TRACS: TRAFFIC ADAPTIVE CONTROL SYSTEM IN SEOUL

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abstract: This paper addresses the outlines of the traffic signal timing principles engaged in Traffic Adaptive Control System(TRACS) and the results of field test. Research team, encompassing research institute, university, and electronic company, conducted the three-year project for developing the new system, named TRACS. The project was successfully completed in 1994. TRACS aims at accomplishing the objectives of better traffic adaptability and more reliable travel time prediction. TRACS operates in real-time adjusting signal timings throughout the system in response to variations in traffic demand and system capacity. Another purpose of TRACS is to provide real-time road traffic information such as volume, speed, delay, travel time, and so on. The performance of the first version of TRACS was compared to the conventional Time of Day(TOD) control through field test. The test result was promising in that TRACS consistantly outperformed the conventional control method. The change of signal timing reacted timely to the variation of traffic demand.

1. INTRODUCTION

A major objective of a traffic control system is to provide the appropriate and necessary timing plans for continuous movement along an arterial or throughout a network of major streets. The most appropriate traffic signal timing plans are obtained by on-line calculations based on detector measurements (RTSI, 1991).

Since early 1980's, a computerized traffic signal system has been running to control surface traffic in Seoul. This signal system uses the UTCS first generation software developed in United States in the 1970's. Currently, more than 1,500 intersections are controlled by four main-frame computers in traffic control center. This first generation systems are also used in operating traffic signals in other major cities in Korea.

The severing traffic conditions of the Seoul metropolitan area urged the establishment of more effective control system since the current signal control system had the limited capabilities of traffic adaptability and link speed measurements. In 1990, the city of Seoul has decided to develop an area traffic control system having advanced features. Basic requirements of the new traffic control system are real-time traffic data collection, real-time traffic adaptive traffic signal control, and traffic surveillance and monitoring. Research team, encompassing research institute, university and electronic company, conducted the three-year project for developing the new system, named TRACS(TRaffic Adaptive Control System)(RTSI, 1992 and RTSI, 1993). The project was successfully completed in 1994.

TRACS is a computer-based area traffic control system. It is a comprehensive system of hardware, software and control philosophy, which is a counterpart of the second generation of UTCS in United States. TRACS aims at accomplishing the objectives of better traffic adaptability and more reliable travel time prediction. TRACS operates in real-time adjusting signal timings throughout the system in response to variations in traffic demand and system capacity. The purpose of TRACS is to control traffic on an area basis rather than an individual uncoordinated intersection basis. Another purpose of TRACS is to provide real-time road traffic information such as volume, speed, delay, travel time and so on.

This paper addresses the outline of the traffic signal timing principles engaged in TRACS and the results of field test.

2. CONTROL PRINCIPLES

2.1 General

Entire city is divided into several regions for the purpose of traffic signal control. The size of the regions is determined by the maximum number of the intersections that the regional computer can handle. In order to control the signalized intersections of the entire city, several regional computers are needed depending on the city size. Since each regional computer controls its region saperately, there is a need to manage the regional computers together. The role of host computer is to receive the road traffic information from the regional computers and build real-time database for the entire city. The host computer does not control traffic signal in direct manner.

In TRACS, an area for signal coordination is divided into subareas consists of several signalized intersections that share a common cycle time. Each subarea contains only one critical intersection having heavy traffic load. This subarea is a basic unit of control. The subareas are initially defined by operaters, and the subareas are automatically linked and unlinked according to road traffic condition.

The basic measurements used in generating the signal timing is the degree of saturation(DS) and queue length on each approach. Traffic data are collected from three kinds of inductive loop detectors classified by their functions: stop-line detectors, mid-block detectors and far-upstream detectors. Primary detector for signal timing is the stop-line detector measuring DS at major approaches. The mid-block detectors and far-upstream detectors are used for the estimation of queue lengths and link speed. Figure 1 shows the type of detectors used in TRACS.

TRACS applies two different control strategies based on the traffic condition, that is, undersaturation and oversaturation. Under light traffic conditions, the signal timing is generated solely using DS data from stop-line detectors. As traffic demand increases, TRACS adjusts cycle lengths and allocates green time to keep the average DS below 1.0 and to balance DS for competing approachs. The control objective for undersaturated conditions is to minimize total delay. When traffic demad becomes too heavy to maintain average DS below 1.0, there is no way to avoid oversaturated condition. For the oversaturated conditions, the control objectives are to manage queue lengths efficiently and to prevent queue spillback at the upstream intersections.

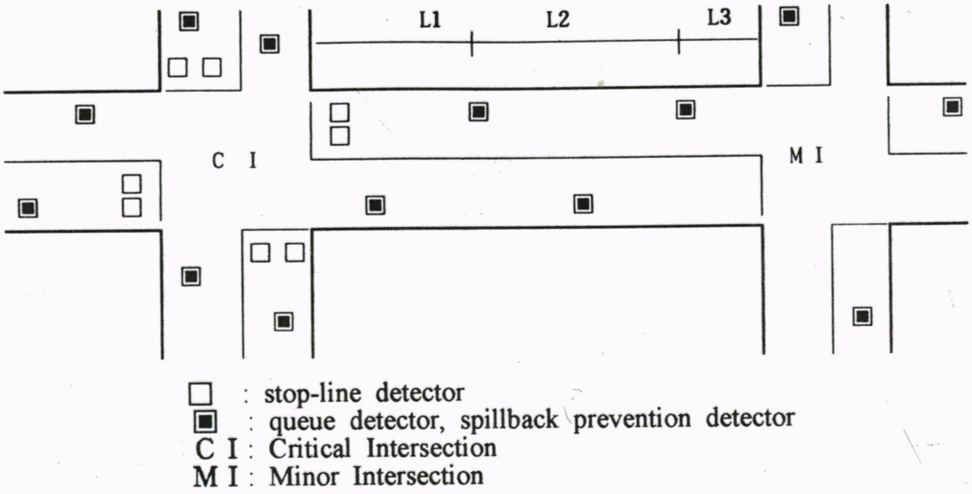


Figure 1. Detector Types

2.2 Multi-Level Control

TRACS performs two levels of control; regional computer level (RC control) and local controller level(LC control). In RC control, the regional computer calculates optimal signal timing for every subarea based on the detector measurements transmitted through the local controllers. The signal timing determined by RC control is sent to the local controllers located at individual intersections. LC control slightly adjusts original signal timing considering local traffic condition. RC control is basically concerned with the determination of suitable signal timings for the subareas in the region based on average prevailing traffic conditions. LC control refer to control at the individual intersection level within the constraints imposed by the RC control. The control concept of TRACS is shown in Figure 2.

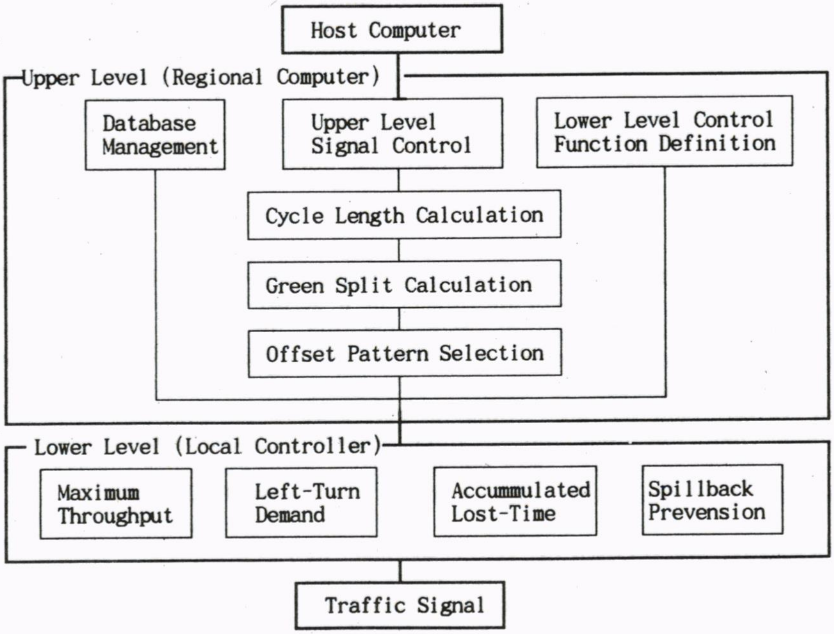


Figure 2. Control Concepts of TRACS

3. TRAFFIC ADAPTIVE (UPPER-LEVEL) CONTROL

3.1 Cycle Length

The cycle length is the time taken to complete one sequence of all phases and must vary to meet the overall level of traffic demand because, in general, increased cycle length increases intersection capacity. TRACS dynamically adjusts cycle length to maintain the highest degree of saturation in a co-ordinated group of signals within acceptable operator defined limits, usually 0.9. It is not desirable that the cycle-length changes are too sensitive to the random fluctuation of traffic demand, so TRACS adjusts the cycle length for stable control based on the trend of traffic demand rather than the row traffic data.

During the normal traffic condition, the cycle length can increases upto maximum extention cycle length. If demand exceeds the level that the maximum extention cycle length can handle, control mode transfers to the oversaturation control. When the cycle length reaches maximum extention cycle length on the oversaturation control, and the extra cycle time required is assigned to the approach having the longest queue length.

3.2 Green Split

Green split refers to the division of the cycle into a sequence of green signals for the competing movements at each intersection and must reflect the relative demands for green time on each approach. The TRACS determination of green splits is essentially to maintain balanced DS on competing approaches. Sometimes, control may be biased to favor major traffic movements when demand approaches saturation. TRACS calculates green splilt using the DS predicted for the next cycle. For unbalaced left-turn traffic, the introduction of overlap phases gives efficient green time allocation, so TRACS employs NEMA's dual-ring eight-phase scheme(NEMA, 1983). It was found that the dual-ring scheme has advantage over traditional 'step' method in calculating overlap phase lengths.

In oversaturated control strategies, green time is determined based on the queue lengths estimated from mid-block detectors rather than based on the DS. The reserved green time in the state of maximum cycle length is assigned to the approach having the longest queue length. The successive assignment of the reserved green times to a particular approach may result in rapidly increasing queue length of the competing approach. The reserved green is timely shifted between the competing approaches to obtain balanced queue lengths.

3.3 Offset

Offset refers to the time relationship between the major phase starting points of adjacent signals. The pattern of offsets in a series of co-ordinated signals must be varied with traffic demand to minimise the delay and the number of stops associated with travel through a network of signals. TRACS selects best-fitted offset pattern based on the inbound/outbound traffic ratio and traffic demand level. Seven offset patterns are available for individual sub-area for normal traffic condition; one for light traffic, three (inbound preference, two-way progression, outbound preference) for mid-range traffic and three for heavy traffic. For oversaturated control, three offset patterns are prepared additionally.

4. TRAFFIC RESPONSIVE (LOWER-LEVEL) CONTROL

The signal timing determined by RC (based on the trend of traffic demand) is sent to the local controllers located at individual intersections. The signal timing might be not appropriate to control current traffic demand when the pattern varies abruptly. LC control therefore slightly adjusts original signal timing (green splits) considering local traffic condition. TRACS has four types of traffic responsive controls: maximum throughput responsive control, left-turn demand responsive control, accummulated lost time responsive control, and splillback prevension control. This section briefly describes the traffic responsive control principles of TRACS. See Reference (RTSI, 1993) for more details.

4.1 Maximum Throughput Responsive Control

The delay is minimized by allocating the available green time in proportion to the degree of saturation of the competing movements. On congested conditions the green time would be allocated to maximize the throughput of the intersection. Maximum throughput responsive control in TRACS is applied to maximize the available green time usage on saturated condition. TRACS determines the critical point during the green time when the outflow rate of the movement starts to decrease. When the critical point searched, TRACS cuts off the green and allocates the available green time to the next green. The critical point is determined by the moving average method (four vehicles) as follows:

$$V_i = \frac{3600 * i}{h_i} \tag{1}$$

$$slope_i = \frac{V_i - V_{i-1}}{h_i - h_{i-1}} \tag{2}$$

$$slope_{avg} = \frac{slope_i + slope_{i-1} + slope_{i-2}}{3} \tag{3}$$

where, V_i = average throughput rate to the i^{th} vehicle
h_i = accummulated headways to the i^{th} vehicle
$slope_i$ = increase(+) or decrease(-) index of average throughput rate to the i^{th} vehicle
$slope_{avg}$ = increase(+) or decrease(-) index of average throughput rate by the moving average method (four-vehicle)
$i = 1, 2, 3, 4$

4.2 Left-Turn Demand Responsive Control

The basic concept of the left-turn demand responsive control is as follows. A left-turn detector is used to identify the arrival of the vehicle; the controller is notified; if the left-turn movement is given the green for just enough time to guarantee that its vehicles are processed, cut-off the left-turn green; the available green time is allocated to the next green.

4.3 Accummulated Lost-Time Responsive Control

Accummulated lost-time responsive control is applied to respond the travel demand on cycle basis on near congested condition. The lost-time is defined as the time subtracting the saturation headway from the measured headway. The green for a movement is cut-off when the accummulated lost-time reaches the threshold, and the available green time is allocated to the next green. The principle of the accummulated lost time control is as follows:

$$t_{lost,i} = hdwy_{measured,l} - hdwy_{sat} \tag{4}$$
$$t_{cumulative} = \sum_i t_{lost,i} \tag{5}$$

if $t_{cumulative} > t_{lost,permitted}$, then cut-off the green and allocate the available green time to the next green.

where, $t_{cumulative}$ = accummulated lost-time
$t_{lost,i}$ = lost-time for the i^{th} vehicle
$hdwy_{measured,l}$ = headway for the i^{th} vehicle
$hdwy_{sat}$ = saturation headway
$t_{lost,permitted}$ = the permitted lost-time (given)

4.4 Spillback Prevension Control

The spillback (intersection blockage) causes the spread of congestion along routes so that the productivity of upstream intersections is ruined by it. Because the spillback degrades the network, its removal must be the prime objective of the network-wide traffic control. The spillback prevension control in TRACS employs of the principles of internal metering plans. The metering concept does not explicitly minimize delay and stops, but rather manages the queue formation in a manner which maximizes the productivity of the congested system. The spillback prevension control manages the volume being discharged at intersections upstream of a critical intersection when the spillback detector identifies the congestion (e.g., under 5km/h) of the downstream intersection.

5. MEASURES OF EFFECTIVENESS

5.1 Average Delay

The calculation of the travel times used in TRACS involves two components: the running time along links and delays at intersections. The average delay for each movement is estimated by the U.S.HCM delay function(TRB,1985).

$$d_i(t) = 0.5 \cdot PF_i(t) \cdot C(t) \frac{\{ 1 - \frac{g_i(t)}{C(t)} \}^2}{\{ 1 - \frac{g_i(t)}{C(t)} \cdot DS_{max}(t) \}} + 225 \cdot DS_{max}(t)^2 \cdot [\{DS_{max}(t) - 1\}$$

$$+\{(DS_{max}(t) - 1)^2 + \frac{16 \cdot DS_{max}(t)}{s_i(t) \cdot g_i(t)/C(t)} \}^{1/2}] \tag{6}$$

where, $d_i(t)$ = average delay of movement i(sec/veh)
$C(t)$ = cycle length (sec)
$g_i(t)$ = green time of movement i(sec)
$DS_{max}(t)$ = maximum degree of saturation
$s_i(t)$ = saturation flow rate of movement i
$PF_i(t)$ = progression factor of movement i

5.2 Average Speed

$$v_{link(k)}(t) = \frac{l_k}{d_{thru(k)}(t) + 3.6\ l_k/v_{det(k)}(t)} \times 3.6 \qquad (7)$$

$$v_{SA}(t) = \frac{\Sigma_k\ l_k}{\Sigma_k\ (d_{thru(k)}(t) + 3.6 l_k/v_{det(k)}(t))} \times 3.6 \qquad (8)$$

where, $v_{link(k)}(t)$ = average speed on link k at cycle t(km/h)
$v_{SA}(t)$ = average travel speed on subarea (km/h)
l_k = link length (m)
$d_{thru(k)}(t)$ = average delay(through movement, sec/veh)
$v_{det(k)}(t)$ = detected speed on link k (km/h)

5.3 Average Travel Time

$$T_{average}(t) = \frac{3.6\ \Sigma_k\ l_k}{60\ v_{SA}(t)} \qquad (9)$$

where, $T_{average}(t)$ = average travel time (minute)
l_k = link length (m)
$v_{SA}(t)$ = average link speed on subarea (km/h)

6. FIELD TEST

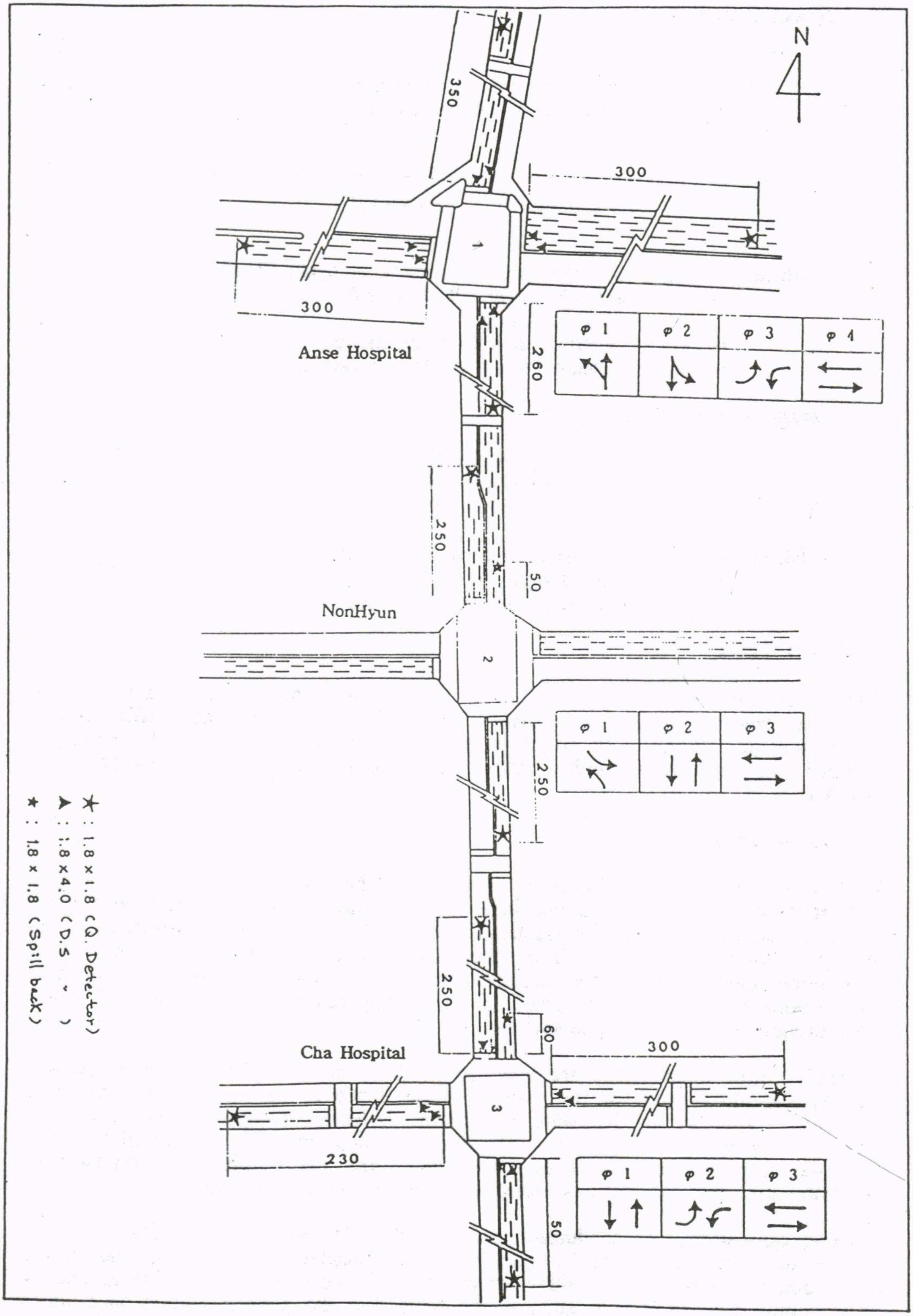
During the research work on TRACS, RTSI(Road Traffic Safety Institute) has conducted several floating car suvery in 1993 to validate the traffic control performance of TRACS. In all cases, the first version of the TRACS method of control was compared with control by fixed time plans, derived from TRANSYT-7F.

6.1 Test Environment

To test the operational performance of TRACS, the test site having the following conditions was selected: good geometric design, little side-friction, and wide range of traffic demand. Three intersections of Non-Hyun street were selected for the test site, shown in Figure 3. The street has six lanes and adequate left-turn bays. The three intersections were grouped into two subareas; Subarea 1 contains Intersections 1 and 2, and Subarea 2 contains Intersection 3. Intersections 1 and 3 were designated as critical intersections.

Currently, three intersections are operated in three or four phases without overlap. Usually the introduction of the overlap phase improves the quality of intersection operation. Due to the hareware limitations, however, comparions are performed using the current phase scheme. 26 inductive loop detectors are installed in the test site: fourteen stop-line detectors(DS detectors), ten mid-block detectors(queue detectors), and two far-upstream detectors(spillback prevention detectors).

Floating car survey was conducted seven times in December 1993. Traffic pattern of the test site shows similar patterns from Tuesday to Thursday, and severe congestion was observed in Friday afternoon. Because it is impossible to operate TOD control and TRACS together at the same day, the periods of two days which shows similar traffic patterns were selected for comparison: one day for TOD control and the other for the TRACS control.



<Figure 3> Geometrics of Test Site and Detector Locations

6.2 Results

Travel speed is a measure of effectiveness(MOE) that one can recognize traffic condition with ease. The travel speed was obtained by dividing the distance of the test street along the south-south direction by the actual travel time measured by the floating car survey. Intersection delay was selected as the secondary MOE for the comparison study. Delay was measured using the point sample method suggested in Highway Capacity Manual(TRB, 1985).

Table 1 summarizes the comparison of travel speed between TRACS and the TOD control. For the most cases, the travel speed resulted by the TRACS control is higher than that by the TOD control. The improvement ranges from 6.7percents to 54.7percents. The increase of 54.7percents during PM-peak inbound seems meaningless, however, because travel speeds are too low on the two type of control. TRACS showed poor performance for outbound traffic during PM-peak. Traffic demand of this period was very heavy, and TRACS operated in oversaturation contol mode. This result implies that TRACS shows good performance in normal traffic condition and not very good in congested condition. It seems to be necessary to perform continuing work for oversaturation control.

Table 1. Comparision of Travel Speeds between TRACS and TOD Control

(unit: km/hour)

Period of the day		outbound			inbound			Note
		TOD	TRACS	Improvements(%)	TOD	TRACS	Improvements(%)	
AM Peak	7-8	26.7	33.9	27.0	22.3	29.5	32.3	TOD:Wed TRACS: Fri.
	8-9	32.8	29.7	-9.0	31.4	33.0	5.1	
	avg.	29.8	31.8	6.7	26.9	31.3	16.4	
Business Hour	1-2	24.2	24.2	0.0	9.7	15.5	59.8	TOD:Fri. TRACS: Fri.
	2-3	21.6	25.1	16.2	15.1	17.4	15.2	
	avg.	22.9	24.7	7.9	12.4	16.5	33.1	
PM Peak	4-5	17.7	16.5	-6.8	6.7	10.2	52.2	TOD:Fri. TRACS: Fri.
	5-6	-	-	-	3.9	6.1	56.4	
	avg.	17.7	16.5	-6.8	5.3	8.2	54.7	

Table 2 shows the average intersection delay resulted by the TRACS control and the TOD control under normal traffic condition. TRACS consistently outperformed TOD contol and the improvements ranges from 36 to 41percents. This promising results is consistent with the results of the travel-speed comparison. Observation of delay under extremely heavy traffic condition was almost impossible because queue lengths extended upto far upstream of link. Delay study for oversaturated condition was skipped in this comparison study.

Table 2. Comparison of Average Delay between TRACS and TOD Mode

(unit: sec/veh)

Period of the day	approach	Intersection 2			Intersection 3		
		TOD	TRACS	improvement(%)	TOD	TRACS	improvement(%)
noon-2:00pm	EB	44.2	24.2	45	47.8	23.1	60
	WB	42.9	24.9	42	42.1	25.5	39
	SB	25.1	18.4	27	49.9	34.7	29
	NB	33.6	18.3	45	40.9	27.7	32
	average	36.4	21.4	41	45.0	28.8	36
4:30-6:00pm	EB	44.0	27.5	38	65.2	27.1	59
	WB	42.0	26.8	36	44.5	25.1	44
	SB	25.3	20.3	20	51.5	43.1	16
	NB	33.7	18.6	45	44.3	27.7	38
	average	36.3	23.3	36	51.5	26.7	48

7. CONCLUSIONS

The control principles and field-test results of TRACS, advanced traffic signal control system developed in Korea, were introduced in this paper. TRACS has the capability of real-time traffic data collection, real-time traffic-responsive signal control, and area-wide traffic surveillance and monitoring. The performance of the first version of TRACS was compared to the conventional TOD contol through field test. The test result was promising in that TRACS consistently outperformed the conventional control method. The change of signal timing reacted timely to the variation of traffic demand.

The feature of real-time travel-time estimation is under study. Extensive opertional test of TRACS will be conducted this year, and some functions will be enhanced.

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