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A Study on the Relationship between the Traffic Signal System and the Air Pollutants emitted by the Motor Vehicles at Intersection

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Abstract

The purpose of this study is to analyze traffic patterns by use of TRANSYT-7F Model, and to choose the optimum traffic-light cycle length and cycle splits to improve traffic flow and air quality at Samsung Intersection in Seoul.

Emission rates of air pollutants are calculated for three time segments 0700-0900, 0900-1800 and 1800-2000. The traffic volume correlated reasonably well with air pollutants emitted ; however, the phasing and timing of traffic signals was found to equally be important. The results of performance with optimal setting indicate that the best cycle length were 80sec(0700-0900), 95sec(0900-1800) and 90sec(1800-2000), res-pectively.

As expected the highest emissions of air pollutants were observed during the evening rush hours (1800-2000). A properly designed signalized intersection can help reduce traffic delay, driver discomfort, fuel consumption, and air pollution by efficiently the capacity of existing intersection.

1. INTRODUCTION

Rapid increase of number of automobiles is partly responsible for the deterioration of air quality in densely populated major urban areas in Korea.

In 1982, the number of motor vehicles in the whole country were about 650,000 ; at the end of September 1992, a rolling fleet of 5,230,000 was registered in the country, with 30% of them in Seoul(Ministry of Traffic, 1993). It is concluded that air pollution problem in major urban areas is mainly caused by automobiles which keeps CO, NOx and HC concentrations higher than the air quality standard especially near main streets and intersections.

In addition, emission heights of mobile sources are generally comparable to the breathing height of pedestrians. This fact requires special attention in the assessment of adverse health effects of vehicle emissions (Perkins, 1974).

Moreover, traffic congestion has become a major environmental problem in most of metropolitan area. A properly designed signalized intersection can help reduce traffic delay, driver discomfort, fuel consumption, and air pollution by utilizing the capacity of existing streets efficiently.

The purpose of this paper is to analyze traffic patterns by use of TRANSYT-7F Model, and to choose the optimum traffic-light cycle length and cycle splits to improve traffic flow and air quality at Samsung Intersection in Seoul.

2. MATERIAL AND METHODS

2. 1. INVESTIGATION SITE

Investigation site is shown in Figure 1.

A video camera is trained at 33th floor of an Intercontinental Hotel Building with a freeze-frame of each vehicle stored on video tape. The tapes were reviewed, and the time period recorded for each vehicle measured.

The vehicles traveled during the morning(0700-0900) and the evening peak(1800-2000) and off-peak periods for a total of approximately thirteen hours in a 2-day period from July 7, 1993 through July 8, 1993. The data collected during each period included the phasing and timing of traffic signals and traffic flow.

Data sheets describing intersection location, various kinds of vehicles, degree of congestion, and length of link were also completed.

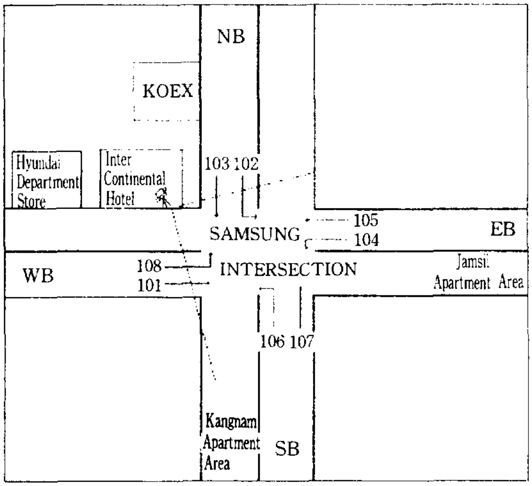

Fig. 1. Traffic Flows for links, at Samsung Intersection.

2. 2. MODEL DESCRIPTION

Details of TRANSYT-7F are on the preceding paper(Min Sun Hong, 1993).

One of the most important measures of effectiveness(MOE) in traffic studies is the delay to vehicles in the system. Delay represents indirect costs to the motorist in terms of time lost and a direct cost in terms of fuel consumption during idling. Excessive delay at signalized intersections reflects the inefficiency of the signal timing. In a field study, delay is usually measured by periodically counting the number of vehicles queued at a signal and integrating this series of counts over time.

The fuel consumption model developed for TRANSYT-7F meets the following criteria :

1) The model predicts fuel consumption based on the MOE's produced by the TRANSYT simulation model.
2) The model accounts for the fact that TRANSYT's optimization can alter the numerical relationship between delay and stops.
3) The model is simple and easy to calibrate.

The MOE's used in the TRANSYT-7F fuel model are the followings :

- Total travel in vehicle-miles(vehicle-kilometers) per hour
- Total delay in vehicle-hours per hour
- Total stops in vehicles per hour
- Free speed on each link

These variables are also used by Claffey(1971) and Robertson(1980) in their fuel consumption models.

The parameters of the TRANSYT-7F fuel model were estimated from experimental studies in which a test vehicle was driven through numerous driving cycles using both typical urban condition and test cycles to vary the stops, delay and cruise speed. During the study, fuel consumption and an analog scan of the periodic time-space trajectory were recorded.

The resultant data were analyzed by stepwise multiple regression, using eq.(1).

$$F = k_1TT + k_2D + k_3S \qquad (1)$$

where F stands for fuel consumed in gallons (liters) per hour
TT, total travel in vehicle-miles (veh-km) per hour
D, total delay in vehicle-hours per hour
S, total stops in stops per hour and

k_i stands for coefficients of regression, which are function of free speed

The total travel in vehicle-miles(or veh-km) has already been mentioned. This value will be constant for any given network and demand distribution. This is simply the aggregate of the product of link volumes and link lengths :

$$TT_i = q_i \times L_i \tag{2}$$

where TT_i stands for total travel on link i in veh-mi (veh-km) per hour
q_i, traffic volume on link i, vph and
L_i stands for length of link i in miles (km)

This MOE will not change in any given optimization, since the basic values(flow rates and link lengths) do not change.

Similar to the total travel, this system MOE is the product of link volumes and total time spent on the links, including delay or :

$$TTT_i = q_i\left(\frac{L_i}{U_i}\right) + D_i \tag{3}$$

where TTTi stands for total travel time in veh-hr per hour on link i
qi, traffic volume on link i, vph
Li, length of Link i in miles (km)
Ui, average free speed on link i in mph (km/hr) and
Di stands for total delay on link i veh-hr per hour

This measure should obviously decrease as the network singal timing is improved to reduce delay.

TRANSYT-7F explicity optimizes phase lengths and offsets for a given cycle length. To determine the best cycle length, an evaluation of a specified range of cycle lengths may also be made. To examine alternative phase sequences, multiple computer runs are required.

When optimizing, TRANSYT-7F minimizes an objective function called the Performance Index (PI).

3. RESULTS AND DISCUSSION

3.1 DATA ANALYSIS

The results of the measurement are presented in Table 1.

Information on the time periods changes of traffic volume at intersection can be obtained by analyzing the data gathered between 0700 and 2000.

Table 1. summarizes the traffic volume as calculated for three time segments 0700-0900, 0900-1800 and 1800-2000(Menachem Luria, 1990).

Fig. 2 shows the ratio for various kinds of vehicles at Samsung Intersection.

Table 1. Diurnal variation of Traffic Flow. (unit : vph)

TIME PERIODS	NB		SB		EB		WB		TOTAL
	LEFT	THRU	LEFT	THRU	LEFT	THRU	LEFT	THRU	
1400-1800	996	2420	613	2642	84	2068	407	1958	11188
1800-2000	988	2563	507	2768	75	1898	236	2303	11388
0700-0900	649	2030	560	2869	59	2286	220	937	9610
0900-1400	987	2250	700	2687	93	2235	348	1536	10836

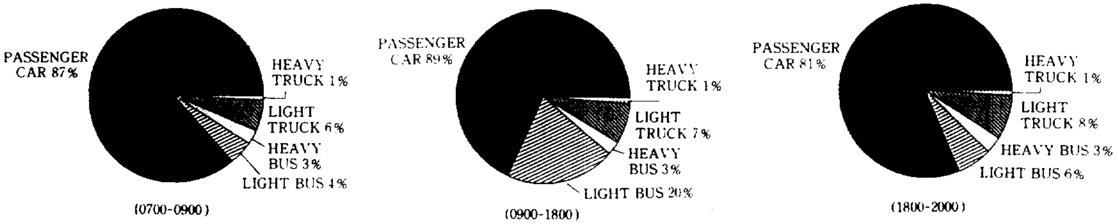

Fig. 2. Ratio for Various Kinds of Vehicles at Samsung Intersection.

At Samsung Intersection, the higher ratio of passenger car is observed during the rush hours (0700-0900, 1800-2000), probably due to the increasing number of owner-drivers.

3.2. VARIATION OF AIR POLLUTANT EMISSIONS

The relationship between the traffic signal system and air pollution emissions were evaluated using the TRANSYT-7F Model. Air pollutants emission rate can be calculated by the results of modeling and Korean type emission factors(Kang-Rae Cho et al, 1990).

The general applicability of this work is to obtain a reasonably accurate prediction of pollutant emissions as shown in Table 2~7 and Fig. 3~10.

Table 2. Performance with Optimal Setting(0700-0900).

LINK NO.	FLOW (veh/h)	SAT FLOW (veh/h)	TOTAL TRAVEL (veh-km/h)	DELAY(veh-h/h)			FUEL CONSUMPTION (ℓ/h)
				UNIFORM	RANDOM	TOTAL	
101	235	2200	73.09	1.44	0.07	1.51	14.91
102	217	2200	116.10	0	0	0	13.80
103	406	2200	217.21	1.98	0.12	2.10	33.94
104	59	500	16.23	0.52	0.77	1.29	6.04
105	572	2200	157.30	4.20	3.00	7.20	43.72
106	187	2200	74.24	0	0	0	9.76
107	718	2200	285.05	4.25	1.23	5.48	55.41
108	220	2200	68.42	1.89	0.65	2.54	17.17
TOTAL			1007.62	14.28	5.84	20.13	194.76

Table 3. Performance with Optimal Setting(0900-1800).

LINKNO	FLOW (veh/h)	SAT FLOW (veh/h)	TOTAL TRAVEL (veh-km/h)	DELAY(veh-h/h)			FUEL CONSUMPTION (ℓ/h)
				UNIFORM	RANDOM	TOTAL	
101	437	2200	135.91	4.02	1.04	5.06	34.17
102	331	2200	177.09	3.45	2.69	6.14	40.63
103	467	2200	249.85	3.63	0.52	4.19	44.58
104	89	500	24.48	1.03	1.36	2.39	10.35
105	538	2200	147.95	5.76	4.50	10.26	50.87
106	219	2200	86.94	2.10	0.33	2.42	19.03
107	667	2200	264.80	6.10	5.61	11.71	70.12
108	378	2200	117.56	4.04	2.90	6.95	36.73
TOTAL			1204.56	30.18	18.96	49.14	306.48

Table 4. Performance with Optimal Setting(1800-2000).

LINK NO.	FLOW (veh/h)	SAT FLOW (veh/h)	TOTAL TRAVEL (veh-km/h)	DELAY(veh-h/h)			FUEL CONSUMPTION (ℓ/h)
				UNIFORM	RANDOM	TOTAL	
101	576	2200	179.14	4.76	1.56	6.32	44.08
102	330	2200	176.55	3.22	2.95	6.17	40.64
103	513	2200	274.46	3.14	0.30	3.44	45.43
104	75	500	20.63	0	0	0	2.97
105	475	2200	130.63	3.69	0.52	4.21	31.36
106	169	2200	67.09	1.50	0.15	1.64	14.02
107	692	2200	274.72	4.72	1.37	6.08	55.62
108	236	2200	73.40	0	0	0	10.28
TOTAL			1196.60	21.02	6.85	27.87	244.40

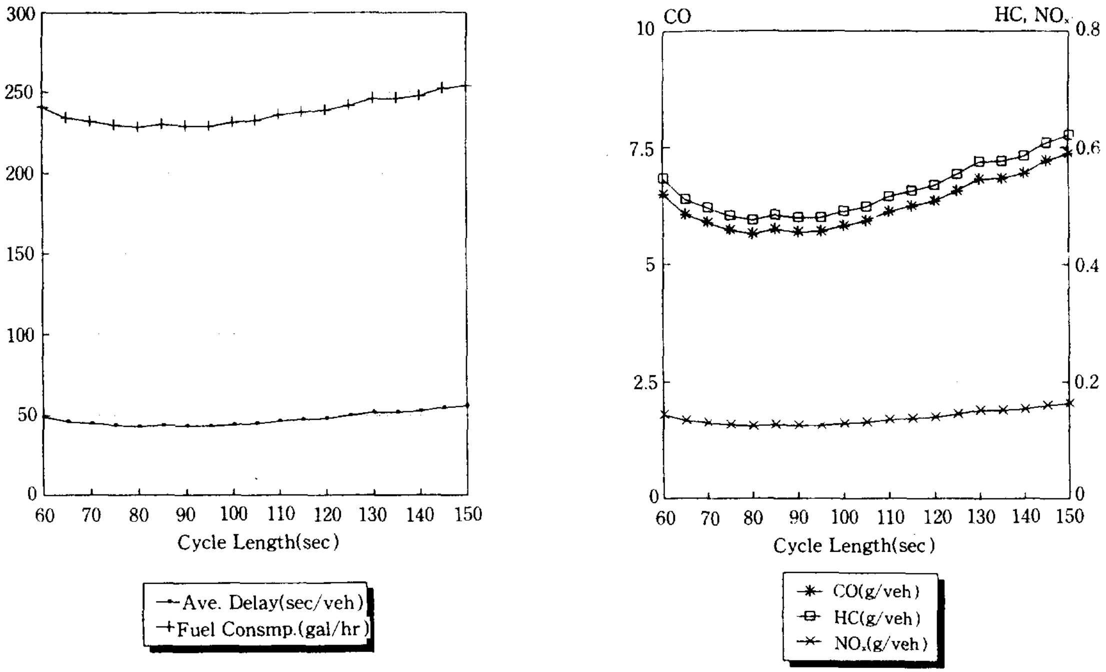

Fig. 3. Exhaust Emissions, Delay and Fuel Consumption for Different Cycle Lengths (0700-0900).

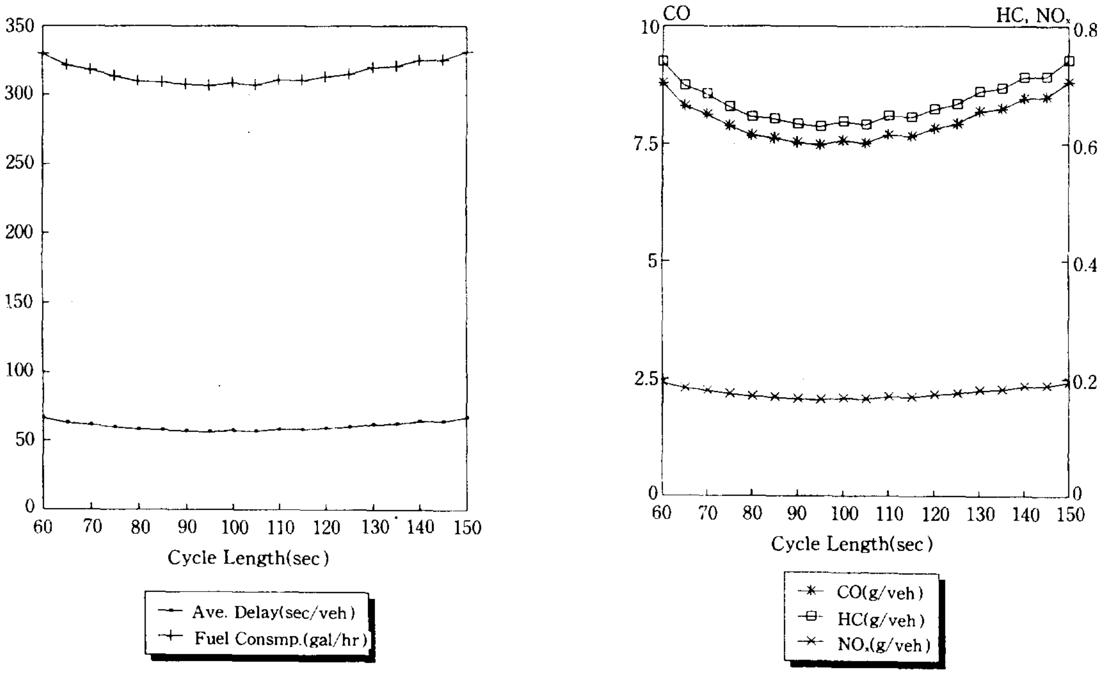

Fig. 4. Exhaust Emissions, Delay and Fuel Consumption for Different Cycle Lengths (0900-1800)

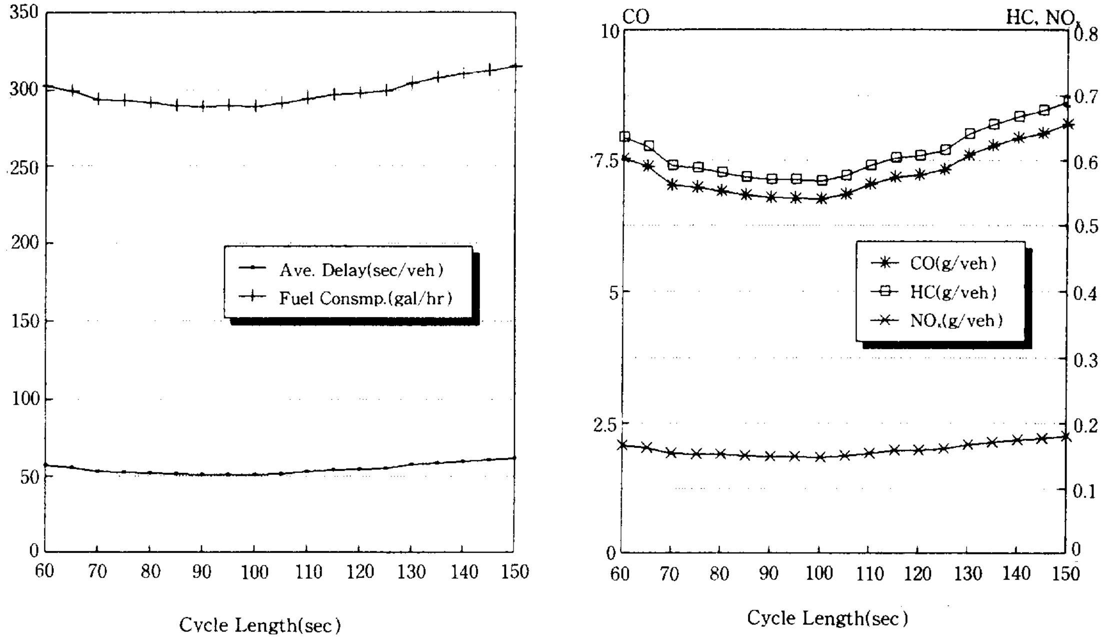

Fig. 5. Exhaust Emissions, Delay and Fuel Consumption for Different Cycle Lengths (1800-2000).

Table 5. Exhaust Emissions and Fuel Economy in Optimal Setting(0700-0900).

LINK NO.	CO (g/hr)	HC (g/hr)	NO (g/hr)	PART. (mg/hr)	SO (g/hr)	FE (km/ℓ)
101	869.04	97.21	58.47	730.9	6.71	4.90
102	1380.43	154.41	92.88	1161.0	6.21	8.41
103	2582.63	288.89	173.77	2172.1	15.27	6.40
104	192.97	21.59	12.98	162.3	2.72	2.69
105	1870.30	209.21	125.84	1573.0	19.67	3.60
106	882.71	98.74	59.39	742.4	4.39	7.61
107	3389.24	379.12	228.04	2850.5	24.93	5.14
108	813.51	91.00	54.74	684.2	7.73	3.98
TOTAL	11,981.83	1,340.17	806.11	10,076.4	87.63	5.34

Table 6. Exhaust Emissions and Fuel Economy in Optimal Setting(0900-1800).

LINK NO.	CO (g /hr)	HC (g /hr)	NO (g /hr)	PART. (mg/hr)	SO (g /hr)	FE (km/ℓ)
101	1615.97	180.76	108.73	1359.1	15.38	3.98
102	2105.60	235.53	141.67	1770.9	18.28	4.36
103	2970.72	332.30	199.88	2498.5	20.06	5.60
104	291.07	32.56	19.58	244.8	4.66	2.37
105	1759.13	196.77	118.36	1479.5	22.89	2.91
106	1033.72	115.63	69.55	869.4	8.56	4.57
107	3148.47	352.18	211.84	2648.0	31.55	3.78
108	1397.79	156.35	94.05	1175.6	16.53	3.20
TOTAL	14,322.47	1,602.08	963.66	12,045.8	139.91	3.85

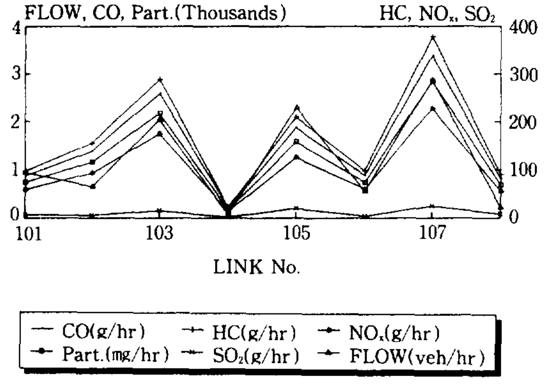

Fig. 6. Variation of Exhaust Emissions, Each Link(0700-0900).

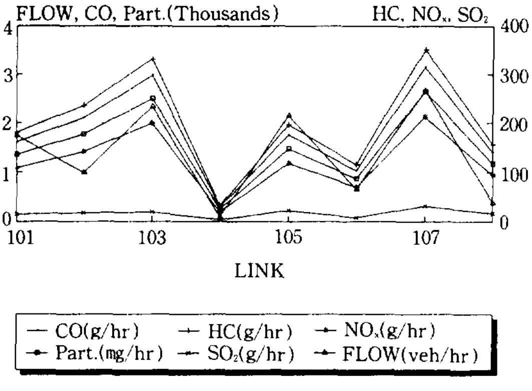

Fig. 7. Variation of Exhaust Emissions, Each Link (0900-1800).

Table 7. Exhaust Emissions and Fuel Economy in Optimal Setting(1800-2000).

LINK NO.	CO (g/hr)	HC (g/hr)	NO (g /hr)	PART. (mg/hr)	SO (g/hr)	FE (km/ℓ)
101	2129.97	238.26	143.31	1791.4	19.84	4.06
102	2099.18	234.81	141.24	1765.5	18.29	4.34
103	3263.33	365.03	219.57	2744.6	20.44	6.04
104	245.29	27.44	16.50	206.3	1.34	6.95
105	1553.19	173.74	104.50	1306.3	14.11	4.17
106	797.70	89.23	53.67	670.9	6.31	4.79
107	3266.42	365.38	219.78	2747.2	25.03	4.94
108	872.73	97.62	58.72	734.0	4.63	7.14
TOTAL	14,227.81	1,591.51	957.29	11,966.2	111.99	5.30

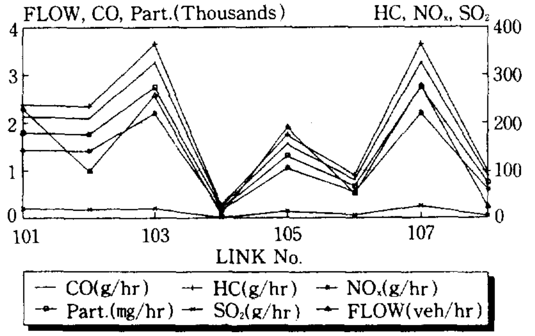

Fig. 8. Variation of Exhaust Emissions, Each Link (1800-2000).

Fig. 3, 4 and 5 show the average delay, fuel consumption and the variation of air pollutants emitted by each vehicle during the different cycle length.

The phasing and timing of traffic signals are the two important factors affecting delay and level of service(LOS)(Linkenheld et al, 1992).

One of the most important measures of effectiveness(MOE) in traffic studies is the delay to vehicles in the system. Delay represents indirect costs to the motorist in terms of time lost and a direct cost in terms of fuel consumption during idling(Webster, 1956).

Findler and Stapp(1992) improved the waiting time averaged over all intersections before optimization process, 29.4sec, has been reduced to 18.82sec, an improvement of 36 percent.

According to our study, as shown in Fig. 3, 4 and 5, the results of performance with optimal setting indicate that the best cycle length were 80 sec(0700-0900), 95 sec(0900-1800) and 90 sec (1800-2000), respectively.

The results of TRANSYT-7F modeling were correlated among delay, fuel consumption and total travel time(see Table 2, 3 and 4).

Emission rates of air pollutants show a considerable decrease as average delay and fuel consumption are decreased.

As expected, highest emissions of air pollutants were observed during the evening rush hours(1800-2000). While those are decreased during the morning rush hours(0700-0900) and are increased again during the period between 0900 and 1800.

As shown in Table 7, as the total delay of link is increased from 3.44 to 6.08 Veh-h/h, the fuel consumption is increased by 22 percent(Performance with optimal setting ; 1800-2000). Increasing the total delay of link from 3.44 to 6.08 Veh-h/h reduced the fuel economy by 18 percent(Performance with optimal setting ; 1800-2000).

Fuel Economy represents a direct cost in terms of fuel consumption during idling. The calculated values of FE were very low in comparison with reasonable FE(aproximately 16 km/l).

The average composition of exhaust gas emitted during the different variable speeds is found by simulation test driving under city and/or suburban conditions, including a typical stop-and-go operation.

For example, the Korean test cycle consists of 40.45% idling, 21.98% acceleration, 19.44% steady speed and 16.87% deceleration at 15~18 KPH (Kang-Rae Cho et al, 1990).

The type of vehicle, its condition, speed and acceleration are then used to predict the total pollutants emitted into the atmosphere.

Fig. 9 shows the relationship between the traffic flow speed and the air pollutants emitted. Here, air pollutants emitted are calculated from general equation according to emission factor of vehicles, in Korea.

As the traffic speed increased, the pollutant emissions which are emitted from the variation of speed shows various patterns.

Fig. 10 shows the relationship between the number of vehicles at Samsung Intersection and the pollutants emitted. As the number of vehicles increases, air pollutants emitted from the vehicles also increases(Al-Samarrai, 1988).

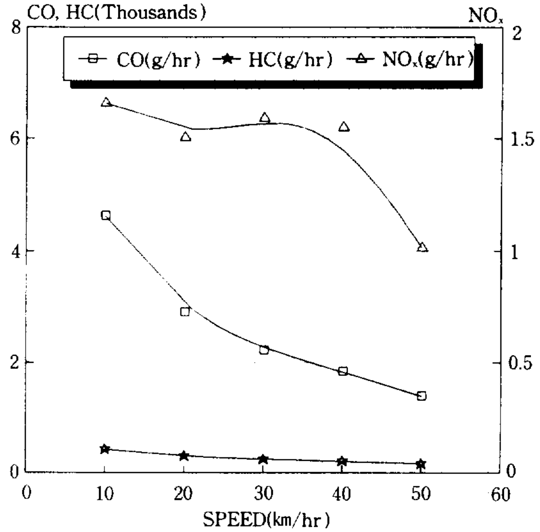

Fig. 9. Variation of Pollutant Emissions during the different Flow Speed.

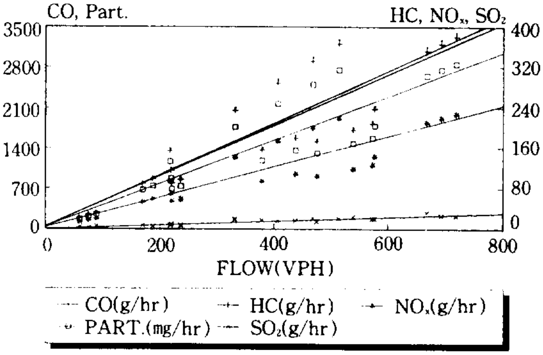

Fig. 10. Traffic Flow and Exhaust Emissions.

The widespread and complex problem of traffic congestion in metropolitan areas worldwide has produced concern regarding the impacts of harmful air pollutants on the health of cronically exposed drivers(Parviz A. Koushki et al, 1992).

This type of knowledge is essential to the development of effective policies for the improvement of air quality and traffic signal system at intersections.

4. CONCLUSION

Emission rates of air pollutants from automobiles at intersection is affected by many parameters such as traffic flow, delay, signal system, geometry, vehicle type, speed and acceleration.

A properly designed signalized intersection can help reduce traffic delay, driver discomfort, fuel consumption, and air pollution by efficiently using the capacity of existing intersection.

Traffic volume correlated reasonably well with pollutant emissions, however, the phasing and timing of traffic signal was found to equally be important.

The phasing and timing of traffic signals are the two important factors affecting delay and level of service(LOS) at Intersection.

Delay represents indirect costs to the motorist in terms of time loss and a direct cost in terms of fuel consumption during idling.

In conclusion, TRANSYT-7F Model is designed to be used for many different studies. The model, if subjected to further development, can be usefully employed to compare its results with those from practical studies to reach more realistic figures.

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