Evaluation Study of Inflow Traffic Control by Ramp Metering on Tokyo Metropolitan Expressway

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EXTENDED ABSTRACT

Traffic congestion is a common problem; particularly in metropolitan areas. It is especially true for the Tokyo Metropolitan Freeway (MEX) which handles about 1.2 million vehicles per day. Thirty percent of these vehicles use the MEX central circular and radial routes causing chronic traffic congestion. A traffic-control center in Japan mitigates the congestion by governing access to MEX entrance ramps using empirical methods per 30 minutes; which is reasonable, albeit a static traffic-control strategy. Ramp metering is another effective and dynamic traffic-control strategy which is not yet implemented and is examined in this study.

The purpose of this study is to evaluate the effects of real-time ramp metering introductions on the MEX radial route #3 (Shibuya) and radial route #4 (Shinjyuku) by traffic simulations. Ramp metering is defined as a method of improving overall freeway operations by limiting, regulating and timing the entrance of vehicles from one or more ramps onto a freeway.

The proposed ramp-metering was initiated by detecting congestion at intersections. The traffic condition was monitored in real time and sent to the ramp signal. The ramp signal received the detector information from a position 200m upstream from the intersection. The actual ramp metering depends on the degree of congestion. Traffic conditions during ramp metering such as the queue length were also monitored to avoid excessive ramp congestion as shown in Figure 1.

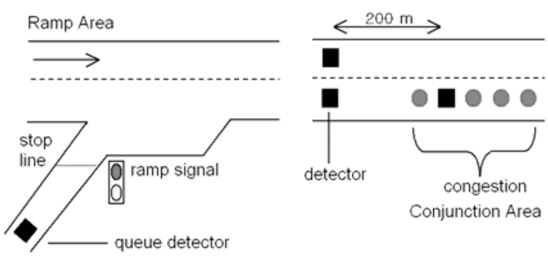

Figure 1. Layout of detectors at the ramp

The traffic simulator 'VISSIM version 3.70' was used with the controlling software 'Vis-Vap'. VISSIM was developed and is distributed by PTV in Germany. VISSIM is the microscopic, time-step and behavior-based simulation software to model urban-traffic and public-transit operations. Vis-Vap enables us to implement the proposed ramp metering in VISSIM traffic simulation.

The observed traffic data was between 5:00am and 8:00pm on December 7, 2000 and was provided by Metropolitan Freeway Public Corporation. The input data consisted of: road network, volume of inflow traffic from each node, vehicle speed distribution, fleet composition, and so on. The output data consisted of: stopping time, average vehicle speed, travel and delay times and number of stops. The output data was computed as a three-hour average. Three evaluation areas were set and used to compute average vehicle-speeds every 450 seconds. The traffic simulations were performed ten times using ten different random number series. Therefore, each output result is the average of these ten traffic simulations.

The proposed ramp-metering was implemented on the MEX radial route #3 and #4 in the traffic simulation by VISSIM. The traffic simulation confirmed following:

(i) ramp metering can reduce traffic congestion within the MEX central circular-route C1 but causes negative effects on the short-distance travelers such as vehicles to/from the same radial routes.

(ii) Ramp metering has mitigated traffic congestion at the intersection between the ramp-metered radial route and the central circular-route; but could not give any measurable average-speed changes at the distant locations of traffic network.

(iii) Ramp metering enhances traffic congestion when it is applied to non-congested inflow traffic.

1. INTRODUCTION

Traffic congestion is a common problem; particularly in metropolitan areas. It is especially true for the Tokyo Metropolitan Freeway (MEX) which handles about 1.2 million vehicles per day. Thirty percent of these vehicles use the MEX central circular and radial routes causing chronic traffic congestion because MEX operate with peak traffic demands that exceed capacity. This results in congestion and delays.

There are two options to improve freeway operations. The first option involves an increase in the supply and the second option involves the control of demand. Increasing the supply (constructing and/or widening roads) is often an undesirable alternative due to physical constraints, cost considerations and environmental impacts. Controlling the demand and spreading it over time and space is often the better alternative. There are many ways to control traffic demand. One such control is the implementation of a ramp-metering strategy.

A traffic-control center in Japan mitigates the congestion by governing access to MEX entrance ramps using empirical methods per 30 minutes; which is reasonable, albeit a static traffic-control strategy. Ramp metering is another effective and dynamic traffic-control strategy which is not yet implemented and is examined in this study.

The purpose of this study is to evaluate the effects of real-time ramp metering introductions on the MEX radial route #3 (Shibuya) and radial route #4 (Shinjyuku) by traffic simulations.

2. RAMP METERING

Ramp metering is defined as a method of improving overall freeway operations by limiting, regulating and timing the entrance of vehicles from one or more ramps onto a freeway. Freeway ramp metering systems have been successfully used in the U.S. since the 1960s to improve traffic flow on urban freeways, increase freeway speeds, reduce overall travel times and improve travel-time consistency. Ramp meters are traffic signals that control traffic at entrances to freeways. The purpose of ramp meters is to regulate the rate at which vehicles are allowed to enter the freeway from entrance ramps. Ramp metering attempts to smooth the merging process between vehicles approaching from the entrance ramp and the freeway traffic.

Ramp metering can be implemented and improve overall freeway operations when freeway-entrance ramps have enough space for waiting vehicles and/or alternative routes for surplus vehicles. Although on-ramp control is applicable to most freeways, it should not automatically be assumed that ramp metering will be desirable and feasible for all freeways. According to Papageorigiou (1990), installation of entrance-ramp metering signals may be warranted when the following occur:

(a) The expected reduction in delay of freeway traffic exceeds the expected delay of ramp users and the added travel time for diverted traffic.

(b) There is adequate storage space for the vehicles that will be delayed.

(c) There are alternative routes that have the capacity for diverted traffic from the entrance ramps with either: (i) a recurring congestion on the freeway due to traffic demand greater than capacity; or (ii) a recurring congestion or a severe accident hazard at the freeway entrance-ramp due to inadequate ramp merging.

3. TRAFFIC SIMULATION

3.1. Proposed Ramp Metering

The proposed ramp-metering was initiated by detecting congestion at intersections. The traffic condition was monitored in real time and sent to the ramp signal. The ramp signal received the detector information from a position 200m upstream from the intersection. The actual ramp metering depends on the degree of congestion. Traffic conditions during ramp metering such as the queue length were also monitored to avoid excessive ramp congestion as shown in Figure 1. The proposed ramp-metering used such traffic conditions at the ramp and downstream conjunctions.

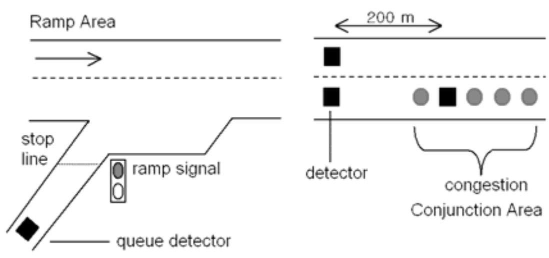

Figure 1. Layout of detectors at the ramp

The ramp-metering control algorithm is presented in Figure 2. The occupancy time was used as the index of ramp congestion. Ramp metering was started when the intersections' occupancy time exceeds their threshold. The ramp-metering rate will be determined by the ramp's queue length and occupancy. The control rate #1 was applied if the ramp queue-length was longer than the permissible queue-length. On the other hand, the control rate was determined by the occupancy near the congested area if the ramp queue-length was shorter than the permissible queue-length. The queue length and occupancy were monitored throughout the simulation period to activate and control ramp metering.

Our simulation set the threshold of the occupancy time, an index of congestion, at 0.6 seconds. The length of the detector is 5m. This means that a vehicle passing the detector in 0.6 seconds is equivalent to having a speed of 30 km/hr. Therefore, the threshold of 0.6 seconds is appropriate because 30 km/hr average indicates traffic congestion in Japan.

Ben-Akiva et al. (2003) have studied the relationship between the ramp metering algorithm, ALINEA and the occupancy, and showed that the best occupancy was 0.19%. Based on their studies, it is not desirable for the occupancy to exceed 0.19%. Therefore, thresholds of occupancy 1 through 3 were set at 0.15%, 0.25% and 0.35%; respectively.

The permissible ramp queue-length depends on the length and structure of each ramp; but it was set at 20 vehicles for all the ramps in our simulation. The ramp signals' green time was a constant 2 seconds to accept only one entering vehicle. The red time will be determined according to the threshold of the queue length and the occupancy. The red time was 1, 5, 10, 15, 20 seconds in the case of control rates 1, 2, 3, 4, and 5; respectively.

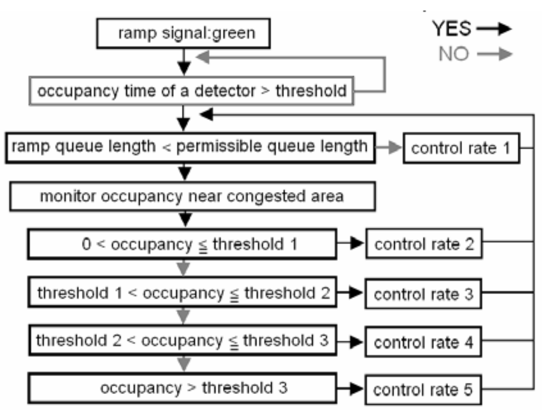

Figure 2. Proposed ramp metering control algorithm

3.2. Traffic Simulator, Research Area and Traffic Data

The traffic simulator 'VISSIM version 3.70' was used with the controlling software 'Vis-Vap'. VISSIM was developed and is distributed by PTV in Germany. VISSIM is the microscopic, time-step and behavior-based simulation software to model urban-traffic and public-transit operations. VISSIM can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, ramp metering and so on. Vis-Vap enables us to implement the proposed ramp metering in VISSIM traffic simulation.

The Tokyo Metropolitan Freeway has chronic traffic congestions at the circular routes with associated radial routes as shown in Figure 3. The target routes were the Tokyo Metropolitan Freeway radial route #3 (Shibuya) and radial route #4 (Shinjuku). There are 22 entrance ramps and 25 exit ramps within the 14.8km MEX central circular route C1. There are 5 entrance-ramps and 6 exit-ramps within the 11.9km radial route #3 that connects to Tomei highway. There are 9 entrance-ramps and 10 exit-ramps within the 13.5km radial route #4 that connects to Chuou highway. The detectors are set at Miyakezaka and Tanimachi conjunction between MEX central circular route and radial routes as shown Figure 3. The detector information at Miyakezaka and Tanimachi JCT is used to control ramp metering on the MEX radial route #4 and #3, respectively.

The observed traffic data was between 5:00am and 8:00pm on December 7, 2000 and was provided by Metropolitan Freeway Public Corporation. The input data consisted of: road network, volume of inflow traffic from each node, vehicle speed distribution, fleet composition, and so on. The output data consisted of: stopping time, average vehicle speed, travel and delay times and number of stops. The output data was computed as a three-hour average. Three evaluation areas were set as shown in Figure 3 and are labeled X, Y and Z. The average vehicle-speeds at X, Y and Z were computed and stored every 450 seconds. The traffic simulations were performed ten times using ten different random number series. Therefore, each output result is the average of these ten traffic simulations.

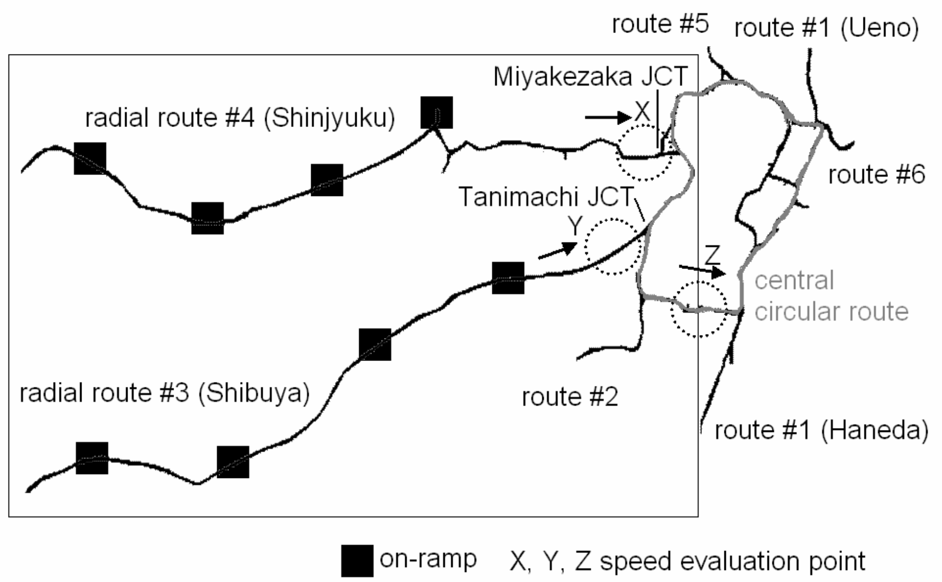

Figure 3. The area of traffic simulation and target routes

The research outline is shown in Figure 4. First, the observed condition was reproduced by traffic simulations in order to evaluate our traffic model by taking the correlation coefficients between the observed and the simulated traffic-conditions. This is the control run and represents the current traffic condition. Then, the proposed ramp-metering was implemented in a traffic simulation. This was the experiment run that presents a regulated traffic-condition using ramp metering. The effects of the proposed ramp-metering were evaluated by comparing the results between the control and simulated runs. However, the network reproducibility could not be secured for this preliminary experiment.

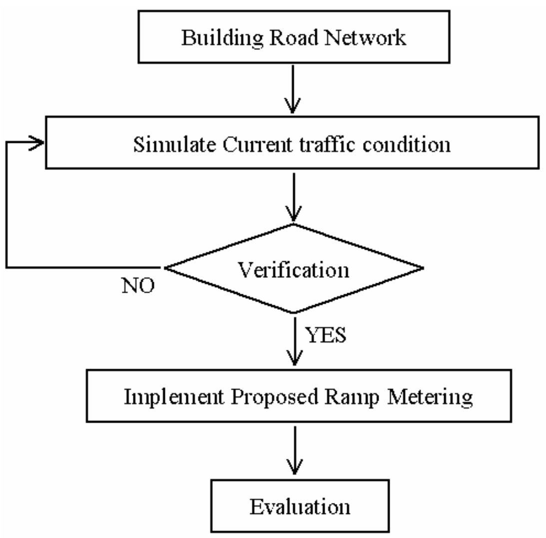

Figure 4. Outline of this research

4. RESULTS

4.1. Travel Time and Traffic Conditions

The ramp-metering effect of incoming traffic onto the MEX radial-route #3 (Shibuya) is shown in table 1. Ramp metering generally increases the delay and stopping times, and mitigates traffic congestions by limiting the inflow of vehicles onto the freeway. Therefore, ramp metering effects depend on the balance between the reduction and the increase in delay and stopping times.

The travel times toward the MEX central circular-route C1, the radial-route #1 (Ueno), the radial-route #5 (Ikebukuro) and the radial-route #6 (Mukoujima) from route #3 have slightly been improved by ramp metering. The mitigating effect of congestion on the freeway using ramp metering was great enough to counterbalance the increase in associated delay and stopping times.

Table 1. Effects of the introduction of ramp metering on the inflow traffic to the radial-route #3 (Shibuya).

	Travel time	Delay time	Stopping time	Number of stops
#3 □ central circular route	-0.6	-2.1	-4.8	1.0
#3 □ route #1 (Ueno)	-0.5	-0.5	-7.9	-2.9
#3 □ route #1 (Haneda)	0.3	1.4	2.1	1.0
#3 □ route #5 (Ikebukuro)	-0.3	-2.8	-4.5	-0.3
#3 □ route #6 (Mukoujima)	-0.2	-2.2	-3.8	-0.7
#3 □ route #3 (Shibuya)	-0.1	-0.7	4.4	12.0

The travel time between radial-route #3 and radial-route #1 (Haneda) was increased. The circular-route C1 traffic flow was either outbound (northbound) or inbound (southbound). The inbound traffic flows to radial-route #1 (Haneda) and the outbound traffic flows to radial-route #5 (Ikebukuro). In this experiment, the outbound traffic was much larger than the inbound traffic at the Tanimachi junction; and hence, ramp metering was more appropriate for the outbound traffic. This was the reason why the increases of travel, delay, and stopping times, and the number of stops for radial-route #1 (Haneda) was caused by ramp metering.

The traffic to/from route #3 showed much larger stopping times and number of stops. It is a natural result because ramp metering applied on route #3 limited the entering vehicles to route #3 in order to reduce the traffic congestion on route #3. Therefore, improvements in traffic from route #3 are only possible when short-distance travelers such as those who travel to/from the same route, experience longer travel times.

The effect of the introduction of ramp metering for incoming traffic onto the MEX radial-route #4 (Shinjyuku) is shown in table 2. The results were similar to radial-route #3. The travel times toward the MEX central circular-route C1; and the radial-routes #1 (Ueno), #5 (Ikebukuro), #6 (Mukoujima) and #2 from route #4 have slightly been improved using ramp metering. Again, the mitigating effect of congestion on the freeway using ramp metering is great enough to counterbalance the increase in associated delay and stopping times. However, the travel, delay and stopping times, and the number of traffic stops between route #4 and radial-routes #1 and #2 were increased. This must be due to the fact that traffic to radial-route #1 was heavier than to radial-route #5. Ramp metering is not good for non-congested traffic.

Table 2. Effects of the introduction of ramp metering on the inflow traffic to the radial-route 4 (Shinjyuku).

	Travel time	Delay time	Stopping time	Number of stops
#4 □ central circular route	-0.7	-2.9	-4.9	1.4
#4 □ route #1 (Ueno)	-0.6	-2.4	-7.5	-1.2
#4 □ route #1 (Haneda)	0.5	2.9	5.3	5.2
#4 □ route #5 (Ikebukuro)	-1.1	-4.3	-15.2	-7.4
#4 □ route #6(Mukoujima)	-0.2	-2.6	-0.8	-0.2
#4 □ route #4 (Shinjyuku)	3.3	27.2	6.5	2.5
#4 route #2 (Meguro)	-0.7	0.6	0.2	0.6

The traffic to/from route #4, show much larger travel, delay and stopping times; and number of stops. It means that improvements in traffic from route #4 were the result of sacrifices of traffic to/ from route #4 as stated for route #3. This indicates that ramp metering causes negative effects on short-distance travelers.

The ramp-metering effects on the traffic of the MEX central circular-route C1 are shown in Table 3. The travel time and other traffic indexes were greatly improved due to the ramp metering applied on the inflow traffic of routes #3 and #4. This is because ramp metering on routes #3 and #4 tend to lower the total traffic volume and increase the traffic capacity of the MEX circular route. It is clear that restricting inflow traffic from radial routes is an effective traffic-management strategy. However, some negative effects were observed between routes #5 and #2. This is probably due to the fact that traffic indexes from route #5 to route #2 were easily influenced by other traffic conditions such as the level of intersection congestion, because the traffic volume between routes #5 and #2 was small.

Table 3. The effect of the introduction of the ramp metering of traffic of the MEX central circular-route C1.

	Travel time	Delay time	Stopping time	Number of stops
route #1 (Haneda) □'route #4 (Shinjuku)	-1.3	-2.2	-8.3	-7.4
route #1 (Haneda) □'route #5 (Ikebukuro)	-0.9	-1.9	-0.5	-1.1
route #2 (Meguro) □'route #4 (Shinjuku)	-1.6	-5.2	-9.7	-10.1
route #2 (Meguro) □'route #5(Ikebukuro)	-2.3	-18.7	-22.8	-8.5
route #5 (Ikeburkuro) □'route #1 (Haneda)	-0.4	-0.5	0.3	-4.8
route #5 (Meguro) □'route #2 (Meguro)	0.1	1.2	0.1	0.2

4.2. Vehicle Speed Changes

The average vehicle-speed changes at intersections between the circular route and the radial-routes #3 and #4, (X and Y in Figure 3), are shown in Figure 5 and 6; respectively.

The proposed ramp-metering only delay the starting time of congestion by 10 minutes. The traffic congestions were observed in accordance with the increase of inflow traffics from radial-routes #3 and #4.

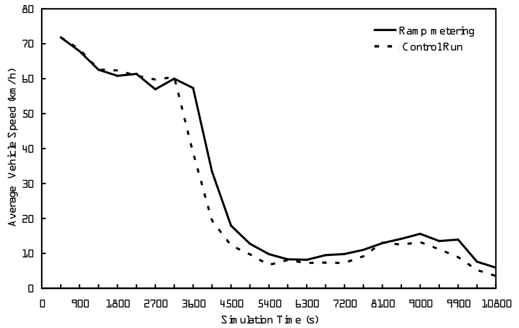

Figure 5. Average vehicle-speed changes at the intersection, X in Figure 3..

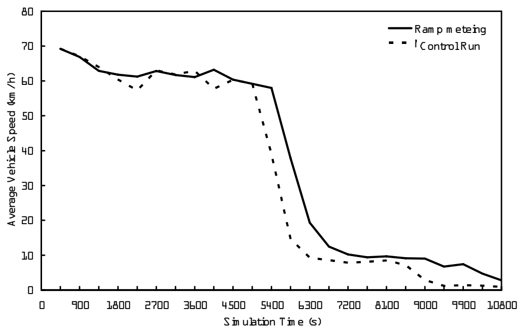

Figure 6. Average vehicle-speed changes at the intersection, Y in Figure 3.

The average vehicle-speed changes bounding for Haneda at Z in Figure3 is shown in Figure 7. Any effect of ramp metering applied on radial-routes #3 and #4 was not confirmed at point Z. Therefore, ramp metering applied on routes #3 and #4 reduce traffic congestion at the intersections between the MEX circular route and the radial-routes #3 and #4, but has no measurable effect on distant locations.

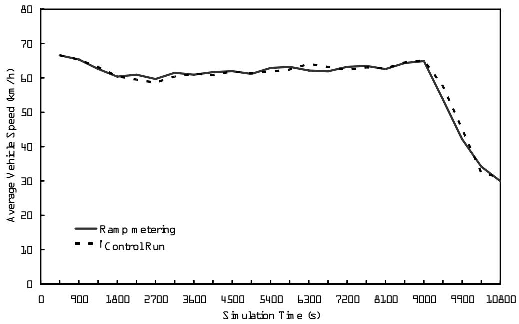

Figure 7. Average vehicle speed changes at Z in Figure 3.

5. CONCLUTIONS

The proposed ramp-metering was implemented on the MEX radial route #3 and #4 in the traffic simulation by VISSIM. The traffic simulation confirmed following:

(i) ramp metering can reduce traffic congestion within the MEX central circular-route C1 but causes negative effects on the short-distance travelers such as vehicles to/from the same radial routes.

(ii) Ramp metering has mitigated traffic congestion at the intersection between the ramp-metered radial route and the central circular-route; but could not give any measurable average-speed changes at the distant locations of traffic network.

(iii) Ramp metering enhances traffic congestion when it is applied to non-congested inflow traffic.

6. ACKNOWLEDGMENTS

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