Evaluating the Effect of Semi-actuated Signal System in Korean National Roadways: Based on a Pilot Project

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Abstract: Korean government considers the semi-actuated signal system as a new countermeasure to reduce the traffic congestion in national roadways. This research evaluated the effects of semi-actuated signal system installed in pilot project. Based on the observed data, the stopped-time delay of 3.1 seconds at 3-legged intersection and 6.2 seconds at 4-legged intersection decreased averagely. Also, g/C of main road increased 0.17 and about 51% of the signal violation was reduced. The socioeconomic benefit of semi-actuated signal system was estimated by using the value of travel time, the reduction of stopped-time delay and daily traffic. The estimation showed that for 2,999 semi-actuated signal systems, the total discounted socioeconomic benefit is about 23,311 million won (2.1 million USD). With this benefit, about 230.3 km of national roadway can be constructed and operated for 30 years. The results in this research can be used for the estimation of the semi-actuated signal system advantages.

Keywords: Semi-actuated signal; Stopped-time delay; Economic analysis; Pilot project

1. INTRODUCTION

Traffic congestion causes a lot of social costs including emissions and time delay. Korean society also regards the traffic congestion as a social problem because the cost of traffic congestion was about 30.3 trillion won, which was approximately 9.3% of the total national budget in 2012. The traffic congestion could be decreased by constructing the new roadways or constructing the alternative public transit service. However, these approaches cost a lot of money. Thus, the effective way is needed to reduce the traffic congestion with relatively small budget. Korean Ministry of Land, Infrastructure and Transport considers the improvement of signal system is the effective way to reduce the congestion with relatively small budget.

In interrupted traffic flow, the signal control is the most important way to improve the road service level because it reduces unnecessary waiting time. There are several approaches to improve the signal system. i.e., optimizing the signal phase, signal coordination and actuated signal system. Among these countermeasures, the optimization and coordination have already been implemented. However, the fixed-time signal has been implemented and caused unnecessary waiting time. Thus, the actuated signal control system recently receives attentions as a solution of traffic congestion in Korean interrupted roadways.

The actuated signal system allocates the green times for each phase based on the variable demands. There are two types of actuated signal systems, i.e., the full actuated signal system and the semi-actuated signal system. The semi-actuated signal system is considered as a suitable system because the Korean national roadways which experience a large difference of traffic volume between arterial and collector. According to Roess *et al.* (2004), semi-actuated signal is used where a small side street intersect with a major arterial or collector while the full actuated signal system is used for all approaches.

Although the semi-actuated signal is considered as a new policy to decrease the travel time in national roadway, it is not clear to estimate the benefits from the semi-actuated signal system. There were several studies that estimated the effects of actuated signal system. Lee et al (2006) assessed the performance of actuated signal control at diamond interchanges and compared it with existing signal control method under oversaturated traffic conditions using a hardware-in-the loop simulation. Lee et al (2014) examined the effects of the operation of actuated four-phase control at diamond interchanges through a CORSIM simulation combined with hardware-in-the-loop simulation technology. Cycle length, average delay, and total stops were the measure of effect (MOE) and they were all shown to be improved. Zhang et al (2014) used VISSIM for the simulation and estimated the effect of actuated signal system in aspect of delay reduction compared to other signal control methods. Also, there were some case studies to evaluate the effect of actuated signal system after the installation. Kim et al (2007) evaluated the semi-actuated signal system project on 4 intersections. They examined the improvement on volume, stopped delay, queue length, phases and pedestrians waiting time. All the MOEs were improved by the signal system. Kim et al (2013) estimated the effect of the semi-actuated signal system project on 18 intersections. They suggested that volume, travel time, number of queueing vehicles were all improved. Our research has discrimination in terms that the benefit of semi-actuated signal system was estimated in financial aspects.

The objective of this research is to evaluate effect of the semi-actuated signal system based on the pilot project in Korean national roadways by Ministry of Land, Infrastructure and Transport. First, the unit of stopped-time delay reduction was developed as the average stopped-time delay reduction by the pilot project. Second, the economic analysis was conducted by using the concept of the socioeconomic benefits. The socioeconomic benefits of semi-actuated signal system and the benefits of road construction project were compared. Next section describes the semi-actuated signal system that installed in Korean national roadways. The unit reduction of stopped-time delay and the economic analysis are followed. Lastly, the finding and the direction of further research is described.

2. PILOT PROJECT OF SEMI-ACTUACTED SIGNAL SYSTEM

In semi-actuated signal system, detectors are placed only on the side street. The green is on the major street at all times unless a call on the side street is noted. The signal time is planned based on the traffic of a main road (Kim et al, 2008). Accordingly if there is no vehicle in a side road or no pedestrian in the crosswalk, the rest of total green time is provided to the phase of main road traffic. This semi-actuated control can be utilized in the rural small and medium-sized cities or urban outer roads where the volumes of each direction is unbalanced. The basic concept of the semi-actuated signal system is described in the Figure 1. The semi-actuated signal system was independently operated by its own control parameters, i.e., cycle, phase, minimum green, maximum green and extension gap.

Pilot project was planned and carried out for the decision of the installation expansion of the semi-actuated signal system. Two sites were chosen for the pilot project. At first, 4 intersections in National roadway 43 through Hwaseong city of Gyeonggi-do were chosen as representatives of roadways with relatively large volume. The annual average daily traffic (AADT) of this section was 31,512 veh/day in 2013. The other 4 intersections in National roadway 87 through Pocheon city of Gyeonggi-do were selected on behalf of roadways with relatively low volume. AADT of this section was 10,455 veh/day in 2013. Each pilot project section was approximately 2.1km long and the semi-actuated signal control system was operated from February to May in 2014.

To describe it specifically, the pilot intersections of Hwaseong were with lots of traffic demands during peak hours but very low demands during non-peak hours. The pilot intersections of Pocheon had relatively short peak hour and large deviation of traffic demands. Also, these intersections had unbalanced traffic volumes between main road and side road but had the same green time plan, which led to frequent signal violations. The parameters of fixed-time signal system in pilot project were variable, i.e., cycle and phase were different each other and time of day. The average cycle is 140.7 seconds, average green time of main road was 97.5 seconds and the average g/C of main road was 0.65.

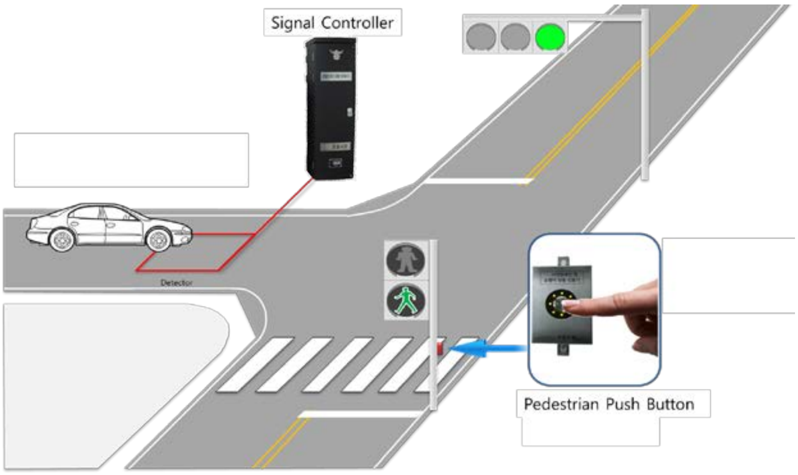

Figure 1 Basic concept of semi-actuated signal system

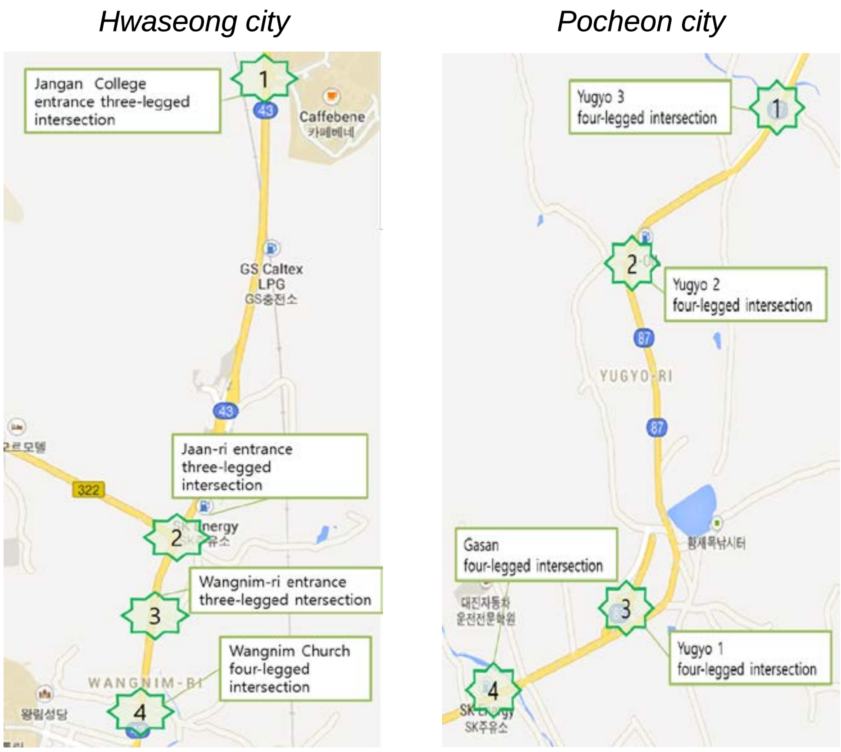

Figure 2 . Pilot project area

3. EFFECTS OF SEMI-ASTUACTED SIGNAL

3.1 Reduction of Stopped-time Delay

According to Roess et al. (2004), stopped-time delay is defined as the time a vehicle is stopped in queue while waiting to pass through the intersections. The average stopped-time delay is the average for all vehicles during a specific time period. The stopped-time delay reduction is employed as a measure of the benefit by semi-actuated signal. The evaluation of stopped-time delay reduction by semi-actuated signal system is conducted in pilot project area of Korean national roadways. According “Highway capacity manual 1994”, the stopped-time delay was calculated by Equation 1. The (Δt) is the short time interval between 10 and 20 seconds to observe the stopped vehicle length in a queue. The observed stopped vehicles at each short time period were added ($\sum Queue$). The $total\ volume$ is observed vehicles that pass the intersection. The stopped-time delay is calculated for each direction. For numerical example, assuming that 100 vehicles were passed at a intersection for 80 seconds. The stopped vehicles in a queue per 16 seconds were 0, 9, 21, 15, 6, 0. Then, the average stopped-time delay is $8.16 = 16 \times (9 + 21 + 15 + 6) \div 100$.

$$Average\ stopped - time\ delay = \frac{(\Delta t + \sum Queue)}{total\ volume} \quad (1)$$

The stopped-time delay was observed at eight intersections on Fridays January 2014. Four intersections are 3-legged and the others are 4-legged. For comparing the stopped-time delays, observations were implemented both when the fixed-time signal was used and the semi-actuated signal used.

The results of stopped-time delay reduction are shown in Table 1. The average stopped-time delay is the weighted mean of the delays at each intersection according to the number of passing vehicles. The average stopped-time delay of the peak and non-peak time delay were measured separately. The stopped-time delay of all day is the weighted mean of peak and non-peak time delay by using the time ratio of peak and non-peak time and the number of passing vehicles. In Korean national roadways, the peak time is 4 hours and the non-peak time is 16 hours (Korea Development Institute, 2008)

The stopped-time delay when the fixed-time signal was used is 8.3 seconds for peak time, 7.0 seconds for non-peak time and 7.2 seconds for a day in 3-legged intersections. The stopped-time delay when the semi-actuated signal was used is 3.6 seconds for peak time, 4.6 seconds for non-peak time and 4.1 seconds for a day in 3-legged intersections. The 3.1 seconds of stopped-time delay was reduced when semi-actuated signal was used for a day in a 3-legged intersection. The stopped-time delays in 4-legged intersection were decreased from 40.9 to 28.0 seconds at peak time, from 6.9 to 4.2 seconds for non-peak time and from 18.6 to 12.4 seconds for a day. For a day, the reduction of stopped-time delay due to the semi-actuated signal was 43.1% in 3-legged intersection and 33.3% in 4-legged intersection.

To examine the effect of stopped-time delay reduction by semi-actuated signal, the travel time reduction was also measured in Hwaseong area. This area consists of three 3-legged intersections and a 4-legged intersection. The calculated travel time reduction by the values in Table 3 is 15.5 seconds. The observed travel time reduction is 20.0second for about 2km traveled and it is similar to the 1.3 times of stopped-time delay. This result supports that the approach delay is the 1.3 times of stopped-time delay in “Highway capacity manual 1994”.

The parameters of signal system were changed by semi-actuated signal system from the fixed-time system. The results are shown in Table 2. The average cycle was changed from 140.7 to 142.7 seconds. The average green time of main road was changed from 97.5 to 116.3 seconds. The average g/C of main road was changed from 0.65 to 0.82. 18.8 seconds of green time and 0.17 of g/C for main road were increased by the semi-actuated signal system.

Table 1. Results of stopped-time delay reduction by semi-actuated signal

Type of intersection	Time of day	Stopped-time delay (seconds/vehicle)		
		Fixed-time signal	Semi-actuated signal	Reduction
3-legged	Peak	8.3	3.6	4.7
	Non-peak	7.0	4.6	2.4
	All day	7.2	4.1	3.1
4-legged	Peak	40.9	28.0	12.9
	Non-peak	6.9	4.2	2.7
	All day	18.6	12.4	6.2

Table 2. Change of signal parameters by Semi-actuated signal

Index	Cycle (seconds)	Green time (seconds)	g/C
Fixed-time signal system	140.7	97.5	0.65
Semi-actuated signal system	142.7	116.3	0.82
Changes due to Semi-actuated signal system	+2.0	+18.8	+0.17

3.2 Reduction of Signal Violation

The reduction of signal violation is another benefit of semi-actuated signal system. This research evaluates the reduction of signal violations for 24 hours in two intersections which are in Hwaseong and in Pocheon area.

The results of reduction of signal violations are shown in Table 3. The number of 657 violations was observed in two intersections for 24 hours when the fixed-time signal was used. It is decreased at 322 violations when the semi-actuated signal was used. About 51% reduction of signal violation is observed due to the semi-actuated signal. About 11.3% of crashes in Korean national roadways were due to the signal violation. Thus, the semi-actuated signal system has a potential to reduce the crashes in intersections.

Table 3. Results of signal violation reduction by semi-actuated signal

Area	Signal violations (per 24 hours)		
	Fixed-time signal	Semi-actuated signal	Reduction
Hwaseong	229	75	154
Pocheon	428	247	181
All	657	322	355

4. BENEFIT EVALUATION

The socioeconomic benefit of operating the semi-actuated signal system was evaluated in this study in the aspect of traffic flow improvement. The traffic flow improvement could be derived by the reduction of stopped delay, which led to the reduction of travel time. It was based on the unit value of average stopped delay of each vehicle and the value of travel time. The total socioeconomic benefit of the semi-actuated signal system was calculated by multiplying the unit value of average stopped delay and the value of travel time of vehicles. After that, it was converted into year unit. This procedure can be described as the equation as follow:

$$B = \sum_{j=1}^{J} \sum_{i=1}^{I} (\Delta t \times V_i \times 365 \times VOT \times \frac{1}{3,600}) \quad (2)$$

where,

B: the socioeconomic benefit of semi-actuated signal system,
Δt: unit value of reduction of stopped delay,
V_i: the average daily traffic volume of intersection i
VOT: the travel time value of each vehicle, and
J: operation years

As mentioned above, the unit value of each type of intersection is 3.11 second for 3-legged intersection and 6.19 second for 4-legged intersection. Among the various vehicle types' average value of travel time, the value of passenger car was chosen for this research. Passenger cars' average value of travel time is 14,990 won (13.63 USD) and it can be converted into 17,660 won (16.06 USD) in 2013 by considering price index (Korea Development Institute, 2008).

To maximize the effects of the semi-actuated signal system, intersections with the roads consisting of more than 3 lanes are excluded due to large amount of right or left turning volume. As a result, 2,999 intersections (1,876 three-legged intersections, 1,123 four-legged intersections) with mostly less than 2 lanes are targeted in the main project.

Based on the evaluation, the socioeconomic benefit of operating total 2,999 semi-actuated signal systems is about 34,421 million won (3.1 million USD). This value did not consider the construction period, persisting period and social discount rate. In this research, the social discount rate is 5.5% which is used in the study of Korea Development Institute (2008). The construction of the semi-actuated signal systems is assumed to begin at the same time in 2015. The construction takes 1 year and the socioeconomic benefit occurs after one year since the completion. The operation period is assumed as 10 years for each signal system. The evaluation result is that discounted socioeconomic benefit is about 23,311 million won (2.1 million USD).

To examine the estimated socioeconomic benefit is reasonable, it is compared with that of roadway constructions. The socioeconomic benefit of semi-actuated signal system and that of 4 lane national roadway construction were compared. To compare them, the socioeconomic benefit of constructing and operating the semi-actuated signal system 10 years was measured against that of constructing and operating 4 lane national roadway 30 years.

For this evaluation, 10 preliminary feasibility studies of recent national roadway construction project which Korea Development Institute were used for the standard value. Studies implemented from 2007 to 2012 were included. The average length of the projects was 18 km. To consider the feasibility of the projects, the projects with value of b/c over than 0.7 was chosen.

The average discounted socioeconomic benefit estimated in the studies was 91,165 million won (83 million USD). This value was converted into the benefit per 4 lanes per km, which average discounted socioeconomic benefit was 10,332 million won (9.4 million USD). Thus, we can find out that with the discounted benefit of semi-actuated signal system, about 230.3 km of national roadway can be constructed and operated for 30 years.

Table 4. Yearly socioeconomic benefit of semi-actuated signal system

Year	Non-Discounted (won)	Discounted (won)
2016	3442.1	2,931.3
2017	3442.1	2,778.5
2018	3442.1	2,633.7
2019	3442.1	2,496.4
2020	3442.1	2,366.2
2021	3442.1	2,242.9
2022	3442.1	2,125.9
2023	3442.1	2,015.1
2024	3442.1	1,910.1
2025	3442.1	1,810.5
Total	34,421.0	23,310.6

Table 5. Road construction projects list of comparison study

No.	National Roadway	Year	Total length (km)	lanes	Discounted benefit (million won)	B/C	Benefit (million won/4lane·km)
1	National roadway 2·77	12	10.60	4	105,187	1.26	9,923
2	National roadway 35	10	11.20	4	3,137	0.88	280
3	National roadway 35	10	80.00	4	36,818	0.83	460
4	National roadway 20	10	9.00	2	59,399	0.77	13,200
5	National roadway 19	09	23.60	4	60,566	0.80	2,566
6	National roadway 33	09	14.28	4	415,533	1.10	29,099
7	National roadway 77	09	4.24	2	41,976	0.81	19,800
8	National roadway 77	09	9.52	2	77,797	0.86	16,344
9	National roadway 5	07	7.10	4	54,830	0.94	7,723
10	National roadway 23	07	14.39	4	56,411	0.82	3,920
Average			18.39	3.40	91,165.46	0.91	10,332

5. CONCLUSIONS

This research evaluates the effects of semi-actuated signal system based on the pilot project in Korean national roadways. The semi-actuated signal systems were installed at eight intersections as a pilot project by Ministry of Land, Infrastructure and Transport. Based on the analysis, the stopped-time delay of 3.1 seconds at 3-legged intersection and 6.2 seconds at 4-legged intersection were decreased averagely for whole day traffic. The 0.17 of g/C of main road was increased by the semi-actuated signal system. About 51% reduction of the signal violation was also observed as a benefit of semi-actuated signal system. The socioeconomic benefits of semi-actuated signal system were estimated by using the value of travel time, the reduction of stopped-time delay and the AADT. 2,999 intersections (1,876 three-legged intersections, 1,123 four-legged intersections) with mostly less than 2 lanes were targeted in the evaluation. The results showed that discounted socioeconomic benefit is about 23,311 million won (2.1 million USD) considering the social discount rate. This amount of benefit was compared to the socioeconomic benefit of 4 way roadway constructions. The average discounted socioeconomic benefit of roadway construction was 10,332 million won (9.4 million USD). The comparing result was that with the discounted benefit of semi-actuated signal system, about 230.3 km of national roadway can be constructed and operated for 30 years. The result of this research can be a practical index of the effect of the semi-actuated signal system in terms that the results were based on the pilot project implemented in real field.

There are some suggestions for further research. First, the unit reduction of stopped-time delay at crosswalk only intersection will be developed. Second, the function of stopped time delay by changing the traffic volume will be conducted by using the micro simulation with the calibration that uses the result of the field test.

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