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論 文

The Ramp Metering System Construction of Urban Freeway by the Intelligent Transportation System (ITS) Technology

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첨단교통체계(ITS)에 의한 도시고속도로의 Ramp Metering 시스템 구축에 관한 연구

김 태 곤

Key Words : Freeway System(고속도로 체계), Traffic Characteristics(교통특성), Flow Analysis(교통류분석), Speed Analysis(속도분석), Occupancy Analysis(점유율분석), Traffic Flow(교통류), Speed(속도), Occupancy(점유율), Ramp Metering(램프미터링), Merge Section(합류부), Delay(지체), Metering Rate(미터율), Intelligent Transportation Systems(첨단교통체계), Detector(검지기)

Abstract

Today freeway is thought to be a very important transportation facility carrying tremendous traffic flow as the main corridor within the area or between the areas. However, freeway is experiencing severe congestion and accidents by increased entrance ramp flow, especially at peak time period. Ramp meters on the freeway entrance ramps that supply traffic to the freeway in a measured or appropriately regulated amount are needed for alleviating freeway congestion. Because ramp meters can be operated to discharge traffic at a measured or regulated rate thus maintaining more uniform speed on the mainline section, maximizing the throughput to the freeway within the capacity of a downstream bottleneck, and reducing the congestion related accidents.

Thus, the objectives in this study were to analyze the traffic characteristics on the freeway I-94 with ramp metering system before/after ITS technology in Detroit (Michigan) area, compare shifts of the traffic characteristics on the freeway I-94 before/after ITS technology,

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and finally suggest a better ramp metering strategy for the freeway system. The following results were obtained :

i) Flow, occupancies, and speeds on the mainline merge section of freeway were shown to be a big difference depending on the peak periods, areas, and directions based on the distribution of traffic flow characteristics on the freeway.

ii) Reduced speed was shown to be more than 5 mph, and ramp flow was also shown to be more than 240 vph at peak periods if there was the ramp metering system constructed on the freeway.

iii) Ramp metering system was shown to be optimally operated on the freeway if ramp flow could be maximized within the range of over 900 vph and reduced occupancy could be also maximized by no more than 2 percent at peak periods.

iv) The average flows on the freeway after the ITS technology were shown to be a decrease of over 20% depending on the peak periods, areas, and directions when compared with those flow on the freeway before the ITS technology.

over 20% depending on the peak periods, areas, and directions when compared with those speeds on the freeway before the ITS technology.

vi) The average metering rates on the freeway after the ITS technology were shown to be an increase of over 10% depending on the peak periods, areas, and directions when compared with those metering rates on the freeway before the ITS technology.

I . INTRODUCTION

Ramp meters are traffic signals installed on the freeway entrance ramps that supply traffic to the freeway in a measured or appropriately regulated amount. That is, ramp meters can be operated to discharge traffic at a measured or regulated rate thus maintaining more uniform speed on the mainline section, maximizing the throughput to the freeway within the capacity of a downstream bottleneck, and reducing the congestion related accidents.

Currently ramp meters are in operation in 20 metropolitan areas in the United States (see Figure 1 and Table 1).

The first metered ramp was installed on the Eisenhower Expressway in Chicago in 1963. In the Los Angeles metropolitan area - the largest

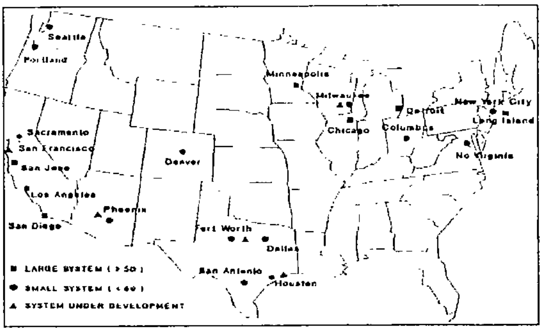

Fig. 1 Ramp Metering Status in the US

system in the US, there are now over 900 ramps in operation since ramp metering began in 1969[1]. These metering systems vary from a fixed time operation at a single ramp to computerized control of every ramp along many miles of a freeway. Especially, in Detroit area selected for this study, one of the above 20 metropolitan

Table 1 Ramp Metering Status as of 1989 in the United States

Area	'No. of Ramp Meters	Types of Ramp Meter	Expansion Plans
Chicago	91	CCRM	-
Columbus	7	FTRM TRRM	Replace existing FTRM with TRRM and add 10 locations under CCRM
Dallas	35	FTRM	US-75 reconstruction under CCRM
Denver	26	CCRM	2 meters on I-70 in 1990 ~ 1991
Detroit	51	CCRM	Has SCANDI Project of Capacity for up to 250 meters
Fort Worth	12	TRRM	12 meters on I-30 in 1990 and 207 meters by 2004
Houston	20	TRRM	Reinstall CCRM on I-45 in Sept. 1989, and 20 meters along the North Freeway by 1990 and 15 meters along I-10 in the early 1990's
Los Angeles	917	TRRM	110 meters in 1989, metering on 22 miles of SR 91 by 1993
Milwaukee	21	TRRM	44 meters, many with HOV bypasses
Minneapolis	66	CCRM	150 fixed time ramp meters in 1989 ~ 1990 and replace them with local traffic responsive over several years
NY City	9	TRRM	-
Long Island in NY	58	CCRM	-
Phoenix	18	FTRM	76 meters on I-17/I-10 and many with HOV bypasses
Portland	29	FTRM	6 meters including 1 freeway to freeway meter in 1989 ~ 1990
Sacramento	14	TRRM	-
San Antonio	9	TRRM	Reinstall the removed meters
San Diego	81	CCRM	170 meters over the next 5 years
San Jose	60	TRRM	Metering throughout the Bay Area
Seattle	23	CCRM	Design metering on new I-90
Virginia	26	CCRM	Feasibility study underway metering and consider metering in the Norfolk Area

FTRM means fixed time ramp metering
TRRM means local traffic responsive ramp metering
CCRM means computer control ramp metering

areas and, there were 51 ramp meters installed in 1989, and 60 ramp meters in operation as of 1998. Also, the Intelligent Transportation Systems (ITS) deployment program was established in Detroit area in 1995[2] (see Figure 2).

Thus, the objectives in this study were to analyze the traffic characteristics on the freeway I-94 with ramp metering system before/after ITS technology in Detroit area, compare shifts of the traffic characteristics on the freeway I-94 before/after ITS technology, and finally suggest a better ramp metering strategy for the freeway system.

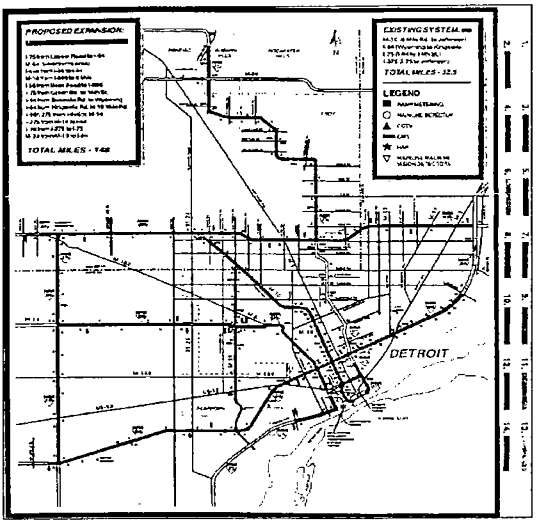

Fig. 2 S.E. Michigan ITS/ATMS Deployment Program : 1995

Ⅱ. LITERATURE REVIEW

Marsden, Blair[3] in Austin (Texas) reported, "Traffic responsive ramp meters were installed at 3 ramps along a 2.6 mile section of northbound I-35 in Austin for operation during the AM peak period by the Texas State Department of Highways and Public Transportation. This section had two bottleneck locations : one was a reduction from 3 to 2 lanes and the other was a high flow entrance ramp just downstream of the lane reduction. The vehicle throughput increased 7.9% and the average peak period mainline speed increased 60%."

The Oregon Department of Transportation-Metropolitan Branch study[2] showed, "The first 16 ramp meters in the Pacific Northwest were installed along a six mile section of I-5 between downtown Portland and the Washington state line in 1981. Nine of the meters were operated in the northbound direction during the PM peak and seven operated in the southbound direction during the AM peak. All the meters were operated in a fixed time mode. Fourteen months after installation, the northbound PM peak hour average speed increased about 156% from 16 MPH to 41MPH and the travel time decreased about 61% from 23 minutes to 9 minutes, but the average speed in the southbound direction AM peak increased only about 7.5% from 40 MPH to 43 MPH resulting in only slight reductions in southbound travel times. Also, there was a reduction in rear-end and side-swipe accidents, and there was a 43% reduction in peak period traffic accidents."

Lidia P. Kostyniuk, et al.[5] in Detroit (Michigan) reported, "The Surveillance Control and Driver Information (SCANDI) ramp metering system was implemented on I-94 in Detroit by the Michigan Department of Transportation (MDOT). The SCANDI metering operation began in November 1982 with six ramps on the eastbound I-94 (Ford Freeway). Nineteen more ramps were added on I-94 in January 1984 and three ramps added in November 1985. The average speed increased about 8%, the peak period flow increased 14% from 5,600 vph to 6,400 vph, the total number of accidents declined nearly 50%, and the injury accidents declined 71%."

James H. Kell & Associates[6)] in Long Island (New York) reported, "The INFORM (Information for Motorists) project which covered a 40 mile long by 5 mile wide corridor at the center of the Long Island Expressway (LIE) included 58 metered ramps on the LIE and the Northern State/Grand Central Parkway. Two months after metering, the mainline travel time decreased 20% from 26 minutes to 21 minutes, the average speed increased 16% from 29 MPH to 35MPH. Also, there was a 6.7% reduction in fuel consumption, 17.4% reduction in carbon monoxide emissions, 13.1% reduction in hydrocarbons, and 2.4% increase in nitrous oxide emissions."

Nick Thompson[6)] in Minneapolis-St. Paul (Minnesota) reported, "Today Intelligent Transportation Systems (ITS) technologies provide a great deal of control than ever before. Especially, ramp metering reduces rear-end accidents associated with stop-and-go conditions and side collisions at merge points. Also, ramp metering increases mainline throughput by 30% and increases speeds on the freeway mainline in peak hours from an average 48 km/h to 77 km/h or 60% higher. In addition, lanes on metered freeways typically carry 2,200 to 2,400 vehicles per hour per lane and sometimes as high as 2,700. And even higher flows are possible as Minnesota's peak hour traffic flows are metered to run smoothly at an optimal 73 km/hr (45mph). On the freeway I-494 equipped with a new generation of control algorithms called an Integrated Corridor Traffic Management-Ramp Metering System (ICTM-RMS), speeds appear to have either increased or remained constant, and the same is true for trip consistency and travel times, while ramp delays are generally down as compared to the Freeway Management System (FMS)."

The results of literature review showed that ramp metering system increased peak traffic flow, travel speed, and improved travel time reliability on the mainline section of freeway. Especially, ramp metering system after the ITS technology was shown to significantly improve more traffic flow to the mainline section and consistently increase travel speed on the mainline section when compared with the ramp metering system before the ITS technology. Also, both of the ramp metering systems were proved to help smooth out peak demands and reduce the accidents on the freeway merge section.

Ⅲ. DATA COLLECTION AND TRAFFIC ANALYSES ON THE FREEWAY MERGE SECTION

Ⅲ.1 DATA COLLECTION

Currently 32.5 miles of the existing ramp metering system was operational and 148 additional miles of the proposed expansion system was planned in Detroit area. Specifically, out of the 60 ramp meters, 25 ramp meters were located on I-94 or the Ford Freeway (Wyoming to Kingsville section), 24 ramp meters on M-10 or Lodge Freeway (8 mile Rd. to Jefferson) and 8 ramp meters on I-75 or Chrysler Freeway (see Figure 1(b)). Also, there were about 400 loop detector stations with 120 stations located on the freeway I-94 with 70mph speed limit.

The freeway I-94 selected for data collection and analyses passed through the downtown area from the suburban area in the east-west direction of Detroit area. There were already one hundred and twenty loop detector stations operated on this section of the freeway I-94. For data collection, twenty stations out of one hundred and twenty loop detector stations were selected consisting of five upstream and downstream loop detector stations in each direction.

Data collection was conducted from a master dataset generated by the Michigan Department of Transportation (MDOT) permanent traffic recorders located on the freeway I-94 in Detroit area. The MDOT master dataset was converted into a format suitable for visual and statistical inspection via a spread sheet. Before-ITS Data obtained for eight months based on the weekdays from January to August, 1997 and After-ITS Data obtained for 4 weeks from middle of November to middle of December, 1998 were used for analyses. Occasionally the MDOT permanent traffic recorders produced bad data. Only those data with valid data for all 24 hours were used in the analyses.

Ⅲ.2 TRAFFIC ANALYSES ON THE FREEWAY MERGE SECTION BEFORE ITS

The equipments installed around the freeway merge section before ITS were ramp metering, mainline detector, and closed-circuit television (CCTV) as shown in Figure 3, and the characteristics were observed as follows :

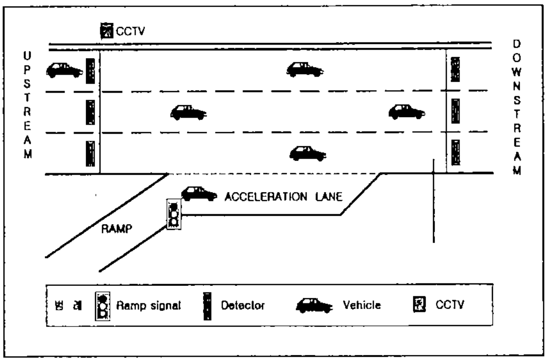

Fig. 3 Geometric Characteristics of Merge Section in Detroit, MI

Geometric characteristics in merge section :

Length between upstream and downstream detector stations ; 1/3mile
Length of on-ramp ; 300m
Lane width of freeway ; 3.6m
Lane width of ramp ; 3.6m + 2@.6m for curb & gutter
Number of lanes on the freeway ; 3 lanes
Number of lanes on ramp ; 1 lane
Speed limit of freeway ; 70 mph
Speed limit of ramp ; 25 mph

Operational characteristics in merge section :

Meter period length of ramp ; 6:30 to 9:00 AM, 3:30 to 6:00 PM), but not if icy, snow, or rain
Ramp signal type ; red or green, flashing yellow at beginning of ramp to show metering active
Metering rate ; 4 to 10 veh/min, 15 to 6 sec/veh
Ramp signal timing ; green time (2 sec constant), red time (variable)

FLOW ANALYSES

The flow pattern on the freeway I-94 with 70 mph speed limit showed the variable traffic flow patterns as shown in Figure 4.

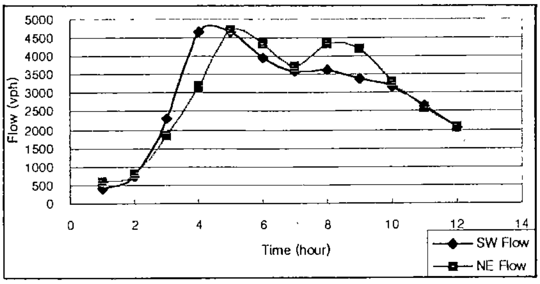

Fig. 4 Flow Patterns on I-94 before ITS

Especially, the average hourly upstream flow (AHUF) on the freeway SW bound I-94 was 2,920 vph, but the AM peak period upstream flow was shown to be 4,470 vph, an increase of 53.1% when compared with the AHUF. The PM peak period upstream flow was shown to be 3,431 vph, an increase of 17.5% when compared with the AHUF. The average hourly upstream flow (AHUF) on the freeway NE bound I-94 was 3,568 vph, but the AM peak period upstream flow was shown to be 3,319 vph, a decrease of 7.0% when compared with the AHUF and the PM peak period upstream flow was shown to be 5,871 vph, an increase of 62.0% when compared with the AHUF (see Table 2).

In addition, the average hourly downstream flow (AHDF) on the freeway SW bound I-94 was 3,325 vph, but the AM peak period downstream flow was shown to be 4,938 vph, an increase of 48.5% when compared with the AHDF. The PM peak period downstream flow was shown to be 3,999 vph, an increase of 20.3% when compared with the AHDF. The average hourly downstream flow (AHDF) on the freeway NE bound I-94 was 3,008 vph, but the AM peak period downstream flow was shown to be 4,196 vph, an increase of 39.5% when compared with the AHDF and the PM peak period downstream flow was shown to be 4,040 vph, an increase of 34.3% when compared with the AHDF (see Table 2).

Also, the average hourly ramp flow (AHRF) on the freeway I-94 showed 405 vph, but the AM peak period ramp flow was shown to be 468 vph, an increase of 15.6% when compared with the AHRF. The PM peak period ramp flow was

Table 2 Shifts of Flow on the I-94 Merge Section before ITS (vph)

Freeway	24 Hours Average Flow	Peak Period Flow			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Flow					
SW I-94	2,920	4,470	53.1	3,431	17.5
NE I-94	3,568	3,319	-7.0	5,871	64.5
I-94	6,488	7,789	20.1	9,302	43.4
Downstream Flow					
SW I-94	3,325	4,938	48.5	3,999	20.3
NE I-94	3,008	4,196	39.5	4,040	34.3
I-94	6,333	9,134	44.2	8,039	26.9
Ramp Flow					
I-94	405	468	15.6	567	40.0

also shown to be 569 vph, an increase of 40.5% when compared with the AHRF (see Table 2).

SPEED ANALYSES

The speed pattern on the freeway I-94 with 70mph speed limit showed the variable speed patterns as shown in Figure 5.

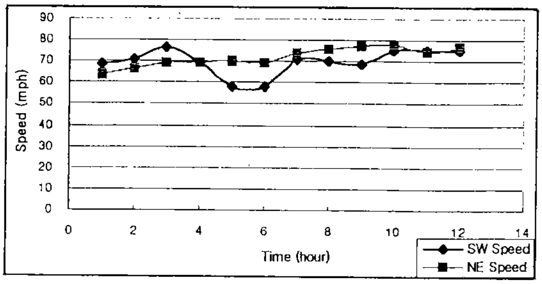

Fig. 5 Speed Patterns on I-94 before ITS

Especially, the average hourly upstream speed (AHUS) on the freeway SW bound I-94 was 69.1 mph, but the AM peak period upstream speed was to be 59.1 mph, a decrease of 14.5% when compared with the AHUS. The PM peak period upstream speed was shown to be 70.1 mph, an increase of 1.4% when compared with the AHUS. The average hourly upstream speed (AHUS) on the freeway NE bound I-94 was 64.5 mph, but the AM peak period upstream speed was shown to be 65.0 mph, a decrease of 0.7% when compared with the AHUS and the PM peak period upstream speed was shown to be 58.5 mph, a decrease of 9.3% when compared with the AHUS (see Table 3).

In addition, the average hourly downstream speed (AHDS) on the freeway SW bound I-94 was 66.7 mph, but the AM peak period downstream speed was shown to be 56.5 mph, a decrease of 15.3% when compared with the AHDS. The PM peak period downstream speed was shown to be 68.6 mph, an increase of 2.8% when compared with the AHDS. The average hourly downstream speed (AHDS) on the freeway NE bound I-94 was 73.2 mph, but the AM peak period downstream speed was shown to be 72.9 mph, a decrease of 0.4% when compared with the AHDS and the PM peak period downstream speed was shown to be 77.2

Table 3 Shifts of Speed on the I-94 Merge Section before ITS (mph)

Freeway	24 Hours Average Speed	Peak Period Speed			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Speed					
SW I-94	69.1	59.1	-14.5	70.1	+1.4
NE I-94	73.2	72.9	-0.4	77.2	+5.5
I-94	71.2	66.0	-7.3	73.7	+3.5
Downstream Speed					
SW I-94	66.7	56.5	-15.3	68.6	+2.8
NE I-94	64.5	65.0	+0.8	58.5	-9.3
I-94	65.6	60.8	-7.3	63.6	-3.0
Reduced Speed					
I-94	5.6	5.2	-7.1	10.1	+80.4

mph, an increase of 5.5% when compared with the AHDS (see Table 3).

Also, the average hourly reduced speed (AHRS) on the freeway I-94 showed 5.6 mph, but the AM peak period reduced speed was shown to be 5.2 mph, a decrease of 7.1% when compared with the AHRS. The PM peak period reduced speed was shown to be 10.1 mph, an increase of 80.4% when compared with the AHRS (see Table 3).

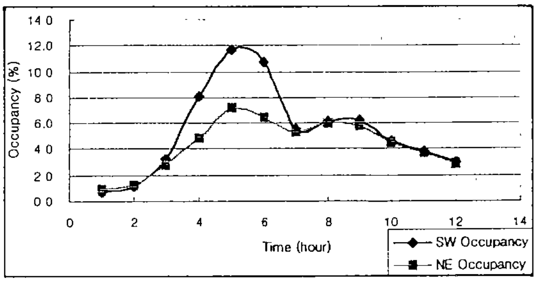

Fig 6 Occupancy Patterns on I-94 before ITS

OCCUPANCY ANALYSES

The occupancy was the ratio of occupied time by vehicles to total observation time at the detector station and expressed as a percentage. The occupancy was computed as follows[8] :

$$\Phi = \frac{(Lv + Ld)}{5280}(K)(100) \qquad (3 \cdot 1)$$

$$K = \frac{Q}{V}$$

where,

- Φ : occupancy (%)
- Lv : length of individual vehicle (feet)
- Ld : detection zone length (feet)
- K : density (veh/mile)
- Q : flow (veh/h)
- V : speed (mile/h)

The occupancy pattern on the freeway I-94 with 70mph speed limit showed the variable occupancy patterns as shown in Figure 6.

Especially, the average hourly upstream occupancy (AHUO) on the freeway SW bound I-94 was 5.6 percent, but the AM peak period upstream occupancy was shown to be 11.0 percent, an increase of 96.4% when compared with the AHUO. The PM peak period upstream occupancy was shown to be 6.1 percent, an increase of 8.9% when compared with the AHUO. The average hourly upstream occupancy (AHUO) on the freeway NE bound I-94 was 6.2 percent, but the AM peak period upstream occupancy was shown to be 5.4 percent, a decrease of 12.9% when compared with the AHUO and the PM peak period upstream occupancy was shown to be 11.7 percent, an increase of 88.7% when compared with the AHUO (see Table 4).

In addition, the average hourly downstream occupancy (AHDO) on the freeway SW bound I-94 was 6.0 percent, but the AM peak period downstream occupancy was shown to be 11.0 percent, an increase of 88.3% when compared with the AHDO. The PM peak period downstream occupancy was shown to be 6.5 percent, an increase of 8.3% when compared with the AHDO. The average hourly downstream occupancy (AHDO) on the freeway NE bound I-94 was 4.2 percent, but the AM peak period downstream occupancy was shown to be 6.3 percent, an increase of 50.0% when compared with the AHDO and the PM peak period downstream occupancy was shown to be 5.4

percent, an increase of 28.6% when compared with the AHDO (see Table 4).

DELAY ANALYSES

Delay which occurred approaching the freeway merge section was computed as follows :

$$D=\frac{Vf-Vm}{Vf}(60) \qquad (3 \cdot 2)$$

$$Vm=\frac{(Vu+Vd)}{2}$$

D occurs if $Vf > Vm$

D does not occur if $Vf \leq Vm$

where,

D : approaching delay on the merge section

Vf : 50th percentile free flow speed in the non-peak periods on the suburban freeway section

Vm : mean speed on the merge section

Vu : speed on the upstream detector station

Vd : speed on the downstream detector station

The average hourly delay (AHDL) on the freeway I-94 was 9.2 MPV, but the AM peak period delay was shown to be 16.4 MPV, an increase of 78.3% when compared with the AHDL. The PM peak period delay was shown to be 8.2 MPV, a decrease of 10.9% when compared with the AHDL (see Table 5).

METERING ANALYSES

Metering rate allowed to enter the freeway merge section from the entrance ramp per minute was computed as follows :

$$Mr=\frac{Fd-Fu}{60} \qquad (3 \cdot 3)$$

Table 4 Shifts of Occupancy on the I-94 Merge Section before ITS (%)

Freeway	24 Hours Average Occupancy	Peak Period Occupancy			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Occupancy					
SW I-94	5.6	11.0	96.4	6.1	8.9
NE I-94	6.2	5.4	-12.9	11.7	88.7
I-94	5.9	8.2	39.0	8.9	50.8
Downstream Occupancy					
SW I-94	6.0	11.0	88.3	6.5	8.3
NE I-94	4.2	6.3	50.0	5.4	28.6
I-94	5.1	8.7	70.6	6.0	17.6

Table 5 Shifts of Delay on the I-94 Merge Section before ITS (MPV)

Freeway	24 Hours Average Delay	Peak Period Delay			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
I-94	9.2	16.4	78.3	8.2	-10.9

where,

Mr : metering rate (veh/min, vpm)

Fd : downstream flow (veh/h)

Fu : upstream flow (veh/h)

The average hourly metering rate (AHMR) on the freeway I-94 was 6.8 VPM, but the AM peak period metering rate was shown to be 7.8 VPM, an increase of 14.7% when compared with the AHMR. The PM peak period metering rate was shown to be 9.5 VPM, an increase of 39.7% when compared with the AHMR (see Table 6).

From the results of the above analyses, the traffic flow, speed and occupancy on the merge section before ITS were shown to be variable depending on the time periods and directions between urban and suburban areas. Thus, the ramp metering system strategy which could appropriately maintain the traffic flow, speed and occupancy, and also maximize the entrance ramp flows to the mainline section within the acceptable range of 240 vehicles per hour to 900 vehicles per hour[8] while still retaining free flow on the freeway should be established.

Ⅲ.3 TRAFFIC ANALYSES ON THE FREEWAY MERGE SECTION AFTER ITS

The equipments newly installed or upgraded around the existing freeway merge section after ITS as shown in Figure 3 were ramp metering, mainline detector, closed-circuit television (CCTV), changeable message sign (CMS), highway advisory radio (HAM) transmitter, and mainline machine vision detector.

FLOW ANALYSES

The flow pattern on the freeway I-94 with 70mph speed limit also showed the variable flow patterns as shown in Figure 7.

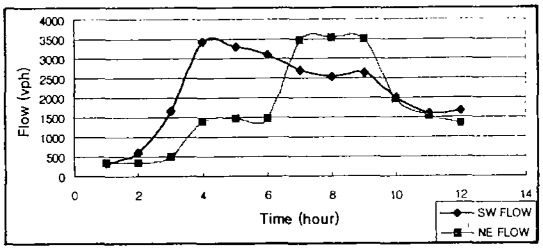

Fig. 7 Flow Patterns on I-94 after ITS

Especially, the average hourly upstream flow (AHUF) on the freeway SW bound I-94 was 2,094 vph, but the AM peak period upstream flow was shown to be 3,208 vph, an increase of 53.2% when compared with the AHUF. The PM peak period upstream flow was shown to be 2,588 vph, an increase of 23.6% when compared with the AHUF. The average hourly upstream flow (AHUF) on the freeway NE bound I-94 was 2,025 vph, but the AM peak period upstream flow was shown to be 1,669 vph, a decrease of 17.6% when compared with the AHUF and the PM peak period upstream flow was shown to be 4,000 vph, an increase of 97.5% when compared with the AHUF (see Table 7).

Table 6 Shifts of Metering Rate on the I-94 Merge Section before ITS (VPM)

Freeway	24 Hours Average Metering Rate	Peak Period Metering Rate			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
I-94	6.8	7.8	14.7	9.5	39.7

In addition, the average hourly downstream flow (AHDF) on the freeway SW bound I-94 was 2,541 vph, but the AM peak period downstream flow was shown to be 3,730 vph, an increase of 46.8% when compared with the AHDF. The PM peak period downstream flow was shown to be 3,197 vph, an increase of 25.8% when compared with the AHDF. The average hourly downstream flow (AHDF) on the freeway NE bound I-94 was 2,219 vph, but the AM peak period downstream flow was shown to be 1,973 vph, a decrease of 11.1% when compared with the AHDF and the PM peak period downstream flow was shown to be 4,345 vph, an increase of 95.8% when compared with the AHDF (see Table 7).

Also, the average hourly ramp flow (AHRF) on the freeway I-94 was 460 vph, but the AM peak period ramp flow was shown to be 523 vph, an increase of 13.7% when compared with the AHRF. The PM peak period ramp flow was shown to be 688 vph, an increase of 49.6% when compared with the AHRF (see Table 7).

SPEED ANALYSES

The speed pattern on the freeway I-94 with 70mph speed limit also showed the variable speed patterns as shown in Figure 8.

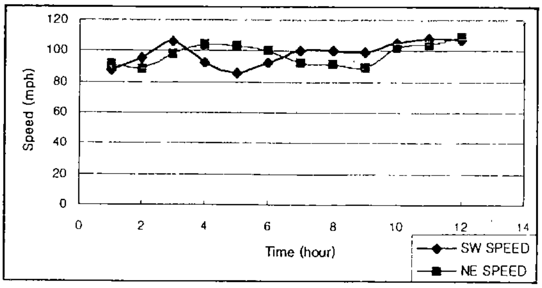

Fig. 8 Speed Patterns on I-94 after ITS

Especially, the average hourly upstream speed (AHUS) on the freeway SW bound I-94 was 98.3 mph, but the AM peak period upstream speed was shown to be 89.6 mph, a decrease of 8.9% when compared with the AHUS. The PM peak period upstream speed was shown to be 100.1 mph, an increase of 1.0% when compared with the AHUS. The average hourly upstream speed (AHUS) on the freeway NE bound I-94 was 97.4 mph, but the AM peak period upstream speed was shown to be 101.4 mph, an increase of 4.1% when compared with the AHUS and the

Table 7 Shifts of Flow on the I-94 Merge Section after ITS

Freeway	24 Hours Average Flow	Peak Period Flow			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Flow					
SW I-94	2094	3,208	53.2	2,588	23.6
NE I-94	2,025	1,669	-17.6	4,000	97.5
I-94	4,119	4,877	18.4	6,588	59.9
Downstream Flow					
SW I-94	2,541	3,730	46.8	3,197	25.8
NE I-94	2,219	1,973	11.1	4,345	95.8
I-94	4,760	5,703	19.8	7,542	58.4
Ramp Flow					
I-94	460	523	13.7	688	49.6

PM peak period upstream speed was shown to be 91.1 mph, a decrease of 6.5% when compared with the AHUS (see Table 8).

In addition, the average hourly downstream speed (AHDS) on the freeway SW bound I-94 was 90.8 mph, but the AM peak period downstream speed was shown to be 83.9 mph, a decrease of 7.6% when compared with the AHDS. The PM peak period downstream speed was shown to be 88.7 mph, a decrease of 2.3% when compared with the AHDS. The average hourly downstream speed (AHDS) on the freeway NE bound I-94 was 91.3 mph, but the AM peak period downstream speed was shown to be 91.5 mph, an increase of 0.2% when compared with the AHDS and the PM peak period downstream speed was shown to be 81.7 mph, a decrease of 10.5% when compared with the AHDS (see Table 8).

Also, the average hourly reduced speed (AHRS) on the freeway I-94 was 6.8 mph, but the AM peak period reduced speed was shown to be 7.7 mph, an increase of 13.20% when compared with the AHRS. The PM peak period reduced speed was shown to be 10.4 mph, an increase of 52.9% when compared with the AHRS (see Table 8).

OCCUPANCY ANALYSES

The occupancy pattern on the freeway I-94 also showed the variable speed patterns as shown in Figure 9.

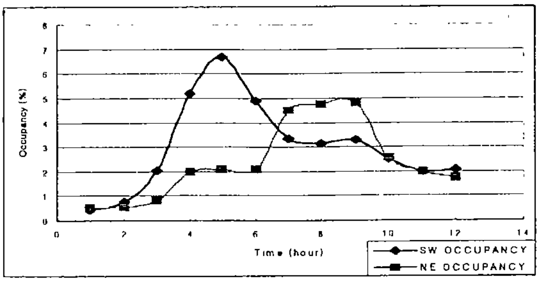

Fig. 9 Occupancy Patterns on I-94 after ITS

Especially, the average hourly upstream occupancy (AHUO) on the freeway SW bound I-94 was 3.1 percent, but the AM peak period upstream occupancy was shown to be 5.7 percent, an increase of 63.9% when compared with the AHUO. The PM peak period upstream occupancy was shown to be 3.3 percent, an increase of 6.5% when compared with the

Table 8 Shifts of Speed on the I-94 Merge Section after ITS (mph)

Freeway	24 Hours Average Speed	Peak Period Speed			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Speed					
SW I-94	98.3	89.6	-8.9	100.1	+1.0
NE I-94	97.4	101.4	4.1	91.1	-6.5
I-94	97.9	95.5	-2.5	95.6	-2.3
Downstream Speed					
SW I-94	90.8	83.9	-7.6	88.7	-2.3
NE I-94	91.3	91.5	+0.2	81.7	-10.5
I-94	91.1	87.7	-3.7	85.2	-6.5
Reduced Speed					
I-94	6.8	7.7	13.2	10.4	52.9

AHUO. The average hourly upstream occupancy (AHUO) on the freeway NE bound I-94 was 2.7 percent, but the AM peak period upstream occupancy was shown to be 2.35 percent, a decrease of 13.0% when compared with the AHUO and the PM peak period upstream occupancy was shown to be 5.25 percent, an increase of 94.4% when compared with the AHUO (see Table 9).

In addition, the average hourly downstream occupancy (AHDO) on the freeway SW bound I-94 was 3.8 percent, but the AM peak period downstream occupancy was shown to be 6.3 vph, an increase of 65.8% when compared with the AHDO. The PM peak period downstream occupancy was shown to be 4.4 vph, an increase of 15.8% when compared with the AHDO. The average hourly downstream occupancy (AHDO) on the freeway NE bound I-94 was 3.3 percent, but the AM peak period downstream percent was shown to be 3.0 percent, a decrease of 9.1% when compared with the AHDO and the PM peak period downstream occupancy was shown to be 6.5 percent, an increase of 59.7% when compared with the AHDO (see Table 9).

DELAY ANALYSES

The average hourly delay (AHDL) on the freeway I-94 was 5.5 MPV, but the AM peak period delay was shown to be 9.9 MPV, an increase of 80.0% when compared with the AHDL. The PM peak period delay was shown to be 8.3 MPV, an increase of 50.9% when compared with the AHDL (see Table 10).

METERING ANALYSES

The average hourly metering rate (AHMR) on the freeway I-94 was 7.7 VPM, but the AM peak period upstream occupancy was shown to be 8.7 VPM, an increase of 13.0% when compared with the AHMR. The PM peak period metering rate was shown to be 11.4 VPM, an increase of 48.1% when compared with the AHMR (see Table 11).

Table 9 Shifts of Occupancy on the I-94 Merge Section after ITS (%)

Freeway	24 Hours Average Occupancy	Peak Period Occupancy			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
Upstream Occupancy					
SW I-94	3.1	5.7	63.9	3.3	6.5
NE I-94	2.7	2.4	-11.1	5.3	96.3
I-94	2.9	4.1	41.4	4.3	48.3
Downstream Occupancy					
SW I-94	3.8	6.3	65.8	4.4	15.8
NE I-94	3.3	3.0	-9.1	6.5	97.0
I-94	3.6	4.7	30.6	5.5	52.8

Table 10 Shifts of Delay on the I-94 Merge Section after ITS (MPV)

Freeway	24 Hours Average Delay	Peak Period Delay			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
I-94	5.5	9.9	80.0	8.3	50.9

Table 11 Shifts of Metering Rate on the I-94 Merge Section after ITS (VPM)

Freeway	24 Hours Average Metering Rate	Peak Period Metering Rate			
		AM Peak Period	Change (%)	PM Peak Period	Change (%)
I-94	7.7	8.7	13.0	11.4	48.1

From the results of the above analyses, the traffic flow, speed and occupancy on the merge section after ITS were also shown to be variable depending on the time periods and directions between urban and suburban areas. Thus, the ramp metering system strategy which could appropriately maintain the traffic flow, speed and occupancy, and also maximize the entrance ramp flows to the mainline section within the acceptable range of 240 vehicles per hour to over 900 vehicles per hour while still retaining free flow on the freeway should be established.

Ⅲ.4 COMPARISON OF TRAFFIC ANALYSES BEFORE/AFTER ITS

FLOW

The average traffic flow on I-94 after ITS was shown to be a decrease of 36.4% when compared with the average flow before ITS. Also, the average peak period flows on I-94 after ITS were shown to be a decrease of 37.4% and 29.2% when compared with the average peak period flow before ITS, respectively (see Figure 10).

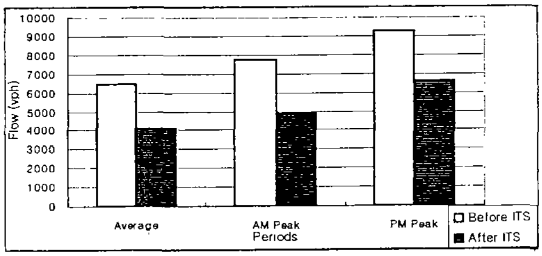

Fig. 10 Flows on I-94 before/after ITS

SPEED

The average speed on I-94 after ITS was shown to be an increase of 37.5% when compared with the average speed before ITS. Also, the average peak period speeds on the freeway I-94 after ITS were shown to be an increase of 44.7% and 29.7% when compared with the average peak period speeds before ITS, respectively (see Figure 11).

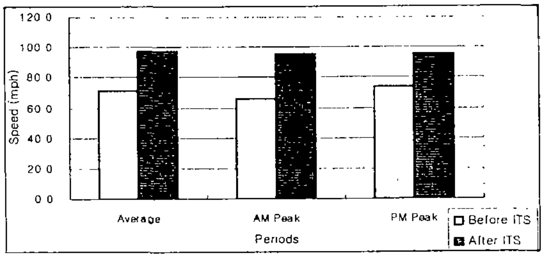

Fig. 11 Speeds on I-94 before/after ITS

OCCUPANCY

The average occupancy on the freeway I-94 after ITS was shown to be a decrease of 50.8% when compared with the average occupancy before ITS. Also, the average peak period occupancies on the freeway I-94 after ITS were shown to be a decrease of 50.0% and 51.7% when compared with the average peak period occupancies before ITS, respectively (see Figure 12).

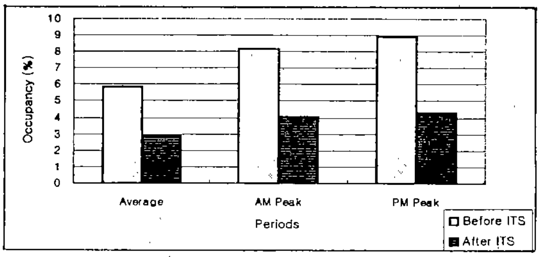

Fig. 12 Occupancies on I-94 before/after ITS

DELAY

The average delay on I-94 after ITS was shown to be a decrease of 40.2% when compared with the average delay before ITS. Also, the AM peak period delay was shown to be a decrease of 39.6%, and the PM peak period delay an increase of 1.2% when compared with peak period delays before ITS (see Figure 13).

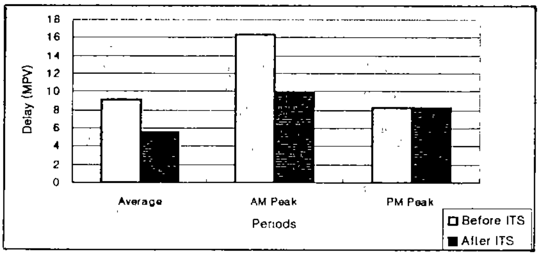

Fig. 13 Delays on I-94 before/after ITS

METERING

The average metering rate on the freeway I-94 after ITS was shown to be an increase of 13.2% when compared with the average metering rate before ITS. Also, the peak period metering rates were shown to be an increase of 11.5% and 20.0% when compared with peak period metering rates before ITS, respectively (see Figure 14).

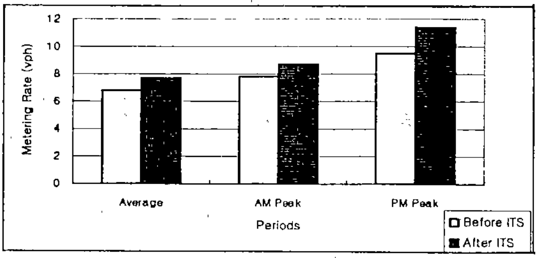

Fig. 14 Metering Rates on I-94 before/after ITS

The above results were shown to maintain the improved mainline characteristics on the freeway I-94 after ITS when compared with before ITS.

Ⅳ. CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS

Before the application of the ramp metering system by the Intelligent Transportation System (ITS) technology, the traffic flow characteristics on the mainline merge section of freeway were reviewed :

i) Flow, occupancies, and speeds on the mainline merge section of freeway were shown to be a big difference depending on the peak periods, areas, and directions based on the distribution of traffic flow characteristics on the freeway.

ii) Reduced speed was shown to be more than 5 mph, and ramp flow was also shown to be more than 240 vph at peak periods if there was the ramp metering system constructed on the freeway (see Figure 15).

iii) Ramp metering system was shown to be optimally operated on the freeway if ramp flow

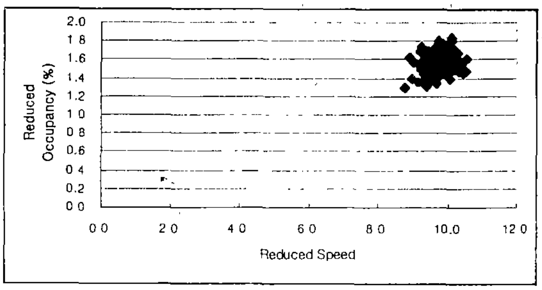

Fig. 15 Relationship of Reduced Speed and Reduced Occupancy on I-94 at AM Peak

could be maximized within the range of over 900 vph and reduced occupancy could be also maximized by no more than 2 percent at peak periods (see Figure 16).

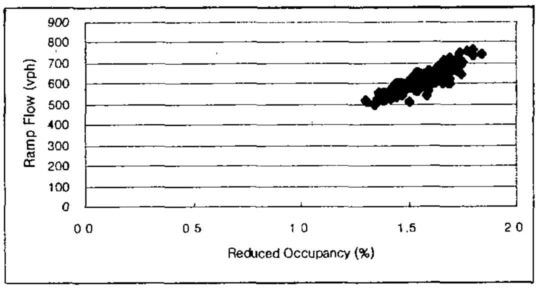

Fig. 16 Relationship of Ramp Flow and Reduced Occupancy on I-94 at AM Peak

After the application of the ramp metering system by the Intelligent Transportation System (ITS) technology, the traffic flow characteristics on the mainline merge section of freeway were reviewed :

i) The average flows on the freeway after the ITS technology were shown to be a decrease of over 20% depending on the peak periods, areas, and directions when compared with those flow on the freeway before the ITS technology.
ii) The average speeds on the freeway after the ITS technology were shown to be an increase of over 20% depending on the peak periods, areas, and directions when compared with those speeds on the freeway before the ITS technology.
iii) The average metering rates on the freeway after the ITS technology were shown to be an increase of over 10% depending on the peak periods, areas, and directions when compared with those metering rates on the freeway before the ITS technology.

SUGGESTIONS

From the above conclusions before/after the application of the ITS technology on the freeway, the suggestions were made :

i) Ramp metering strategy should be established such that the fixed time ramp metering system could be first of all implemented after reviewing the measurement of effectiveness (MOE) in ramp metering types before the application of the ITS technology.
ii) Ramp metering system should be considered only after reviewing traffic flow and geometric characteristics on the freeway and service roads.
iii) Ramp metering system should be determined based on the shifts of the flow, occupancies, and speeds depending on the peak periods, areas and directions on the freeway.
iv) Ramp metering system should be positively considered if reduced speed is more than 5 miles per hour (mph) and metering rate is more than 240 vph on the new freeway at peak periods.
v) Ramp metering system should be established

such that ramp flow could be maximized within the range of over 900 vph and reduced occupancy could be increased by no more than 2 percent.

vi) Ramp metering types should be determined based on the distribution characteristics of traffic flows, occupancies and speeds depending on the time periods, areas, directions of freeway, and financial circumstances.

요 약

오늘날 고속도로는 지역내 또는 지역간 막대한 수송능력을 지닌 중요한 간선도로가 되고 있다. 그러나, 이러한 고속도로가 과다한 유입교통량으로 심각한 교통체증과 교통사고를 겪고 있다. 선진국에서는 이러한 문제를 다소나마 해결하기 위해 고속도로의 합류부에 램프미터링 시스템을 도입하고 있는 추세다.

본 연구에서는 이러한 램프미터링 시스템이 설치되어있는 미국 미시간주 디트로이트지역의 핵심 고속도로인 I-94를 중심으로 첨단교통체계(ITS) 기술의 도입 전·후 고속도로 교통분석과 특성변화에 대해서 비교·분석하였다.

결과적으로, 고속도로의 교통특성은 시간대별, 방향별로 많은 변화가 발생하고 있었으므로 시간대에 적절한 미터링 시스템구축이 요구되었다. 특히, 첨단교통체계(ITS)를 적용하기 전·후의 시스템특성변화에 있어서 ITS기술을 도입한 후에 고속도로의 교통특성 및 미터링 비율이 한층 향상되었음을 확인할 수 있었다.

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