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현장적용을 위한 연동형 반감응 신호제어 개발 및 분석

Developing and Evaluation of Coordinated Semi-Actuated Signal Control for Field Application

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요약

본 연구에서는 지방부 간선 또는 지선 축에서 효과적으로 사용 가능한 연동형 반감응 신호제어 알고리즘을 개발하고 이를 평가하였다. 연동형 반감응 신호제어에 대한 모의실험 결과를 살펴보면, 주・부 도로의 교통량 차이가 커질수록 연동형 반감응 신호제어의 지체가 최적화된 고정식 신호제어에 비해 감소하는 것을 확인하였다. 그러나 주부도로의 교통량이 같거나 전체 교통량이 많아지면 최적화된 고정식 신호제어의 지체가 더 낮게 나타났으며, 횡단 보행량이 많아질수록 차량 지체가 증가하는 것으로 확인되었다. 따라서 연동형 반감응 신호제어는 차량 교통량이 일정수준 이하인 곳에 적용하되, 횡단 보행량을 고려하여 적용 지역을 선별해야 할 것이다.

■ 중심어 : | 연동 | 반감응 신호제어 | 보행자 감응 | 신호제어 알고리즘 | 교통시뮬레이션 |

Abstract

In this paper, Coordinated Semi-Actuated Signal Control algorithm was developed and evaluated. According to the analysis of simulation, the coordinated semi-actuated signal control led to reduced vehicle delay as the difference of traffic volume between major and minor streets was getting bigger. But when there was relatively high traffic volume, or the equivalent amount of traffic volume on major and minor streets, optimized pre-timed signal control was verified to lower delay times compared to coordinated semi-actuated signal control; however, it might increase pedestrian delay. Therefore, the coordinated semi-actuated signal control should be implemented at intersections where traffic volume is relatively low.

■ keyword : | Coordination | Semi-actuated Signal Control | Pedestrian Actuation | Traffic Signal Algorithm | Traffic Simulation |

Ⅰ. Introduction

1. Background

Traffic flow fluctuations frequently occur in a short period at a rural arterial or corridor. The pre-timed signal control (this signal control is openly called as TOD that means Time Of Day schedule) systems, and the adaptive signal control system, were not

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suitable at this area. These systems are insufficient to immediately adapt according to the traffic demand due to allocated green intervals always should be applied at a traffic controller. In these systems, problems lead drivers to violate the traffic signals or to increase intersection delay because green intervals are displayed every cycle, even if there is no traffic demand at all.

In this study, a coordinated semi-actuated signal control algorithm was developed to quickly adapt to traffic demand and to operate coordination at a rural arterial or a local corridor. The algorithm can be efficiently used in a minor road which are less in both traffic volumes and pedestrians than in the major one. Alternatives to maximize g/C ratio of a coordinated corridor, leading to have a decrease in delay on the main roads, are to set the minimum green interval of the minor one to the pedestrian interval or to skip the phase of the minor one.

2. Research Objective

The aim of this study is to develop a coordinated semi-actuated signal control algorithm which can maximize coordinated effects between Sub-Critical Intersections (SCIs) and Minor Intersections (MIs), and evaluate its performance. This is the basic framework which allows maximization of effects of a coordinated corridor through this algorithm, even if this corridor does not include Critical Intersections (CIs). The coordinated semi-actuated signal control algorithm was implemented to minimize traffic delays with a pedestrian actuation function. The main frame of this study is as following[Fig.1].

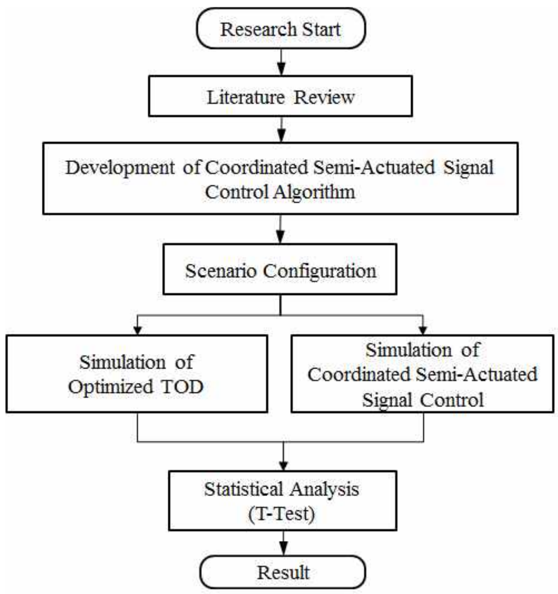


Fig. 1. Research Flow Chart

Ⅱ. Literature Review

1. Actuated signal control

Actuated signal control method can be classified into a fully-actuated signal control and semi-actuated signal control. In a fully-actuated signal control, it is possible to extend, decrease or skip a green interval based on vehicle detectors installed at every approach to an intersection. Therefore, it is efficient to use at locations where there is fluctuation in traffic in a short time period. The semi-actuated signal control requires vehicle detectors to be located at minor approaches in order to be more efficient in the coordinated actuated operation[1]. It means that a green signal on the main road only appears, however, when a vehicle is detected at the detector on the minor road, a green signal is transferred to the minor road.

The actuated signal control can be operated by three basic parameters; minimum green time, maximum green time, and unit extension time[2]. To operate an additional function, volume density management, supplementary variables including variable initial, passage time, time before reduction, time to reduce, and minimum gap are required.

According to recent studies, the minimum and maximum green time which were arbitrarily used by engineers, leads an intersection to experience delay. A lot of research has been proposed to overcome this circumstance. Kim and Courage (2003) proposed to find the optimal solution to minimize the intersection control delay[3]. This solution was utilizing hybrid genetic algorithm and hill climbing search method, and evaluated by the CORSIM RTE. Zhang and Wang (2011) studied the optimal minimum and maximum green time. This research approached a stochastic model established to dynamically optimize the minimum and maximum green time using VISSIM. However, theses studies were focused on isolated intersections under fully actuated signal control[4].

2. Signal Coordination

Coordination is to provide the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system. The coordinated signals lead to decreased vehicle travel times, stops, delay, fuel consumption, etc. Also, it provides smooth and stabilized driving for a traffic flow on the arterial or local corridor. As the coordination system is used at continuous signalized intersections along a corridor, and the fundamental elements for the coordination system are signal factors such as cycle, yield point, force-off, and offset.

Shoup and Bullock (1999) proposed a dynamic offset of actuated signal control which is based on link travel time to increase the coordinated effectiveness of a corridor located in state route 26. According to the proposed method, the "early return to green" problem as a negative impact in coordinated actuated signal control was overcome[5]. However, it has a restriction in practical use due to the travel time of an individual vehicle needs to be known. Yin et al. (2007) suggested an offline offset refiner method for actuated signal control system. The main algorithms contained a maximization of expected bandwidth and a minimization of red-meeting probability using travel time of individual vehicles. It attempted to address the problem of uncertain starts/ends of green in determination of offsets. This method was verified to be superior compared to the existing methods; nevertheless it also has limitations in time period (day to day) to collect travel time data and use of travel time of individual vehicles[6].

Kang (2008) studied semi-actuated signal control using Max-band model for improving arterial coordination and evaluated its performance by micro simulation VISSIM[7]. And Kim (2011) estimated semi-actuated signal control of NEMA by processing of validation and calibration[8]. These studies were not development of semi-actuated signal control algorithm but appreciation of existing optimized model and algorithm. Ko (2011) evaluated pedestrian actuated semi-actuated signal control[9]. However, in this paper, the algorithm was also conventional NEMA's actuated method and it did not estimated about various traffic flow scenarios.

The recent trend in research of signal control systems has focused on network level for optimizing its performance index. Multiple studies of the coordinated semi-actuated signal control system substantiated that its effect was superior for synchronizing the progression. However, most of them were not be concerned about relation of signal pedestrians and its various scenarios. Therefore, to establish the efficiency of corridor or arterial highway including pedestrian crossing, newly developed coordinative semi-actuated signal control fitted on Korean highway should be developed and evaluated.

Ⅲ. Methodology

1. Development Environments

In this study new signal control algorithms were developed, and the evaluation process was performed to enhance corridor performance. For further development, an appropriate simulator should be adopted to implement and evaluate the algorithms. All of the algorithms of this research were implemented by VisVAP of VISSIM.

Also SYNCHRO 5.0 was used to optimize the signal timings of TOD signal control. SYNCHRO is also widely used such as TRANSYT-7F. However, SYNCHRO has an advantage in order to optimize the signal sequence unlike TRANSYT-7F. This is the reason why SYNCHRO was utilized to optimize the signal parameters.

2. Evaluation Procedure

The developed new signal control algorithms were evaluated on various scenarios according to the change of volume per saturation ratio for one hour time period by simulation. The evaluation criterion of the simulation was by average delay. The developed signal control algorithm was compared with TOD control optimized by SYNCHRO. The simulation to derive the delay was VISSIM, and the results of delay were verified through the statistical analysis.

The reason why the delay of optimized TOD was the performance index is that optimize TOD signal control was superior in terms of delay reduction compared to other traffic signal control systems as traffic responsive control, adaptive signal control and actuated signal control under traffic volume known in advance.

3. Development of Signal Control Algorithm

The coordinative semi-actuated signal controller should be equipped with a detection system to detect straight and left turn vehicles on a minor road and left turn vehicles on a major road. This system executes a gap out, an initial green and a green extension function for skipping or terminating phases by assessing whether there is a vehicle on a road or not.

The commonly used vehicle detector is an inductive loop detector which checks the magnetic variation of electric current and decides existence of a vehicle. The types of inductive loop detector are classified into a presence mode and a pulse mode, and presence mode detects an existence of a vehicle to skip a phase. The pulse mode detects a vehicle to use for calculation of the green extension, the initial green interval, and signal control such as gap out and gap reduction. This coordinated semi-actuated algorithm was composed to allow the phase skip with the presence mode loop detector installed at a stop line, and along with it. Also the pulse mode loop detector was composed to allow green extension and gap out located at approaches.

The following [Fig. 2] shows the detector system to be applied for the coordinated semi-actuated signal control algorithm. As shown, the detector system of main streets is only installed at the left turn lanes, and the detector system of minor streets is applied at every lane to detect traffic flow per direction. The detector located at the stop line is a long loop type detector with a length of 8 meters and composed in the presence mode, and the detector installed at approaches where a rear of the stop line is a pulse mode and its length is five meters. The installation location is 30 meters (left turn lane) or 50 meters (straight lane) from the stop line.

In this study, the coordinated Semi-actuated Signal Control algorithm was applied to maintain the dual ring system suggested by NEMA, and to establish its coordination phase with phase 2 and 6. Moreover, some of the actuated signal operation methods including green extension, phase skip, gap out, and pedestrian actuation signals were realized. The coordinated semi-actuated signal control algorithm realized at this study is described in [Fig. 3].

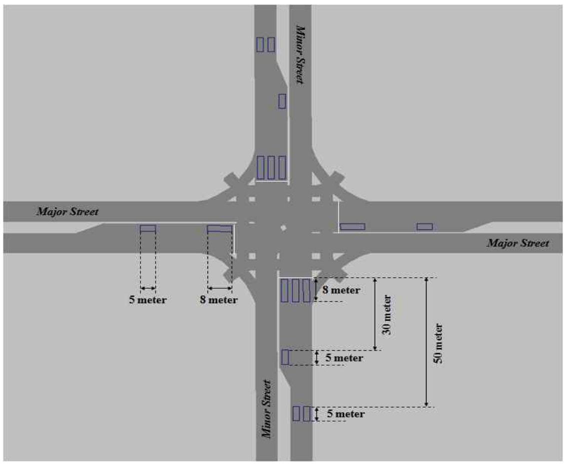


Fig. 2. Detection system of coordinated semi-actuated signal control

4. Control Parameters

To configure the semi-actuated signal control, signal control timings including the minimum green interval, the maximum green interval, and the unit extension interval are required.

4.1 Minimum green interval

The minimum green interval, provided during the green interval, is given to each phase. Basically, the minimum green interval depends on the number of vehicles that can be stored between a stop line and a detector. Upon the location of a detector and detection types, the green interval should be set. Despite such

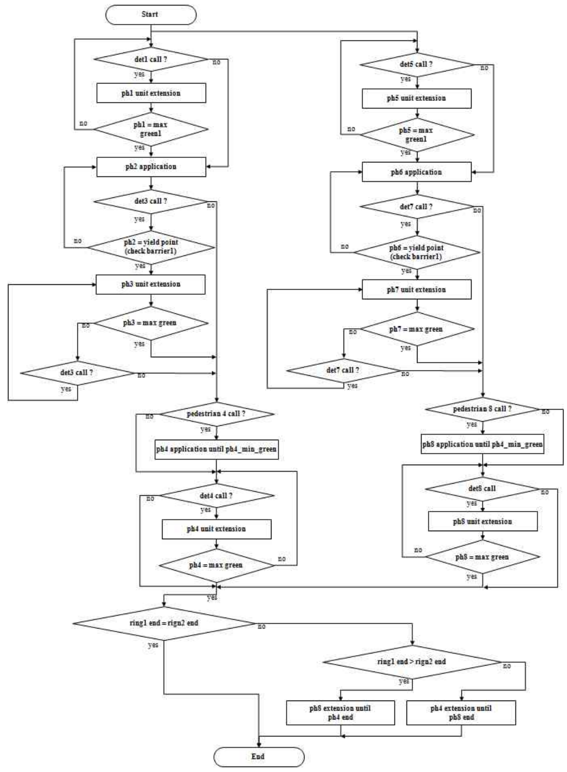


Fig. 3. Coordinated semi-actuated algorithm

conditions, at the coordinated semi-actuated signal controller suggested by this study, the minimum green interval on straight and left turn of a minor road, and left turn of a main road, were set as 0 second so phase skip could be possible when there was no traffic demand.

4.2 Maximum green interval

The maximum green interval is the period the current phase can be extended at the maximum when a vehicle is detected on the conflicted phase. The extension of a green interval is terminated (max out) at the maximum green time.

In this study, the straight phase of a main road was set as the cycle length of the maximum green interval. It is because the straight, and left turn on a minor road, and left turn on a main road, can be omitted and the extra time can be used at coordinated phase of the main road. The maximum green interval of a minor road for the left-turn phase and the straight phase were set as 27 seconds and 40 seconds respectively.

These values did not reflect the latest calculation method of minimum and maximum green time which was proposed by Kim and Courage[3] and Zhang and Wang[4]. The aim of this research did not develop an optimal signal timing of a coordinated semi-actuated signal control. Hence, maximum green duration was set to 30 from 60 seconds that is generally used in a coordinated semi-actuated signal control.

4.3 Unit extension interval

The unit extension interval is commonly defined as the time elapsed from a vehicle moving from detector to an intersection. When the gap time between continuous vehicles exceeds the unit extension interval, the green phase is terminated (gap out).

When the unit extension interval is set higher than necessary, the green phase indicates too long and causes increased delay on the conflict road. On the other hand, if it is set too short, the current phase becomes terminated even before a detected vehicle passing an intersection and its extensions significance is decreased. Therefore, the proper unit extension interval is very important for the actuated signal control.

The unit extension interval for this study was set as three seconds which was commonly used considering the installation location of a detector and speed of a vehicle. As before seen the [Fig. 2], the width of intersection contained five lanes. This means that a vehicle should cross 67 meters (detection is located far from 50 meters to stop line and intersection width is about 17 meters) from the extension detector. The vehicle speed set as 80 km/h (22.22 m/sec). Therefore, the vehicle located in the detection needs more than three seconds to pass the intersection.

Ⅳ. Analysis of Simulation

It would be ideal to evaluate effectiveness of the coordinated semi-actuated signal control with a before-and-after study comparing the existing system. Unfortunately there are a number of practical limitations to conducting a before-and-after study such as economical issues, time issues and traffic accidents. Therefore, a microscopic traffic simulation was adopted as an alternate way to compare and estimate its effectiveness. The most commonly used microscopic traffic simulations are CORSIM, PARAMICS, and VISSIM. VISSIM which could realize the coordinated semi-actuated signal control suggested by this study was applied to verify some additional functions such as a pedestrian actuation function. VISSIM can add a new algorithm using Application Programming Interface (API) and Vehicle Actuated Programming (VAP). While it is possible to assess a new algorithm with CORSIM and PARAMICS through API, but for a more realistic and objective assessment of pedestrians, VISSIM was employed.

1. Composition of Scenarios

Scenarios for estimating Measure of Effectiveness (MOE) of a coordinated semi-actuated signal control are classified into a TOD signal control and a coordinated semi-actuated algorithm. The detailed compositions of each scenario are summarized in [Table 1]. As shown in [Table 1], "*v*" means projected demand flow rate, and "*s*" is saturation flow rate. In this scenario, the saturation flow rate was set as 1,800 pc/h/lane.

Table 1. Scenarios of simulation

Signal Control	v/s of Each Approach		Intersection Pedestrian (ped/hr)							
	Major	Minor	12	20	40	60	80	100	120	160
Optimal TOD	0.4	0.4	S1	S2	S3	S4	S5	S6	S7	S8
		0.3	S9	S10	S11	S12	S13	S14	S15	S16
		0.2	S17	S18	S19	S20	S21	S22	S23	S24
		0.1	S25	S26	S27	S28	S29	S30	S31	S32
	0.3	0.3	S33	S34	S35	S36	S37	S38	S39	S40
		0.2	S41	S42	S43	S44	S45	S46	S47	S48
		0.1	S49	S50	S51	S52	S53	S54	S55	S56
Semi Act.	0.4	0.4	S57	S58	S59	S60	S61	S62	S63	S64
		0.3	S65	S66	S67	S68	S69	S70	S71	S72
		0.2	S73	S74	S75	S76	S77	S78	S79	S80
		0.1	S81	S82	S83	S84	S85	S86	S87	S88
	0.3	0.3	S89	S90	S91	S92	S93	S94	S95	S96
		0.2	S97	S98	S99	S100	S101	S102	S103	S104
		0.1	S105	S106	S107	S108	S109	S110	S111	S112

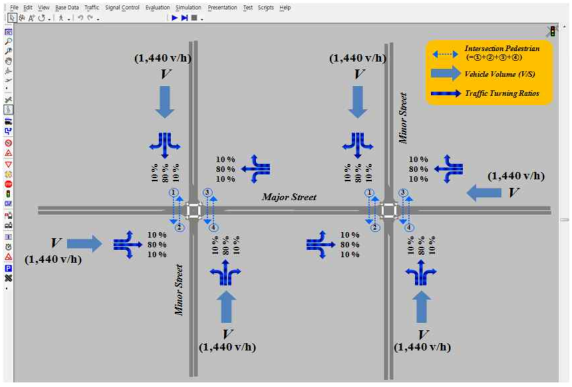


Fig. 4. Traffic condition of each scenario (v/s = 0.4 : 0.4, Major : Minor)

To analyze the coordinated semi-actuated signal control, 56 scenarios of TOD signal control were composed as well. It was prepared to be used as an objective comparison index, and signal control timings used in the TOD signal control were optimized with SYNCHRO version 5.0, a signal optimization program. The turning ratios of each scenario were set at 10%, 80%, and 10% in left, through, and right movements respectively; and a rate of heavy vehicles was set as 2%. The offset used at the coordinated semi-actuated signal control was the same as the TOD signal control. The detail traffic condition of scenarios is described in [Fig. 4].

For the quantitative comparison with an optimized TOD signal control, SYNCHRO 5.0, a signal optimization program was executed. The results are summarized in [Table 2].

2. Implementation of Developed Algorithm

The simulation for the analysis was composed with VISSIM version 5.2, a microscopic traffic flow analysis program, and a coordinated semi-actuated signal control algorithm was implemented with VisVAP of VISSIM as shown following [Fig. 5].

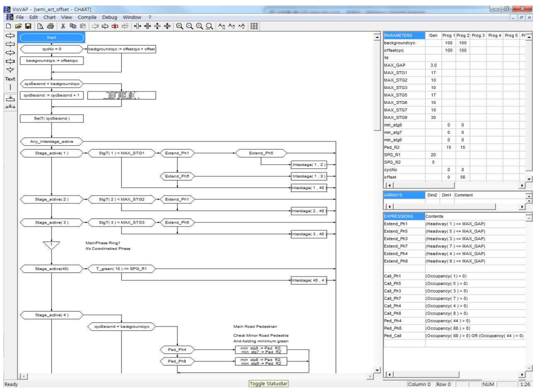


Fig. 5. Implementation of semi-actuated signal control algorithm

Table 2. Optimized traffic signal timings of TOD signal control

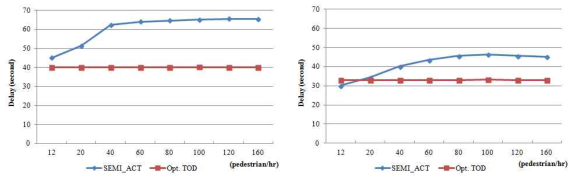
v/s of Each Approach		Intersection 1						v/s of Each Approach		Intersection 2					
Major	Minor	phase1	phase2	phase3	phase4	Cycle	offset	Major	Minor	phase1	phase2	phase3	phase4	Cycle	offset
0.4	0.4	20	45	20	45	130	0	0.4	0.4	20	45	20	45	130	65
	0.3	20	37	19	24	100	0		0.3	20	37	20	23	100	56
	0.2	20	38	17	25	100	0		0.2	20	38	20	22	100	41
	0.1	20	40	15	25	100	0		0.1	20	40	20	20	100	56
0.3	0.3	20	30	20	30	100	0	0.3	0.3	20	30	20	30	100	43
	0.2	20	29	20	21	90	0		0.2	20	29	20	21	90	45
	0.1	20	30	20	20	90	0		0.1	20	30	20	20	90	45

The statistical analysis was estimated with the paired t-test on the average delay, since the traffic volume and the geometric design of these two groups were the same besides the signal control system, so that it could not be seen as independent samples. The hypothesis of the statistical validation to inspect the average delay, is the MOE of the coordinated semi-actuated signal control and the optimized TOD signal control, is as follows equation (1).

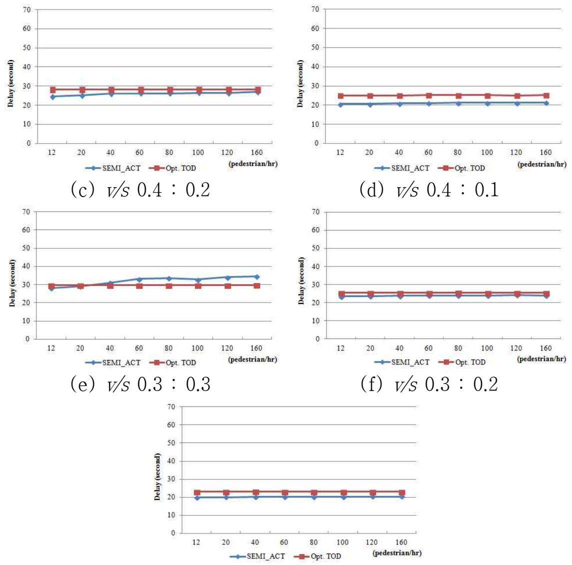
$$H_0 : \mu_{SA} = \mu_{TOD} \quad (1)$$
$$H_1 : \mu_{SA} \neq \mu_{TOD}$$

3.1 Vehicle Delay

When vehicle delay for each scenario composed by traffic volume conditions was reviewed, it was confirmed that the coordinated semi-actuated signal control reduced vehicle delay and the optimized TOD was the difference of traffic volumes between major and minor streets gradually growing. However, when there was relatively high volume of traffic or the equivalent amount of traffic volume of major and minor streets, the optimized TOD was identified as a lower delay than the coordinated semi-actuated signal control. Also, in the *v/s* case as 0.4:0.4, 0.4:0.3, and 0.3:0.3, the vehicle delay of the coordinated semi-actuated signal control prominently increased as crossing pedestrian volume grew. Even at the statistical analysis of a paired *t*-test, above mentioned elucidations were confirmed at a 95% confidence level. Each scenario case of *v/s* was explained in particular with the following [Fig. 6] and [Table 3].



(a) *v/s* 0.4 : 0.4　　(b) *v/s* 0.4 : 0.3



(c) *v/s* 0.4 : 0.2　　(d) *v/s* 0.4 : 0.1

(e) *v/s* 0.3 : 0.3　　(f) *v/s* 0.3 : 0.2

(g) *v/s* 0.3 : 0.1

Fig. 6. Vehicle average delay

Table 3. Simulation results of vehicles

v/s		Ped. per Hour	Coordinative Semi-Act.		Opt. TOD		Paired t-test	
Maj.	Min.		Delay (sec/veh)	STD	Delay (sec/veh)	STD	Sig.	H_0
0.4	0.4	12	45.0	6.2	40.0	0.6	0.001	rejected
		20	51.4	5.9	40.0	0.6	0.001	rejected
		40	62.3	4.9	40.0	0.6	0.001	rejected
		60	64.0	5.4	40.1	0.6	0.001	rejected
		80	64.6	4.7	40.0	0.6	0.001	rejected
		100	65.1	4.7	40.2	0.7	0.001	rejected
		120	65.5	4.2	40.1	0.7	0.001	rejected
		160	65.3	3.4	40.1	0.7	0.001	rejected
	0.3	12	30.2	2.5	33.0	0.7	0.001	rejected
		20	34.3	4.4	32.9	0.7	0.075	not rejected
		40	40.4	5.5	33.0	0.7	0.001	rejected
		60	43.5	5.3	33.0	0.7	0.001	rejected
		80	45.6	4.4	33.0	0.7	0.001	rejected
		100	46.5	6.5	33.2	0.6	0.001	rejected
		120	45.7	6.4	33.1	0.8	0.001	rejected
		160	45.3	6.3	33.0	0.7	0.001	rejected
	0.2	12	24.5	0.7	28.2	0.5	0.001	rejected
		20	25.1	0.9	28.2	0.5	0.001	rejected
		40	26.1	1.5	28.2	0.5	0.001	rejected
		60	26.1	1.6	28.2	0.5	0.001	rejected
		80	26.2	1.2	28.2	0.5	0.001	rejected
		100	26.5	1.9	28.2	0.5	0.001	rejected
		120	26.3	1.3	28.2	0.5	0.001	rejected
		160	26.9	1.5	28.2	0.5	0.001	rejected
	0.1	12	20.6	0.3	25.1	0.4	0.001	rejected
		20	20.7	0.4	25.1	0.4	0.001	rejected
		40	21.0	0.4	25.1	0.4	0.001	rejected
		60	21.2	0.6	25.2	0.4	0.001	rejected
		80	21.3	0.4	25.1	0.4	0.001	rejected
		100	21.4	0.4	25.2	0.4	0.001	rejected
		120	21.4	0.4	25.1	0.4	0.001	rejected

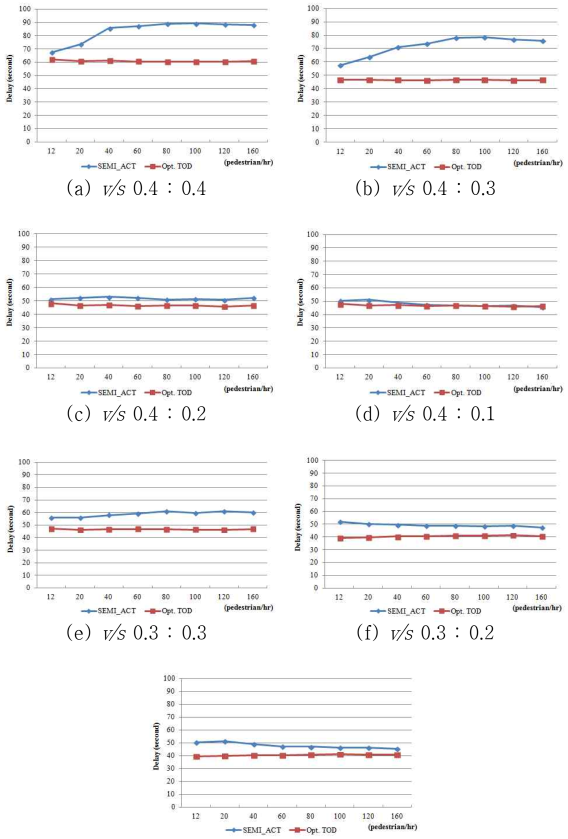
		160	21.4	0.4	25.2	0.5	0.001	rejected
0.3	0.3	12	28.3	2.4	29.7	0.5	0.004	rejected
		20	29.2	2.8	29.8	0.4	0.296	not rejected
		40	31.2	4.2	29.7	0.5	0.087	not rejected
		60	33.1	5.1	29.8	0.4	0.001	rejected
		80	33.7	4.4	29.8	0.5	0.001	rejected
		100	32.8	5.2	29.8	0.4	0.003	rejected
		120	34.2	4.8	29.8	0.5	0.001	rejected
		160	34.6	5.7	29.8	0.4	0.001	rejected
	0.2	12	23.5	0.8	25.5	0.4	0.001	rejected
		20	23.6	0.7	25.6	0.3	0.001	rejected
		40	23.9	0.9	25.6	0.3	0.001	rejected
		60	24.0	1.1	25.6	0.3	0.001	rejected
		80	24.1	1.2	25.6	0.3	0.001	rejected
		100	24.0	1.0	25.6	0.3	0.001	rejected
		120	24.2	1.4	25.6	0.3	0.001	rejected
		160	24.1	1.1	25.6	0.3	0.001	rejected
	0.1	12	19.9	0.4	23.0	0.4	0.001	rejected
		20	20.0	0.4	23.0	0.3	0.001	rejected
		40	20.2	0.4	23.0	0.4	0.001	rejected
		60	20.3	0.5	23.0	0.4	0.001	rejected
		80	20.3	0.5	23.0	0.4	0.001	rejected
		100	20.3	0.4	23.0	0.4	0.001	rejected
		120	20.3	0.4	23.0	0.4	0.001	rejected
		160	20.3	0.4	23.0	0.4	0.001	rejected

※ H_0 : No significant difference in average delays of Semi-actuated Control and Optimized TOD. (Application of .05 of a significant level)

3.2 Pedestrian Delay

When the pedestrian delay for each scenario was reviewed, it was revealed that the optimized fixed signal control had less delay than the coordinated semi-actuated signal control in most cases. However, when major street v/s and minor street v/s were 0.4:0.4 and 0.4:0.2, there was no significant difference in an average delay in a scenario with 12 pedestrians per hour. Also, when there was 0.4 and 0.1 of major street v/s and minor street v/s, differences in pedestrian delays with 12, 80, 120, and 180 pedestrian per hour did not seem to be significantly different. The pedestrian delay is described in detail from [Fig. 7] with a short explanation.

The following [Table 4] shows the results of average delay per pedestrian and of statistical analysis concluded by analyzing the scenarios with different signal controls for 30 times simulation running.



(a) v/s 0.4 : 0.4 (b) v/s 0.4 : 0.3 (c) v/s 0.4 : 0.2 (d) v/s 0.4 : 0.1 (e) v/s 0.3 : 0.3 (f) v/s 0.3 : 0.2 (g) v/s 0.3 : 0.1

Fig. 7. Pedestrian average delay

Considering the vehicle and pedestrian delays, the application conditions of the coordinated semi-actuated signal control could be summarized as Table 5. However these results came from the statistical comparison of the optimized TOD with the coordinated semi-actuated signal control. Therefore, in general situation which traffic volume is fluctuated in a short duration, the coordinated semi-actuated signal control might be more effective than TOD. Also, through the optimized signal parameters of actuated signal control, the coordinated semi-actuated signal control could have similar or superior results with the optimized TOD.

Table 4. Simulation results of pedestrian

v/s		Ped. per Hour	Coordinative Semi-Act.		Opt. TOD		Paired t-test	
Maj.	Min.		Delay (sec/veh)	STD	Delay (sec/veh)	STD	Sig.	H0
0.4	0.4	12	67.5	13.5	62.3	7.0	0.079	not rejected
		20	73.7	7.5	60.6	5.8	0.001	rejected
		40	85.7	7.8	61.2	5.0	0.001	rejected
		60	87.2	6.1	60.6	4.0	0.001	rejected
		80	89.0	6.8	60.5	3.6	0.001	rejected
		100	89.2	6.7	60.5	3.6	0.001	rejected
		120	88.5	5.2	60.3	3.4	0.001	rejected
		160	88.2	5.8	61.0	2.4	0.001	rejected
	0.3	12	57.7	9.1	46.6	4.7	0.001	rejected
		20	63.9	8.9	46.7	3.3	0.001	rejected
		40	71.2	8.1	46.4	2.0	0.001	rejected
		60	73.6	8.6	46.3	2.5	0.001	rejected
		80	77.9	5.8	46.8	1.8	0.001	rejected
		100	78.7	9.3	46.6	2.0	0.001	rejected
		120	76.6	9.2	46.1	1.7	0.001	rejected
		160	75.9	8.9	46.4	1.3	0.001	rejected
	0.2	12	51.2	5.9	48.1	5.5	0.092	not rejected
		20	52.2	5.2	46.6	4.0	0.001	rejected
		40	53.0	5.6	47.2	3.0	0.001	rejected
		60	52.2	4.3	46.2	2.9	0.001	rejected
		80	51.1	3.5	46.7	2.0	0.001	rejected
		100	51.6	4.1	46.5	2.1	0.001	rejected
		120	50.8	3.7	45.8	1.6	0.001	rejected
		160	52.2	4.4	46.4	1.6	0.001	rejected
	0.1	12	50.5	6.7	48.0	5.1	0.193	not rejected
		20	51.2	3.5	46.9	2.4	0.001	rejected
		40	48.9	3.2	47.1	3.3	0.037	rejected
		60	47.4	2.2	46.3	2.8	0.138	not rejected
		80	47.0	1.4	46.8	2.1	0.764	not rejected
		100	46.5	1.4	46.5	1.7	0.850	not rejected
		120	46.7	1.8	46.0	1.4	0.201	not rejected
		160	45.5	2.0	46.4	1.6	0.159	not rejected
0.3	0.3	12	55.8	6.8	47.2	4.6	0.001	rejected
		20	55.7	6.4	46.1	2.6	0.001	rejected
		40	58.0	7.1	46.6	2.4	0.001	rejected
		60	59.1	7.1	46.9	2.8	0.001	rejected
		80	60.8	6.8	46.5	2.0	0.001	rejected
		100	59.4	7.6	46.4	1.6	0.001	rejected
		120	61.1	7.2	46.1	1.6	0.001	rejected
		160	60.0	7.6	46.8	1.4	0.001	rejected
	0.2	12	51.9	6.6	39.2	3.6	0.001	rejected
		20	50.3	4.6	39.5	2.6	0.001	rejected
		40	49.5	3.4	40.3	2.1	0.001	rejected
		60	48.9	3.3	40.5	2.0	0.001	rejected
		80	48.9	3.1	41.0	1.7	0.001	rejected
		100	48.3	2.7	41.1	2.1	0.001	rejected
		120	48.8	3.5	41.3	1.6	0.001	rejected
		160	47.6	2.3	40.7	1.2	0.001	rejected
	0.1	12	50.5	6.2	39.6	3.8	0.001	rejected
		20	51.0	3.4	39.8	2.5	0.001	rejected
		40	49.0	3.3	40.2	2.0	0.001	rejected
		60	47.0	1.8	40.2	1.9	0.001	rejected
		80	46.9	1.5	40.6	1.3	0.001	rejected
		100	46.4	1.7	41.1	1.8	0.001	rejected
		120	46.2	1.5	41.0	1.5	0.001	rejected
		160	45.4	1.8	40.8	1.3	0.001	rejected

※ H_0 : No significant difference in average delays of Semi-actuated Control and Optimized TOD. (Application of .05 of a significant level)

Table 5. Traffic condition to apply coordinative semi-actuated signal control

	v/s of Each Approach		Intersection Pedestrian (ped/hr)							
	Major	Minor	12	20	40	60	80	100	120	160
Vehicle	0.4	0.4	N	N	N	N	N	N	N	N
		0.3	P	P	N	N	N	N	N	N
		0.2	P	P	P	P	P	P	P	P
		0.1	P	P	P	P	P	P	P	P
	0.3	0.3	P	P	P	N	N	N	N	N
		0.2	P	P	P	P	P	P	P	P
		0.1	P	P	P	P	P	P	P	P
Pedestrian	0.4	0.4	P	N	N	N	N	N	N	N
		0.3	N	N	N	N	N	N	N	N
		0.2	P	N	N	N	N	N	N	N
		0.1	P	N	N	P	P	P	P	P
	0.3	0.3	N	N	N	N	N	N	N	N
		0.2	N	N	N	N	N	N	N	N
		0.1	N	N	N	N	N	N	N	N

※ P : Positive to Apply the Coordinated Semi-actuated Signal Control

※ N : Negative to Apply the Coordinated Semi-actuated Signal Control

V. Conclusion

The semi-actuated signal control for coordination in a rural arterial, or corridor, can be implemented at an intersection where the number of pedestrians and traffic volume of a minor road is less than a major road. In this study, the coordinated semi-Actuated signal control algorithm was developed. This algorithm can maintain the dual ring system suggested by NEMA, and includes green extension, phase skip, gap out and a pedestrian actuation functions. Effectiveness of the developed coordinated semi-actuated signal control algorithm were confirmed by comparing with the optimized fixed signal control, and from that, the vehicle delay was revealed by changing the number of pedestrians.

The simulation was executed with pedestrian volumes which were 12, 20, 40, 60, 80, 100, 120 and 160 and with vehicle *v/s* ratios which were distinguished into major and minor streets from 0.4 to 0.1. The simulation was estimated with comparison to the optimized fixed signal control, with the coordinated semi-actuated signal control, on the vehicle and pedestrian delay.

According to the analysis of the vehicle delay, the coordinated semi-actuated signal control led to reduced vehicle delays as traffic volumes between major and minor streets gradually grew. However, when there was relatively high traffic volume, or the equivalent amount of traffic volume, of major and minor streets, the optimized TOD was verified to make lower delays than the coordinated semi-actuated signal control. Also, in the *v/s* case as 0.4:0.4, 0.4:0.3, and 0.3:0.3, the vehicle delay of the coordinated semi-actuated signal control prominently tended to increase as crossing pedestrian volume grew.

It was also shown that the optimized fixed signal control would cause less pedestrian delay than the coordinated semi-actuated signal control in most of cases. However, when there were 0.4:0.4 and 0.4:0.2 of major street *v/s* and minor street *v/s*, there was no significant difference in an average delay at a scenario under 12 pedestrians per hour. Also, when there were 0.4 and 0.1, pedestrian delays did not have a significant difference where 12, 80, 120, and 180 pedestrian per hour.

From analysis of the simulation with the coordinated semi-actuated signal control and the optimized TOD, it would be reasonable to assume that effects of the coordinated semi-actuated signal control would be excellent in aspects of decreasing the vehicle delay. It has negative sides as well. It might increase the pedestrian delay. Due to these conditions, the coordinated semi-actuated signal control should only be applied to places where traffic volume of vehicles and pedestrians is less than a specific level.

This study was developed and appreciated based on un-saturated condition, so that it was not verified on the saturated condition. In the future, research on saturated condition of a corridor should be considered. And also, optimized operation parameters are required for improving its performance and appling on field by calibration and validation of simulation.

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