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都市地域 固定式 信號體系의 效率的 運營

The Efficient Operations of the Pretimed Signal System(PSS) in Urban Area

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Ⅰ. INTRODUCTION

Today transportation problems are becoming severer with the increase of the vehicles and travel demand at most of the big cities in the world. However, transportation facilities maintained in the big cities are not sufficient, and the financial resources and lands for the expansion of new transportation facilities are also limited. Therefore, the appropriate Transportation System Management(TSM) techniques which could improve the existing transportation systems are absolutely required for solving the impending transportation problems simultaneously with the continuous expansion of the new transportation facilities in the big cities. An exception could not be made for the application of the appropriate TSM techniques with the expansion of the transportation facilities in Pusan, Korea.

In the City of Pusan, as one of the big cities in Korea, urban transportation problems due to serious traffic congestion are occurring regardless of the rush-hours from morning till night as shown in Fig. 1. Because the rate of road (about 14.5% in 1996) maintained in Pusan area is too low to appropriately cope with the increasing traffic volumes and the mixed ones with the heavy trucks, and the detour and alternated roads are also almost non-existent under the circumstances of the mountainous terrain of more than thirty percentage and the belt-typed roadway from the south to the north bound. What is worse, urban transportation problems in Pusan area are being worsened because of the travel demand rapidly increasing by about 16.8% and the transportation facilities being expanded only by less than 1% per year. Also, the transportation systems (i.e., travel system, roadway system and signal system) which are inefficiently operated on major arterials in Pusan area are reducing travel capacity and aggravating traffic congestion on arterials. Especially, there are about 900 signalized intersections being operated in Pusan area, but most of the signalized intersections are operated by the pretimed signal system instead of the actuated system which could reduce traffic delay and increase travel capacity on those intersections.

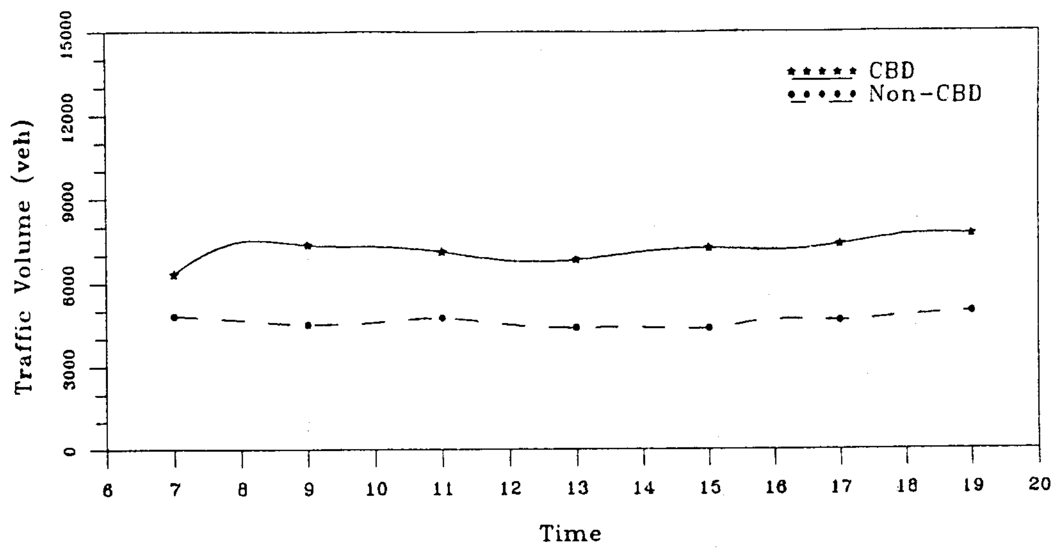


Fig. 1 Hourly Vehicle Distribution of the Intersections

Thus, the purpose in this study was to review the characteristics of the transportation systems on the Pretimed Signalized Intersections(PSI) under the study, construct the transportation systems for the different time-periods : the AM on-Peak, the AM off-Peak, the PM off-Peak, and the PM on-Peak based upon those characteristics of the transportation systems reviewed, and finally suggest the efficient transportation systems which could reduce traffic delay and fuel consumption, and increase travel capacity on the Pretimed Signalized Intersections(PSI) based upon the transportation systems constructed.

According to the studies related with the efficient operations of the signalized intersections, Mctrans(1) reported, "The signal operations which were constructed for 56 signalized intersections at the Central Business Districts(CBD) in Tallahassee, Florida were optimized by Larry Hagen based upon five different time-periods : the AM peak, the AM off-peak, the noon peak, the PM peak, and the evening off-peak. The results of the study showed a reduction of delays, stops, and fuel consumption corresponding to the operating cost savings of U$7.68 million per year." W. H. Kraft(2) reported, "Effective traffic signal management on arterials and local streets would reduce delays by 15%, and traffic operation improvements could increase capacity by 15%. Capacity on suburban arterials could be increased up to 50% by adding up left-turn lanes, minimizing parking interaction, and optimizing traffic signal system operations."

Also, A. K. Rathi and E. B. Lieberman(3) reported, "Repeated observation of the traffic movements within the study area and on its approaches as the low-cost transportation system management(TSM) confirmed a marked reduction in blockage. Simulation results with the existing signal phase sequence and phase duration well-designed showed 39.9% reduction in traffic delay and 7.1% increase in vehicle trips." Marshall Jacks, JR(4) reported, "By improving traffic signal control systems (i.e., improving hardware and optimizing signal timings), travel time could be increased by as much as 10%. Arterial congestion could also be reduced through traditional traffic operations improvements, such as turn lanes, one-way streets, channelization, reversible lanes. By using these relatively low cost-improvements, it was possible to increase throughput by as much as 15%."

Moreover, Institute of Transportation Engineers(ITE) technical committee 4A-24(5) reported, "The simplest and most direct way to reduce excessive queue length on an approach to a signalized intersection was to increase the green-to-cycle-length ratio(G / C). Increasing G / C would always reduce the upstream queue." Also, Shui-Ying Wong(6) reported, "There were improvements in the model results constructed using TRANSYT-7F and the field studies conducted for 16 signalized intersections within the downtown area of Shenzhen, China. Even if the magnitude of improvements from the field studies was relatively small compared with the model results, it represented more improvements than what the numbers showed."

Based upon the studies reviewed in the above, transportation system analyses (i.e., travel system analysis, roadway system analysis, and signal system analysis) on the Pretimed Signalized Intersections(PSI) in Pusan area were required for the efficient operations of those signalized intersections regardless of the peak-time periods.

II. TRANSPORTATION SYSTEM ANALYSES

In Pusan area, urban transportation problems were getting worse and worse because of the low rate of road, the insufficient detour and alternated roads, and the inefficient transportation system operations. Also, the financial support and lands for the expansion of new transportation facilities were not sufficient in Pusan area. What was worse, the peak-time periods were not equal to the rush-hours as shown in Fig. 1. Because traffic congestion was occurring on most of the signalized intersections from morning till night regardless of the rush-hours : 07 : 00 ~09 : 00 in the morning and 17 : 00 ~19 : 00 in the afternoon.

Thus, transportation system analyses (i.e., travel system analysis, roadway system analysis, and signal system analysis) were conducted for the pretimed signalized intersections as one of the low-cost transportation system improvements in Pusan area.

II. 1 Travel System Analysis

Reviewing the hourly vehicle distribution concentrated on the intersections under the study, there was no difference in the total traffic volumes between the time-periods as shown in Fig. 1. However, there was a considerably big difference in the directional link traffic volumes between the time-periods. Because more traffic volumes were coming into urban area from suburban areas in the morning, but more traffic volumes were going out to suburban areas from urban area in the afternoon(8, 9). Therefore, it must be absolutely reviewed to categorize the total traffic volumes into the directional link traffic volumes based on the time-periods.

Thus, the time-periods reviewed were categorized into 4 different peak periods : the AM on-peak (07 : 00 ~09 : 00 in the morning), the AM off-peak (09 : 00 ~12 : 00 in the morning), the PM off-peak (14 : 00 ~17 : 00 in the afternoon), and the PM on-peak (17 : 00 ~19 : 00 in the afternoon) for the grasp of the directional travel characteristics of the vehicles on the signalized intersections under the study. Especially, the peak-time traffic volumes for each time period which were computed by the Passenger Car Units(PCU) based upon the size and the weight of the vehicles were used for signal system analysis (see Fig. . 2 and Table 1).

Table 1 Passenger Car Units for the Vehicles

(Unit : PCU)

Veh. Type	Passenger Car	Taxi	Van	Truck	Bus	Autobicycle	Special Truck	Container Truck
PCU	1	1	1.5	2.5	2	0.5	2.5	4

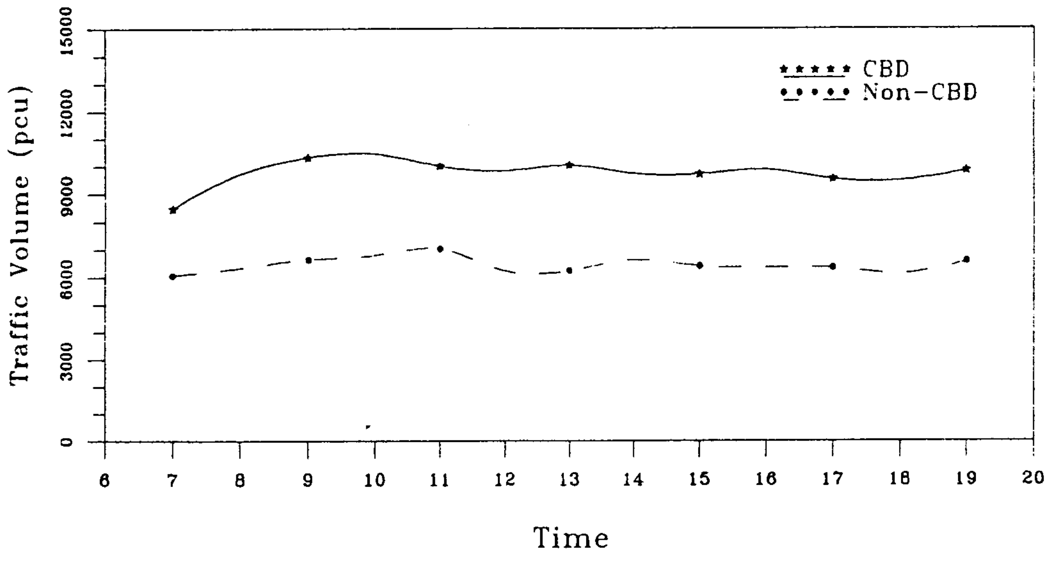


Fig. 2 Hourly PCU Distribution of the Intersections

II. 2 Roadway System Analysis

Reviewing the geometric characteristics of the streets and the intersections of roadway system under the study, there was a marked difference in the number of lanes, lane width, and the shape in the intersections. Especially, the widths of the intersections selected were maintaining about 10M ~ 38M, and the lane widths which were maintaining about 3M ~ 5M showed a distinct difference compared with the ideal lane width of 3.6M (12 feet). Also, the number of lanes in the intersections was maintaining 1 ~ 7 lanes for each direction. So, the lane capacity of the intersections was computed based upon the criteria of the Highway Capacity Manual(HCM)(10) and the TRANSYT-7F(11) used for the optimization of signal system considering the geometric characteristics of roadway system and the size of the vehicles in the country.

Thus, the lane capacity allocated was 2,250 Passenger Car Unit(PCU) for the thru lane width of 3.6M, 2,000PCU for the turning lane width of 3.6M, and 3,000PCU for the shared lane width of 3.6M, respectively. Especially, if the primary link was for the thru direction in the capacity allocation of the shared lane, the primary link capacity used was 2,250PCU and the secondary link capacity 750PCU. Also, if the primary link was for the turing direction, the primary link capacity used was 2,000PCU and the secondary link capacity 1,000PCU.

II. 3 Signal System Analysis

Reviewing the signal system characteristics in Pusan area, most of the intersections were controlled not by the actuated signal system, but by the pretimed signal system. Moreover, signal timings, phases, signs, markings, or channelizations which were not appropriate for the passage of the vehicles were worsening traffic congestion on the signalized intersections. Especially, the cycle lengths of the intersections selected in the Central Business Districts(CBD) were operated by 140sec ~ 200sec on the whole, signal phases were composed of 2 phases ~ 6 phases, and the effective green time(G / C) in the main direction of the intersections in the CBD showed about 0.21 ~ 0.77, but the cycle lengths of the signalized intersections in the Non-CBD were operated by 110sec ~ 280sec on the whole, signal phases were composed of 2 phases ~ 5 phases, and the effective green time(G / C) in the main direction of the intersections in the Non-CBD showed about 0.21 ~ 0.59.

For the simulation and the optimization results of signal system on the intersections under the study, the objective function of TRANSYT-7F widely used was :

$$\text{Minimize } DI = \sum_{i=1}^{n} \{ [W_{di} d_i + K W_{si} S_i] + U_i [W_{di-1} d_{i-1} + K W_{si-1} S_{i-1}] + Q B_i [W_q (q_i - qc_i)^2] \}$$

where DI : disutility index (analogous to the original TRANSYT performance Index) ;

d_i : delay on the link i (of n links) [and on an optional user-specified upstream input link (designated here as link I-1)] in veh-hr ;

K : a user coded "stop penalty" factor to express the importance of stops relative to delay (note, if coded as '-1' in TRANSYT, the base W_{xi} are set internally so that the base DI is equivalent to excess fuel consumption) ;

S_i : stops on the link i (and similarly for link I-1) in stops/sec) ;

W_{xi} : link specific weighting factors for delay (d) and stops (s) for link i (and I-1) ;

U_i : a binary variable which is '1' if link-to-link weighting has been established for link I, or zero otherwise ;

Q : a binary variable set by the user which if '1' includes the maximum back of queue penalty in the DI, or zero otherwise ;

B_i : a binary variable which is '1' if the maximum back of queue (q_i) exceeds the user-specified storage capacity, or zero otherwise ;

W_q : a network-wide "penalty" applied to the excess queue "spillover" ;

q_i : computed maximum back of queue on link I ; and

qc_i : maximum back of queue "capacity" for link I.

Thus, transportation system analyses must be reconducted because the existing transportation systems on the signalized intersections in urban area were not appropriate for the travel characteristics of the vehicles. Especially, the transportation system analyses must be reconducted based upon the different time-periods because there was a big difference shown in the directional link traffic volumes for the different time-periods.

III. ANALYSES OF THE INTERSECTIONS

Based upon transportation system analyses in the above : travel system analysis, roadway system analysis, and signal system analysis, 20 intersections which consisted of 10 intersections in the Central Business Districts(CBD) and 10 ones in the Non-CBD were selected for analyses of the intersections.

III. 1 Analyses of the intersections in the CBD

The intersections in the CBD which took the shapes of 3-leg ~ 5-leg were operated by the cycle lengths of 140sec ~ 180sec. Also, the total traffic volumes concentrated on the intersections showed about 7,000PCU ~ 16,000PCU during the AM on-peak period, about 7,500PCU ~ 16,000PCU during the AM off-peak and PM off-peak periods, and about 7,800PCU ~ 14,500PCU during the PM on-peak period.

The results of analyses showed that average delay(AD) and fuel consumption(FC) on the CBD intersections under the existing signal settings compared with those under the optimal settings were increased by about 52% and 51%, respectively. Especially, these results showed that applying the same signal system to the different time periods increased average delay and fuel consumption on the intersections by about 36% and 34%.

III. 2 Analyses of the Intersections in the Non-CBD

The intersections in the Non-CBD which took the shapes of 3-leg ~ 5-leg were operated by the cycle length of 130sec ~ 180sec. Also, the total traffic volumes concentrated on the intersections showed about 4,300PCU ~ 9,000PCU during the AM on-peak period, about 5,500PCU ~ 11,400PCU during the AM off-peak and PM off-peak periods, and about 4,900PCU ~ 9,800PCU during the PM on-peak period.

The results of analyses showed that average delay(AD) and fuel consumption(FC) on the Non-CBD intersections under the existing signal settings compared with those under the optimal settings were increased by about 53% and 50%, respectively. These results showed that applying the same signal system to the different time periods increased average delay and fuel consumption on the intersections by about 36% and 34%.

In illustration of analyses of the intersection, the intersection M (Soo Young Intersection) located in the Non-CBD was the 3-leg intersection, and also operated by the cycle length of 180sec and 3 phases. The peak-time traffic volumes, showing a big difference in the directional link traffic volumes for the different time-periods, were 6,860PCU during the AM on-peak period, 8,040PCU during the AM off-peak period, 7,090PCU during the PM off-peak period, and 7,270PCU during the PM on-peak period, respectively.

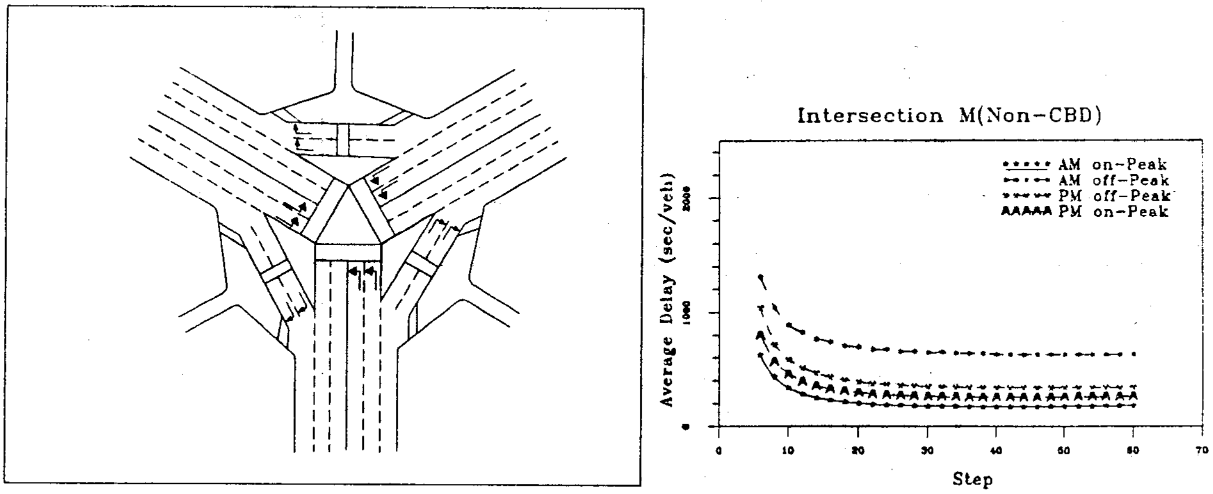


Fig. 3 Intersection M and the Cycle Evaluation

The results of analyses showed that transportation system improvments of the intersection reduced average delay(AD) by 34% during the AM on-peak period, 3% during the AM off-peak period, 12% during the PM off-peak period, and 5% during the PM on-peak period. These results showed that fuel consumption(FC) was reduced by 33% during the AM on-peak period, 3% during the AM off-peak period, 12% during the PM off-peak period, and 5% during the PM on-peak period (see Table III.1).

Table 2 Measures of Effectiveness(MOE) during the Peak Periods (Intersection M)

Analyses Parameter	AM on-Peak			AM off-Peak			PM off-Peak			PM on-Peak		
	Initial Setting	Optimal Setting	Rates of Reduction	Initial Setting	Optimal Setting	Rates of Reduction	Initial Setting	Optimal Setting	Rates of Reduction	Initial Setting	Optimal Setting	Rates of Reduction
Average Delay (sec/veh)	261	171	34%	647	625	3%	385	338	13%	267	254	5%
Fuel Consumption (lit/hr)	1,426	952	33%	4,063	3,929	3%	2,150	1,893	12%	1,543	1,469	5%

Especially, the results of analyses under the different time period-based optimal setting showed the MOE reductions corresponding to about 27% increase of average delay and 26% increase of fuel consumption when the AM on-peak optimal setting was applied to the different time periods. These results also showed the MOE reductions corresponding to about 34% increase of average delay and 33% increase of fuel consumption when the AM off-peak optimal setting was applied to those time periods, about 33% increase of average delay and 32% increase of fuel consumption when the PM off-peak optimal setting was applied to those time periods, and about 15% increase of average delay and 14% increase of fuel consumption when the PM on-peak optimal setting was applied to those time periods, respectively (see Tables 3, 4, 5, 6).

Table 3 MOE Reductions under the AM on-peak Optimal Setting (Intersection M)

Analyses Parameter	AM off-Peak			PM off-Peak			PM on-Peak		
	Optimal Setting	the AM on-Peak Optimal Setting	Rates of Increase	Optimal Setting	the AM on-Peak Optimal Setting	Rates of Increase	Optimal Setting	the AM on-Peak Optimal Setting	Rates of Increase
Average Delay (sec/veh)	625	798	28%	338	452	34%	254	303	19%
Fuel Consumption (lit/hr)	3,929	4,998	27%	1,893	2,516	33%	1,469	1,745	19%

Table 4 MOE Reductions under the AM off-peak Optimal Setting (Intersection M)

Analyses / Parameter	AM on-Peak			PM off-Peak			PM on-Peak		
	Optimal Setting	the AM off-Peak Optimal Setting	Rates of Increase	Optimal Setting	the AM off-Peak Optimal Setting	Rates of Increase	Optimal Setting	the AM off-Peak Optimal Setting	Rates of Increase
Average Delay (sec/veh)	171	313	83%	338	345	2%	254	300	18%
Fuel Consumption (lit/hr)	952	1,703	79%	1,893	1,933	2%	1,469	1,727	18%

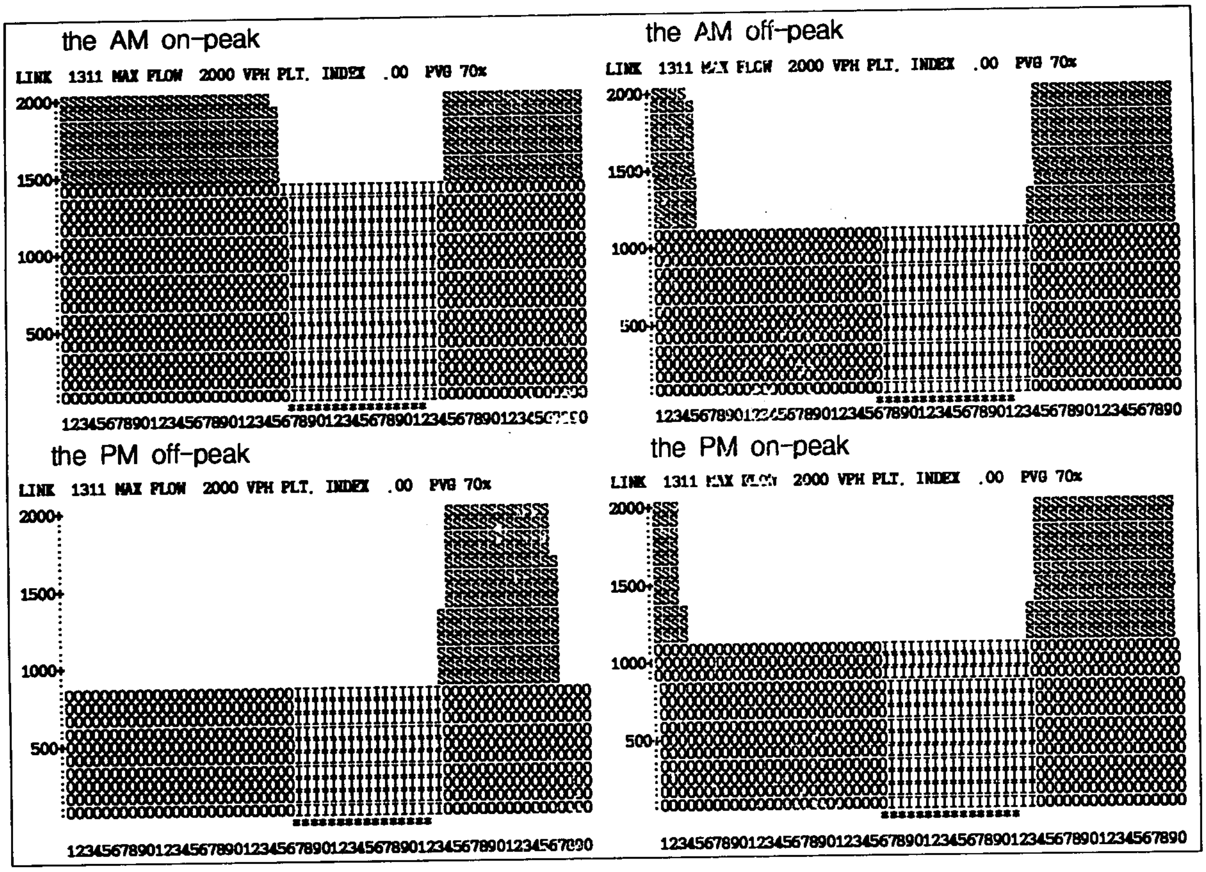
Table 5 MOE Reductions under the PM off-peak Optimal Setting (Intersection M)

Analyses / Parameter	AM on-Peak			AM off-Peak			PM on-Peak		
	Optimal Setting	the PM off-Peak Optimal Setting	Rates of Increase	Optimal Setting	the PM off-Peak Optimal Setting	Rates of Increase	Optimal Setting	the PM off-Peak Optimal Setting	Rates of Increase
Average Delay (sec/veh)	171	304	78%	625	674	2%	254	384	20%
Fuel Consumption (lit/hr)	952	1,655	74%	3,929	3,991	2%	1,469	1,756	20%

Table 6 MOE Reductions under the PM on-peak Optimal Setting (Intersection M)

Analyses / Parameter	AM on-Peak			AM off-Peak			PM off-Peak		
	Optimal Setting	the PM on-Peak Optimal Setting	Rates of Increase	Optimal Setting	the PM on-Peak Optimal Setting	Rates of Increase	Optimal Setting	the PM on-Peak Optimal Setting	Rates of Increase
Average Delay (sec/veh)	171	211	23%	625	674	8%	338	384	14%
Fuel Consumption (lit/hr)	952	1,163	22%	3,929	4,231	8%	1,893	2,147	13%

Thus, the results of analyses showed that the transportation systems must be efficiently constructed based upon the travel characteristics of the vehicles for the different time-periods as shown in Fig. 4. Because although there was no difference in the total traffic volumes concentrated on the intersections for the different time-periods (i.e., the AM on-peak, the AM off-peak, the PM off-peak, and the PM on-peak), there was a considerably big difference in the directional link traffic volumes. Also, these results showed that the optimal transportation systems of the intersections must be taken into consideration for the different time-periods as shown in Fig. 5. Because travel capacity of the intersections was increased by readjusting cycle length and phase duration such that stop delay could be reduced on the red signal of the intersections.



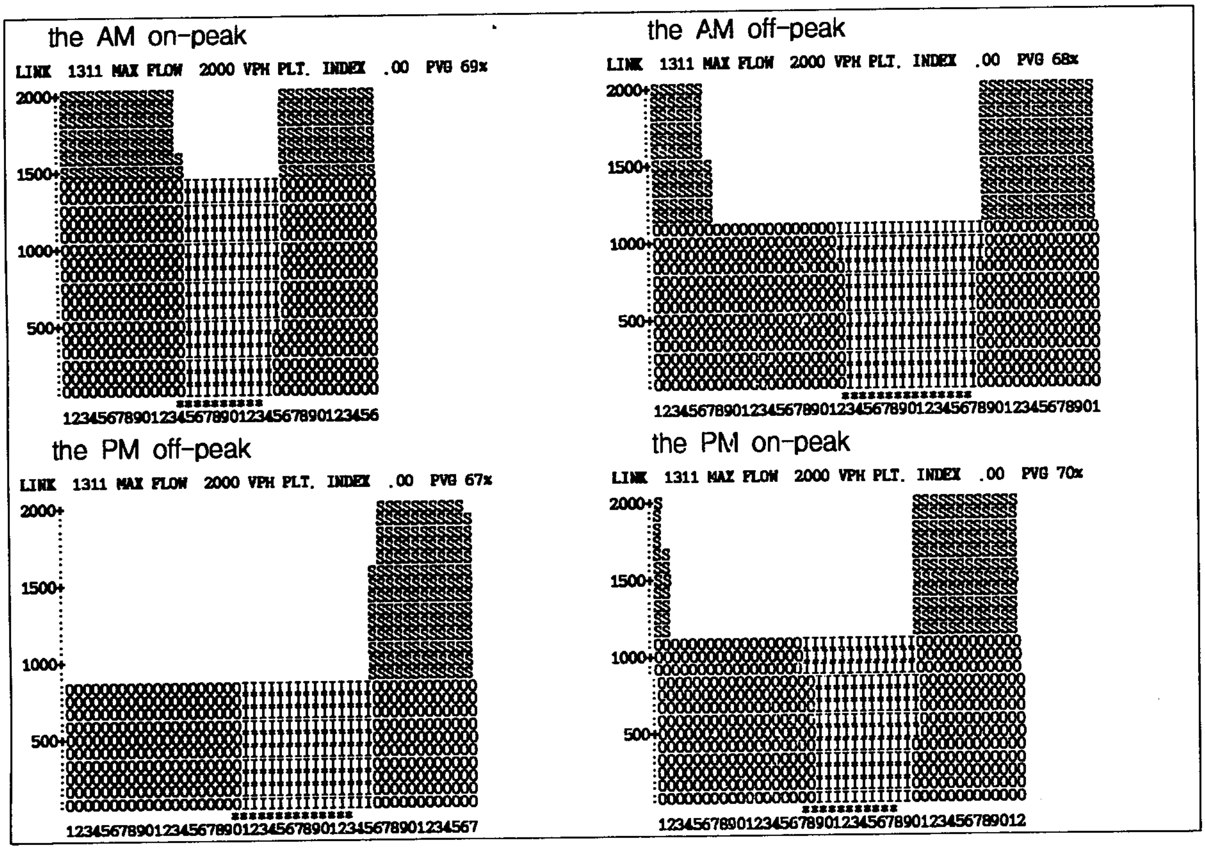
the AM on-peak

the AM off-peak

the PM off-peak

the PM on-peak

Fig. 4 Flow Profile Diagram of Link 1311 under the Initial Setting



the AM on-peak

the AM off-peak

the PM off-peak

the PM on-peak

Fig. 5 Flow Profile Diagram of Link 1311 under the Optimal Setting

Ⅳ. CONCLUSIONS AND SUGGESTIONS

Based upon the results of analyses for the efficient operations of the pretimed signal system in urban area, the following conclusions were drawn :

i) There was no distinct difference in the total traffic volumes concentrated on most of the pretimed signalized intersections(PSI) under the study for the different time-periods, but a considerably big difference in the directional link traffic volumes. Therefore, transportation system analyses must be reconducted for all the different time periods reviewed, respectively ;

ii) There were about 53% reduction of average delay and 51% reduction of fuel consumption by transportation system improvements in the CBD and the Non-CBD. Therefore, transportation system improvements on the intersections must be implemented regardless of the CBD and the Non-CBD ;

iii) There were about 36% increase of average delay and 34% increase of fuel consumption regardless of the CBD and the Non-CBD when the equal signal systems for the different time-periods were applied on the signalized intersections. Therefore, different signal systems for the different time-periods must be constructed for the reduction of average delay and fuel consumption ;

iv) Actuated signal systems were already known better than the pretimed signal systems in reducing traffic delay and fuel consumption, and increasing travel capacity on the signalized intersections in urban area. Therefore, signal operating system must be remodeled into the actuated systems from the pretimed systems in urban area ; and

v) The overall Data Base in Transportation was absolutely required for the better transportation system improvements in urban area. Therefore, the overall Data Base construction in Transportation must be made for the continuous studies on the existing transportation systems.

SOURCES

1. Mctrans, "Study Shows TRANSYT-7F Benefits Tallahassee Motorists", Transportation Research Center, University of Florida, Dec. 1995, Vol. 10, No. 2, p.
2. W. H. Kraft, "Traffic Congestion - What have we learned?", ITE Journal, Feb. 1989, pp. 24 - 26.
3. A. K. Rathi and E. B. Lieberman, "Reducing Traffic Congestion in Herald Square", ITE Journal, Sep. 1986, pp. 27 - 31.
4. Marshall Jacks, JR, "Urban Congestion - A Local Problem Requiring a National Response", ITE Journal Feb. 1989, pp. 22 - 23.
5. ITE Technical Council Committee 4A-24, "Management of Damaging Traffic Queues (A Summary Report)", ITE Journal, Jun. 1988, pp. 37 - 38.
6. Shui-Ying Wong, "Application of TRANSYT-7F in China", ITE Journal, Aug. 1988, pp. 38 - 42.
7. Taegon Kim, "A Study on the Optimum Design of the Arterial-Based Signal System for the relief of Transportation Problems in Metropolitan Areas", Journal of the Korean Institute of Port Research, Vol. 8, no. 2, Dec. 1994, pp. 1 - 35.
8. Pusan Metropolitan City, "Reports of Average Daily Traffic Data in Pusan, 1994", Dec. 1994.
9. Pusan Metropolitan City, "Reports of Average Daily Traffic Data in Pusan, 1995", Dec. 1995.
10. Transportation Research Board, "Highway Capacity Manual", TRB, Special Report 209, 1985.
11. McTrans, "TRANSYT-7F Software (Ver. 7.2) Users Manual", Transportation Research Center, University of Florida, Dec. 1991.