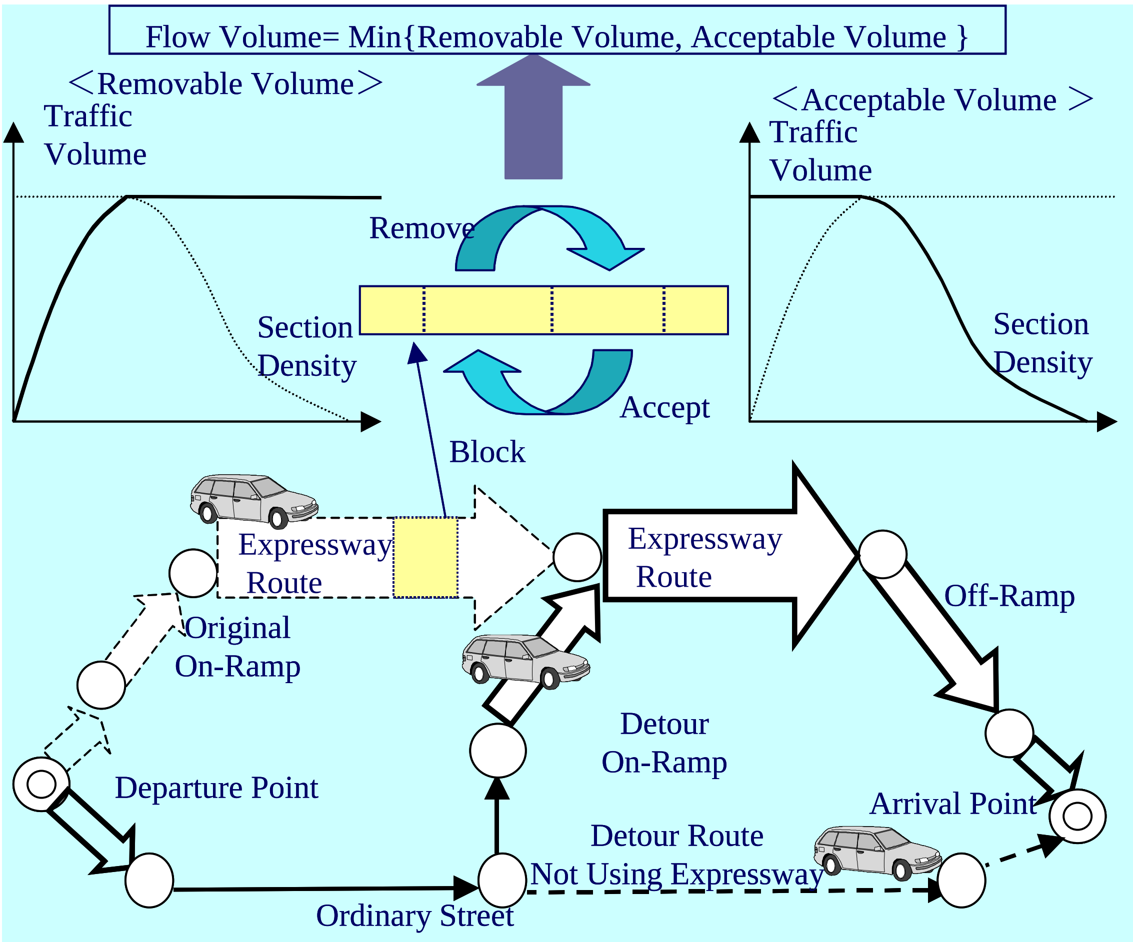
$$T_{i,n} = \max\left\{ T_{i,n-1} + (Q_i - C_i) / C_i \times \Delta t \,, \quad T_{i,0} \right\} \qquad (3)$$

$T_{i,n}$: Travel Time of a Vehicle into Link [i] at Scan [n]

$T_{i,0}$: Travel Time of a Vehicle into Link [i] at the Zero Flow.

Q_i : Inflow Volume of Link[i] per Δt

C_i : Capacity of Link[i] per Δt



Δt : Scan Interval of flow model on ordinary streets (constant of 60sec)

Fig.3 Flow model and Alternative Route

Relation between flow model and behavior model

Initial Set of Route

Original route on expressway between on-ramp and off-ramp is researched by minimum tree on free travel time. Detour route on ordinary streets between on-ramp and off-ramp, and detour routes to alternative on-ramp are also researched by minimum tree on free travel time.

Individualizing and Gathering

According to the number of gathering vehicles for the flow model, each vehicle is identified. For the flow model, the number of vehicles is counted at each section. On the flow model, several variables (density, speed, occupancy, flow volume) are calculated based on the number of vehicles in each block.

Traffic Information Set and Summing of route value

Most recently traffic information by flow model is set for links at each 5 minutes. The route value (travel time, length of congestion, original ramp control or not, etc.) is summed at each route.

Route Choice

By the driver's route choice model at the on-ramp, each vehicle's route is determined. So, first the probability of using a detour route to contain only ordinary streets' link is estimated by the route value (rate of congestion length, etc.) and a driver selects to use the expressway or not. Secondly, the probability of using the detour on-ramp is estimated by the route value (original ramp control or not, etc.) and a driver selects to use the original on-ramp or not.

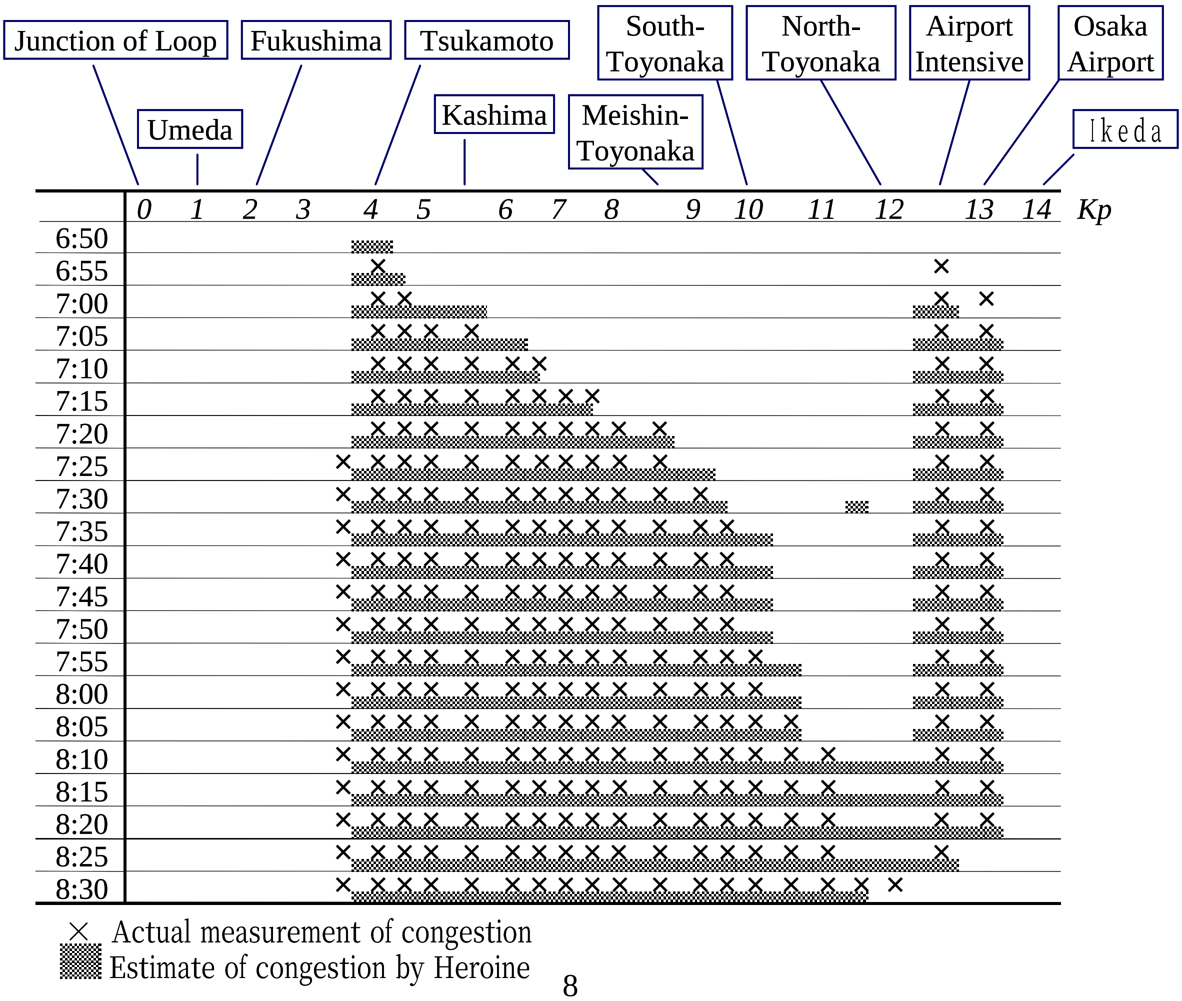


Fig.4 Comparison of Actual and Estimate congestion

Validation by Estimation of Current Situation

Set of the Inflow Demand Volume

As the result of driver's route choice, Observed inflow volume was realized. So we estimated potential of inflow demand volume with observed inflow volume by detector and the probability of using expressway, which was calculated by route choice model with rate of observed congestion length. Estimated demand of inflow volume at the Osaka-Ikeda Line on Hanshin Expressway is 10,489 vehicles (+3.3%up) between 6:30-8:30, 10,486 vehicles (+3.8%up) between 14:00-16:00, 9,549 vehicles (+3.1%up) between 17:00-19:00.

With these estimated demand volumes, inflow volumes at each ramp were calculated to 10,159 vehicles (error: +0.1%) between 6:30-8:30, 10,233 vehicles (error: +1.3%) between 14:00-16:00, 9,356 vehicles (error: +1.1%) between 17:00-19:00. So the difference between estimated volume and observed volume is very small. The route choice model is available to adopt for the estimation of traffic condition with alternative traffic control method.

Validation of the Flow model

By estimation of the current situation on the expressway, the flow model on HEROINE was validated. Fig.4 shows that the estimate value by flow model was compared with observed value by detectors. On the whole it was confirmed that the traffic simulator reproduced the occurred time and point, and the expending and contracting of traffic congestion.

ESTIMATION OF RESULT AND EVALUATION

Each "On-Ramp Closure and Booth Restriction Control Method", "On-Ramp Metering Control Method" and current situation was evaluated by the estimation results calculated using HEROINE.

On Expressway

The result of "On-Ramp Metering Control" was more volume of inflow, less volume of congestion, and higher average travel speed than others. Because the control caused congestion to ease early, the traffic situation didn't need the inflow control at the tollgates. Therefore, drivers made a choice to use the expressway, so the volume of inflow recovered in short time.

The length of the waiting queue at on-ramps reached nearly the limit of the waiting area. (Definitely, it couldn't pass over that limit without affecting ordinary streets.)

Especially at the tollgate of Osaka-Airport, several hundred vehicles need to wait.

Table.1 Evaluation of Control Method by the Results on Expressway

Control Method		Current Estimation (Not Control)	On-Ramp Closure & Booth Restriction Control	On-Ramp Metering Control
Express Way	Congestion Volume (km*hour)	12.5	11.2	10.9
	Inflow Volume (vehicles)	10159	10159	10192
	Travel Time (hour)	2773	2710	2650
	Average Speed (km/hour)	29.3	30.1	30.5
Ordinary Streets	**Travel Time of Detour Trip(hour)**	**82**	**85**	**75**
	Travel Time of Original Trip(hour)	**21534**	**21543**	**21530**

At Osaka-Ikeda Line on Hanshin Expressway between 6:30-8:30

<u>Average of Travel Time from Each Ramp</u>

By ramp control, the average travel time of vehicles decreased, which flowed into a farther ramp from the bottleneck section. On the other hand, it took longer time for the vehicles into a ramp near the bottleneck to travel than the case, in which the ramp control was not adopted (fig.5). However, the difference between ramps (regions) was eased more by “On-Ramp Metering” than “On-Ramp Closure and Booth Restriction”.

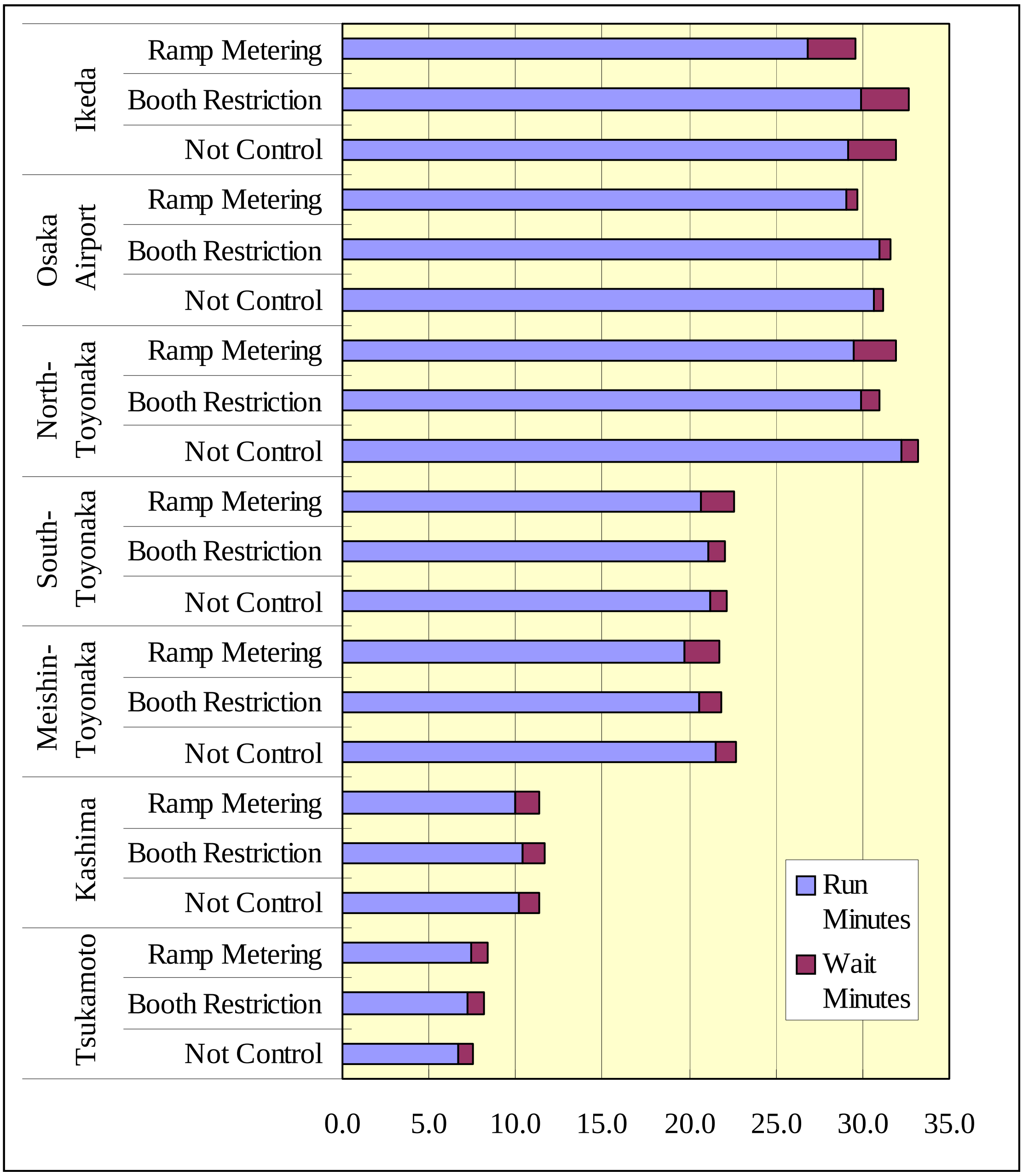
<u>On ordinary streets</u>

As traffic congestion was eased by on-ramp control, the ratio of expressway users recovered, and the volume of detour traffic was the same in each case. So, little influence of detour traffic was shown.

<u>Total Evaluation</u>

As a result of evaluation, proposed “On-Ramp Metering Control Method” was proved to be more effective than “On-Ramp Closure and Booth Restriction Control Method” now in use, and was able to manage traffic condition more reasonably.

Basically, economical evaluation was supposedly needed. However, with the progress of the “Intelligent Transportation System”, the observation equipment, the tollgate equipment for ETC, and the infrastructure of electrical data communication and other methods being promoted, the investment of setting equipment and the developing system for “On-Ramp Metering” decreased appreciably.



At Osaka-Ikeda Line on Hanshin Expressway between 6:30-8:30

Fig.5 Average of Travel Time from Each Ramp

CONCLUSIONS AND NEXT STEPS

Firstly, in this study, the details of the practical traffic control method on urban expressways, both of “On-Ramp Closure and Booth Restriction Control” and “On-Ramp Metering Control” are described, and we developed a traffic control model to apply for 2 types of method as above.

Secondly, for the evaluation of traffic control method, we extended the traffic simulator (HEROINE) with the traffic control model and route choice model at the ramps and flow model on the ordinary streets. Each model was validated by comparison of estimated value and observed value on current condition.

Thirdly, from the look of the only result for estimation, “Ramp-Metering Control Method” might be proved to be more effective than “On-Ramp Closure and Booth Restriction Control Method” now in use, and be expected to reduce the traffic congestion on the Hanshin Expressway. On ordinary roads, little influence of detour traffic was shown by estimate results.

The next step needs actual proof of expected effect by social experiment, for example, on the Osaka-Ikeda line where one of the most severe traffic congestions has occurred. Such a social experiment is expected to make social agreement for traffic control.

To control interval of vehicles flowing into tollgates actually, technical availability of actually application have to be confirmed.

On online real-time, HEROINE will be used to estimate the traffic condition in short term. So, we need to develop a more advanced control method with considering estimation of inflow demand and length of congestion.

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