Development and Evaluation of Lane-by-Lane Gap-out Based Actuated Traffic Signal Control

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DEVELOPMENT AND EVALUATION OF LANE-BY-LANE GAP-OUT BASED ACTUATED TRAFFIC SIGNAL CONTROL

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16. Abstract

Actuated traffic signal controls at isolated intersections largely benefit from gap-out and phase skip features as they allow unused green times to be re-allocated to those movements need them. A few studies indicated that lane-by-lane gap-out should be implemented for multi-lane approaches instead of traditional combined single channel gap-out. While the lane-by-lane gap-out is logically better than the combined channel gap-out, no studies have shown the delay benefits under the optimized green splits and gap-out times.

This research developed a lane-by-lane gap-out-based actuated signal control optimization method and evaluated its performance using four demand cases covering volume-to-capacity ratios between 0.4 and 1.3. A simulation-based study indicated that the lane-by-lane gap-out outperformed the combined single channel gap-out for all these cases. It was found that over 12% total delay savings were observed for high volume-to-capacity ratio cases.

17. Key Words lane-by-lane gap-out, actuated traffic signal control, simulation, and optimization

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ABSTRACT

Actuated traffic signal controls at isolated intersections largely benefit from gap-out and phase skip features as they allow unused green times to be re-allocated to those movements need them. A few studies indicated that lane-by-lane gap-out should be implemented for multi-lane approaches instead of traditional combined single channel gap-out. While the lane-by-lane gap-out is logically better than the combined channel gap-out, no studies have shown the delay benefits under the optimized green splits and gap-out times.

This research developed a lane-by-lane gap-out-based actuated signal control optimization method and evaluated its performance using four demand cases covering volume-to-capacity ratios between 0.4 and 1.3. A simulation-based study indicated that the lane-by-lane gap-out outperformed the combined single channel gap-out for all these cases. It was found that over 12% total delay savings were observed for high volume-to-capacity ratio cases.

Key words: lane-by-lane gap-out, actuated traffic signal control, simulation, and optimization

INTRODUCTION

Background

Traffic signal operations can provide several advantages at the signalized intersections including provisions of right of ways to conflicting movements and operational efficiency with optimized timing plans and the use of advanced controller features. One of advanced controller features is an actuated control implementing phase gap-out and phase skip using detector (or vehicle actuation) information. This gap-out feature allows reallocation of existing green times to other phases when the current phase does not have continuous vehicle arrivals, typically determined by a gap-out (or extension) time threshold value. Thus, amount of green times assigned to the actuated phases can be flexible within the range between the minimum and maximum green times. As long as vehicles continue to arrive within the gap-out time, the existing green is extended until maximum green is reached. An interesting point to be made is that traditional single channel detection scheme (also called movement-based detection or combined detection schemes) on a multilane approach often keeps extending green time while vehicles do not arrive in a dense platoon. This is because vehicle actuations are recognized regardless of their lanes as indicated by Smaglick et al. (2005).

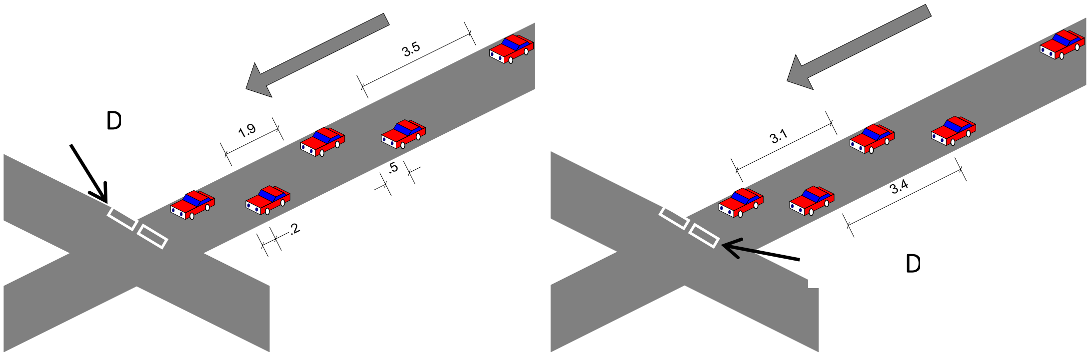
While several studies demonstrated the benefits of the lane-by-lane detection scheme over the traditional single channel detection scheme, the comparisons were mainly made on the basis of green utilizations (Smaglick et al. 2005), green durations (Smaglick et al. 2007) or green extensions (Tian and Urbanik 2006). Furthermore, none of these studies made an attempt to optimize traffic signal timing plans especially for the gap-out (or extension) times under the lane-by-lane detection scheme. It is noted that no existing computer software including Synchro and TRANSYT-7F can optimize timing plans under the lane-by-lane detection scheme. Thus, any comparisons made by either field observations or simulations might not have used the optimal timing plans, resulting in possibly biased comparisons. In addition, as clearly demonstrated by Smaglick (2007), the lane-by-lane detection scheme can be implemented in the field. It is clear that a study quantifying the benefits of lane-by-lane detection using intersection performance such as average delay instead of green utilizations using the optimized green times and gap-out times for both the lane-by-lane and the single channel detection schemes would be crucial for making a decision for adopting the lane-by-lane detection scheme to traffic signal operators and traffic signal controller vendors. This is because detectors installed across multiple lanes are combined into single lead-line to the controller (Sharma, 2006). That is, if the lane-by-lane is to be used, each detector should have its own lead-line to the controller in which requires hardware installations. Thus, it is necessary to assess the benefits of the lane-by-lane control under the timing plan optimized for the lane-by-lane control. As noted, existing literature utilized a timing plan developed without explicitly considering the lane-by-lane control.

This research quantifies the benefits of lane-by-lane detection scheme by implementing optimizations of traffic signal timing plans for both the lane-by-lane and the traditional single channel detection schemes. This ensures the optimized timing plans are to be evaluated instead of timing plans that are developed heuristically or optimized under the traditional single channel scheme. Motivated by this fact, the objective of this research seeks to answer the following questions: 1) whether there is a different optimal signal timing for the lane-by-lane detection and 2) under what volume conditions lane-by-lane detection operates with greater efficiency than the single-channel detection.

Lane-by-lane Gap-out vs. Single Channel Gap-out

Urbanik et al. (2003) proposed the lane-by-lane detection scheme over the traditional single channel detection scheme for determining gap-out. Figure 1 shows the schema of the single channel detection, which operates by measuring the gap in seconds between vehicle actuations on the roadway. Since it counts both (or multiple) lanes as a single channel, the gaps between approaching vehicles tend to be shorter than they would if each lane were treated separately, as shown in Figure 1(a). Single channel detection tends to prolong the green light as the vehicles approach. Obviously, this additional green time does not accurately represent the traffic volume on the roadway and may cause additional delay for vehicles waiting at the intersection on the other approaches. As illustrated in Figure 1(b), the lane-by-lane detection operates the timer separately for each lane on the approach, instead of for the approach as a whole. Under the lane-by-lane detection, when one lane reaches its desired gap in seconds, a flag variable assigned to the lane is triggered. Once the other lanes have reached their desired gaps, the signal changes to yellow and then red, allowing other approaches to cross the intersection.

The lane-by-lane detection is a recently developed concept for improving actuated traffic signals operations. It is designed to more accurately represent the traffic on multi-lane approaches. The single-channel detection method currently in use indicates, in general, higher traffic volumes to the traffic signal controller and thus extends the green time for the approach. This extension can increase overall delay at the intersection.



(a) Single channel detection

(b) Lane-by-lane detection

Figure 1 Single Channel Detection vs. Lane-by-lane Detection

A numerical example further illustrates how the green time is reduced and the delay is minimized. In Figures 1 (a) and (b), it is assumed that the first begins to pass over a stop-bar detector at the intersection at 20 seconds of green time. Assuming 3 seconds of the gap-out time and each car takes 0.5 seconds to completely go through the stop-bar detector, Figure 1(a) indicates that single-channel detection need green time for the phase by 27.1 seconds (i.e., 0.5+0.2+0.5+1.9+0.5+0.5+3 = 27.1). Whereas, the lane-by-lane detection, shown in Figure 1(b), would allow only 23.5(0.5+3 = 23.5) seconds of green tine because the headway of the right-most lane is bigger than the gap-out time, resulting in terminating green time before the left-most lane reaches to the gap-out.

LITERATURE REVIEW

A few recent research efforts examined the performance of the lane-by-lane gap-out feature by addressing the short comings of single channel gap-out feature when the approach has more than one lane. In this section, such efforts are briefly reviewed and summarized.

Tian and Urbanik (2006) proposed an idea of lane-by-lane detection for actuated intersections. The lane-by-Lane detection monitors the headways on a lane-by-lane basis. This paper addressed the forming of a simulation model to evaluate and compare the two different detection schemes. The comparisons were made on the basis of green extensions over a wide range of traffic flow scenarios. The paper called for this type of detection to be performed using a standard traffic simulation model to evaluate the differences using more than just green extension times. This paper described the lane-by-lane gap-out as follows. For a 4 lane roadway; if a vehicle in lane 1 arrives at 4.8 seconds since the signal turned green then the following headway is 3.6 sec (>3 sec) then lane 1 reaches gap out condition first. If Lane 2 then sees a vehicle arrives at 6.1 seconds and no other vehicle arrives within 3 seconds then the green phase would terminate at 6.1 + 3.0 = 9.1 seconds. The simulation model developed for this paper provided estimates on green time extension utilizing the two different schemes at many different traffic volumes. However, the simulation model was challenging to handle various vehicle types and travel speeds. By employing the Highway Capacity Manual- based delay formula, each simulation run used generated 200 green extension times and represented 200 cycles of signal operations. The average difference in green extension found was only about 2.3 seconds and about 60% of the runs returned exactly the same green extension time.

Sharma et al. (2006) demonstrated the limitations of the single channel gap-out logic. This paper identified the way gap-out works and how it causes many dilemma zone incursions. Under the existing condition not only are all of the detectors pooled into one signal which is sent to the controller but also the main street phases are pooled and do not switch until both through phases have gapped out. The safety benefits of simultaneous gap out are negated whenever the signal must run to max out conditions and change without regard to approaching traffic. It does not consider methods where the yellow time and all red time can be dynamically extended to help alleviate potential for accidents due to dilemma zone incursions. Simultaneous part of the simultaneous gap out means that, under these conditions, both main street through phases must see a gap of sufficient size at the same time to gap out, otherwise the signal will extend the green phase and continue to monitor the gaps. The study discussed the ideal approach which uses previous knowledge to choose the best detection scheme in real-time (Vehicle Infrastructure Integration or VII, also known as connected vehicle technology). It was also discussed how under high volume conditions where queues are never dissipated on the approach this VII would have no benefits over existing logic.

Wang (2008) assessed the value of the lane-by-lane detection scheme in comparison to the standard single channel detection of multilane approaches by using VISSIM, a microscopic simulation model (PTV, 2012a) and its Vehicle Actuated Programming (VAP) feature (PTV, 2012b). This paper simulated the same isolated intersection using both the single channel and the lane-by-lane detection schemes under varying traffic volume conditions. The lane-by-lane detection scheme had many constraints placed on the intersections. Some of the restrictions mentioned are that all approaches are symmetric, there is one left lane with protected movements, and there was one through lane which allowed right turns to happen. So, the number of through lanes was varied and the different detection schemes applied to the through lanes only. 90% of the traffic for the study was used with each through movement and 5% was allocated to the right and left turns for each approach. The maximum green time was set to 50 seconds. The conclusions showed that the more lanes if there are the better lane- by-lane detection operates for the intersection.

Smaglik et al. (2005) examined the performance of lane-by-lane detection by comparing to traditional detection. The lane-by-lane detection scheme was tested on an isolated intersection in Indiana, where is known as an Indiana DOT's test bed intersection. This paper logically explained how the lane-by-lane logic works in this scenario. For the test procedure, the logic behind the lane-by-lane detection was programmed in and then the traffic signal was put online with the new detection logic. A computer hooked to the controller logged the phase and time of termination to help determine the benefits of lane by lane detection versus traditional single channel detection. A scatter plot was made of efficiency gained versus volume to capacity ratio. The results of this test showed an average efficiency gain of 3% to 5% for a multilane facility. It is noted that the extension time used greatly affected the benefits of lane-by-lane gap-out. The longer the extension time the better efficiency lane-by-lane gap-out produces. This article claimed that modest benefits can be gained by using this detection scheme.

Smaglik et al. (2007) implemented a lane-by-lane detection on a test bed intersection in Noblesville, Indiana. Data was collected at this intersection over a continuous three week period for both single channel and lane-by-lane detection. The data which was collected includes green intervals on all phases, volume to capacity ratios and cycle lengths. The results from the comparisons show that when low to moderate volume conditions exist there is a statistically significant decrease in green duration and cycle times and increase in v/c ratios. From the information gained in this paper, it raises further questions. Such as, what were the traffic volume distribution between left and thru as well as cross and main streets? Also, on further investigation of the results almost all significant improvement was found in the through movements of the street this is because of the fact that there is only one left turn lane in each direction for the test bed intersection. It would be interesting to evaluate lane-by-lane detection at an intersection with multiple left turn bays.

In summary, previous research has been conducted concerning which traffic volumes lane-by-lane detection performs better than single-channel detection. The best results for lane-by-lane detection were observed under moderate traffic volumes. Given high traffic volumes, each lane of the intersection is very busy preventing either type of detection from reaching its desired gap time thus yielding little if any improvement for lane-by-lane detection. If the traffic volumes are low, the opposite problem happens; there are so many gaps in the traffic that both types of detection find their desired gap at about the same time. Low traffic volumes produce only moderate results with the lane-by-lane detection because of the frequency of the gaps. More gaps equated to a higher chance that both lane-by-lane and single-channel detection would gap-out at the same time. The previous research was challenging in its scope; almost exclusively testing those scenarios which were determined theoretically to yield the most benefit from utilizing the lane-by-lane detection.

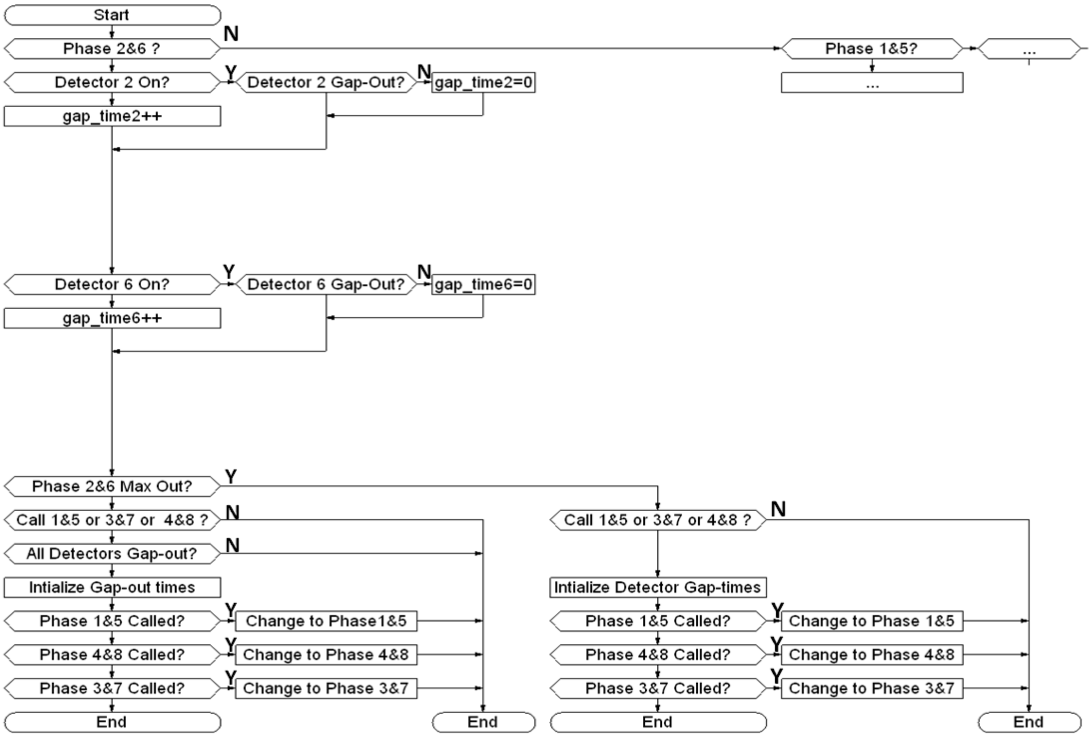
METHODOLOGY

As noted, the objective of this research was to quantify the benefits of the lane-by-lane detection scheme by comparing the performance of the optimized traffic signal timing plans developed under the single channel and the lane-by-lane detection schemes. Given that none of existing traffic signal timing optimization programs (e.g., Synchro, TRANSYT-7F, and PASSER-V) is capable of implementing the lane-by-lane gap-out scheme, a stochastic traffic signal optimization method integrating a Genetic Algorithm (GA) and the VISSIM microscopic simulator is employed. It is noted that the GA has been widely applied for traffic signal timing optimization using stochastic simulators such as VISSIM (Yun and Park, 2012; Park and Lee, 2009; Stevanovic et al., 2007; Park et al., 1999). The implementation of the lane-by-lane gap-out scheme requires detecting vehicular gap times on each lane and determines gap-out if all lanes do gap-out. A microscopic simulation model, VISSIM, was chosen for its unique capability providing a relatively easy application programming interface for external traffic signal control. This section presents the methodology proposed for assessing the benefits of the lane-by-lane gap-out feature in detail.

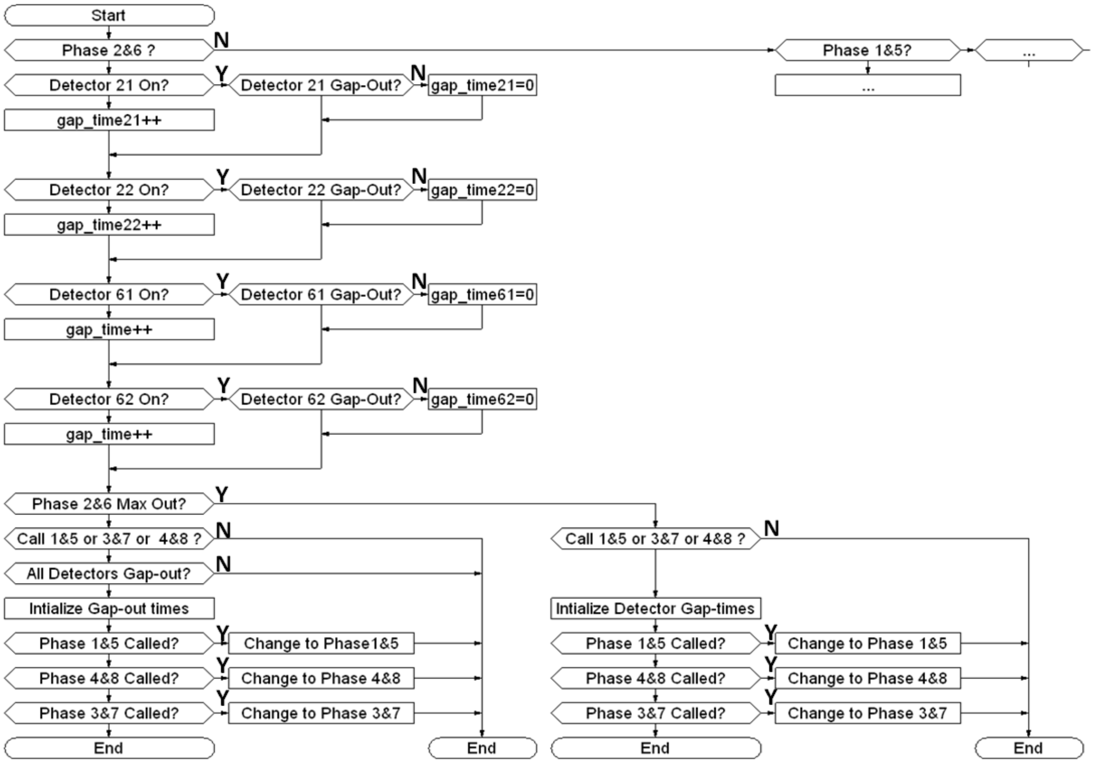
Lane-by-lane Gap-out Implementation in VISSIM

The VISSIM program provides a Vehicle Actuated Programming (VAP) feature allowing users to develop free-defined signal control logics. As the name implies, the VAP is a structural programming language enabling for users to handle the data from detectors, and to manipulate controllers. As such, with the VAP, users can not only set up conventional signal timing parameters such as cycle length, offsets, max greens, or gap-out times, but also control sensors' detection mechanism including detection channel splits. In this paper, the VAP controls traffic signal status based on the vehicular gap times obtained from sensors. In other words, the VAP code developed in this research determines gap-out based on the lane-by-lane control logic discussed earlier.

Figure 2 shows a part of control scheme of the traditional single channel gap-out control (i.e., Figure 2(a)) and the newly proposed lane-by-lane gap-out control (i.e., Figure 2(b)). Note that the picture size of whole control scheme would be too big to be fitted in this report, the case of Phase 2 and 6 is demonstrated, but the same logic is applied for the other phase groups. As shown in Figure 2, the difference between the single channel control and the lane-by-lane control takes place in the determination of the gap-out status. While the single channel gap-out control checks the gap-out status based on the aggregated detection information over all lanes, the lane-by-lane gap-out control examines each detector's gap-out status. Once the current phase group reaches to max-out, the both control schemes look for any demand calls from the other phase groups. Given max-out to the current phase group, both control schemes directly move to the corresponding phases to accommodate the current demand call. Even though the current phase is still under max-green time, if all detectors are gaped-out, the control logics also move to the demanding phases. The VISSIM program executes whole process of the control scheme at every simulation interval, which set to 0.1 seconds for this research.



(a) Single channel gap-out control scheme in the VAP



(b) Lane-by-lane gap-out control scheme in the VAP

Figure 2. VAP control schemes

GA-based Traffic Signal Timing Optimization

As the performance of these gap-out schemes would depend on the signal timing plans like cycle length, maximum green times, and even the gap-out times, it is necessary to have the optimal timing plans for each detection scheme before conducting the performance comparisons. Given that none of existing traffic signal optimization packages like TRANSYT-7F or Synchro have the capability of explicitly considering the gap-out time for the optimization of signal timing plan, this study developed a Genetic Algorithm (GA)-based traffic signal timing optimization program as depicted in Figure 3. The optimization program consists of two parts: the VISSIM program controlled by its COM interface, and the MATLAB-based GA optimizer.

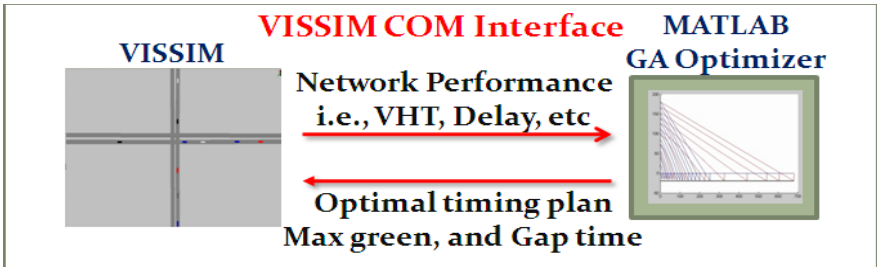


Figure 3. Framework of optimization program

The GA optimizer embedded in MATLAB has been widely adopted by researchers for its reliability and applicability. However, it is still difficult for traffic engineers to use it in the field as it requires MATLAB to run the GA optimizer. To avoid this issue, this research developed a MATLAB-free standalone program by converting the GA optimizer program into a single Dynamic Linked Library (DLL)-type external module.

Note that the signal phase plan of this study is excluded from the signal timing plan optimization as frequently changing phase sequence would violate drivers' expectancy and often resulting in potential safety concerns. However, as long as the same phase plan is used for the implementations of both the lane-by-lane and the single channel detection schemes, it would be acceptable to conduct the performance comparison. The minimum green time for each phase group was fixed at 10 seconds for phases 2 and 6 (i.e., major street through movement) and 5 seconds for the other phases, and 3 seconds of yellow time was used for each phase. Therefore, the total number of variables to be optimized is 12: eight gap-out times for 8 phases, and four max green times for four phase groups as shown in Figure 4.

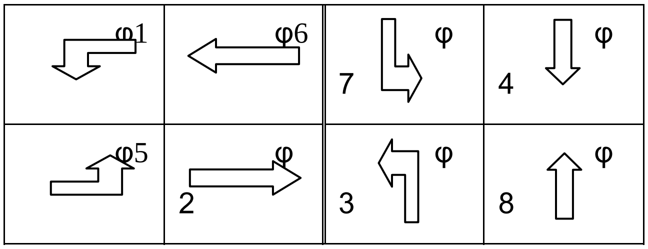


Figure 4. Phase Sequence

Finally, the GA parameters and methods used for the optimizations of signal timing plans are summarized in Table 1. It is noted that these values were typically used by the GA-based traffic signal timing optimization applications (Yun and Park, 2012; Park and Lee, 2009; Stevanovic et al., 2007; Park et al., 1999). Each chromosome was evaluated 10 times and the mean value of the total travel time was used for the fitness function value.

Table 1. GA Parameter Setting

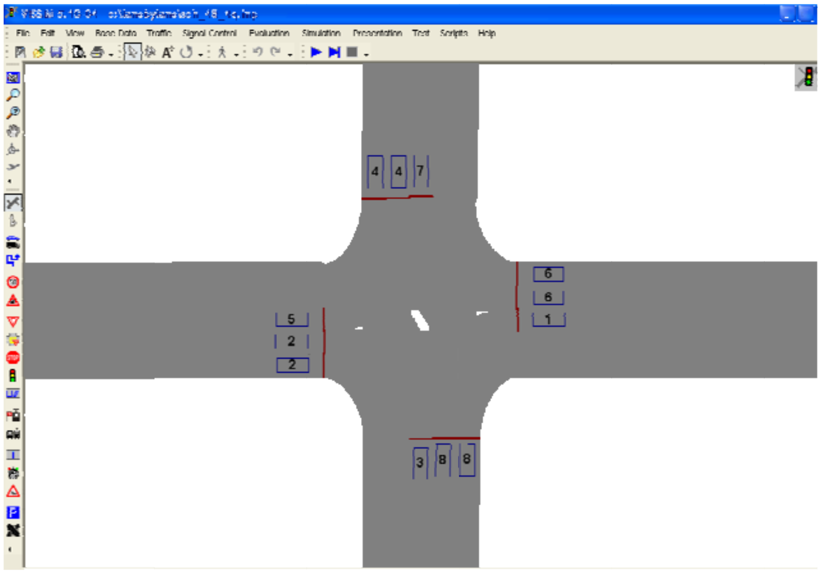
GA Parameters/Methods	Setting
Populations	20
Maximum Generations	120
Elitists	2
Mutation Probability	2%
Selection	Stochastic Uniform
Crossover	Scattered (Multi-points) Crossover

CASE STUDY

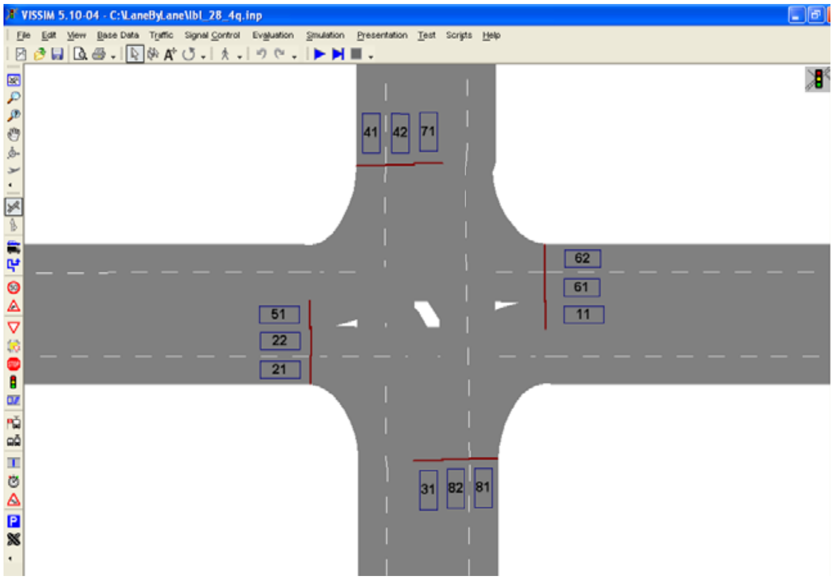
Test Intersection

A hypothetical isolated intersection with two through lanes and a single left-turn lane on both main street and cross street is prepared. The speed limits on main and cross streets are set at 40 mph and 30 mph, respectively. The detectors are located near the stop bars for both main and cross streets.

Since the detector setting of the single channel detection is different from that of the lane-by-lane control, the two different networks based on the detection scheme are created, and their detector layouts are displayed in Figure 5. Unlike the detector setting for the single channel detection in Figure 5(a), the detectors for the lane-by-lane control have different channel numbers to separately monitor the traffics on each lane.



(a) Single channel detector setting



(b) Lane-by-lane detector setting

Figure 5. Detector setting for the test network

Evaluation Scenarios

In order to examine the performance of the lane-by-lane detection, this research evaluated 4 different traffic volume cases as summarized in Table 2. Starting from a volume condition making the overall volume-to-capacity (V/C) ratio of intersection to be approximately 1.3 (i.e., 100% volume case), additional 3 volume condition decreased by 25% to examine the impact of the traffic congestion on the performance of the lane-by-lane gap-out control.

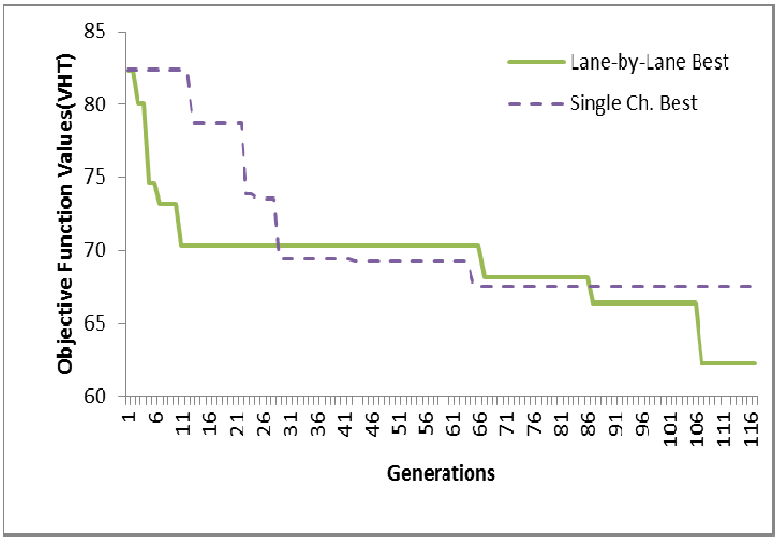
Table 2. Traffic Volumes for Evaluation

Approach	Phase #	Movement	Volume Case			
			100% (V/C=1.3)	75% (V/C=1.0)	50% (V/C=0.7)	25% (V/C=0.4)
NB	3	LT	257	192	128	64
	8	TH	522	391	261	130
		RT	86	64	43	21
		Sum	865	648	432	216
EB	5	LT	183	137	91	45
	2	TH	1,553	1,164	776	388
		RT	178	133	89	44
		Sum	1,914	1,435	957	478
SB	7	LT	187	140	93	46
	4	TH	441	330	220	110
		RT	63	47	31	15
		Sum	691	518	345	172
WB	1	LT	270	202	135	67
	6	TH	1,548	1,161	774	387
		RT	102	76	51	25
		Sum	1,920	1,440	960	480
Total			5,390	4,042	2,695	1,347

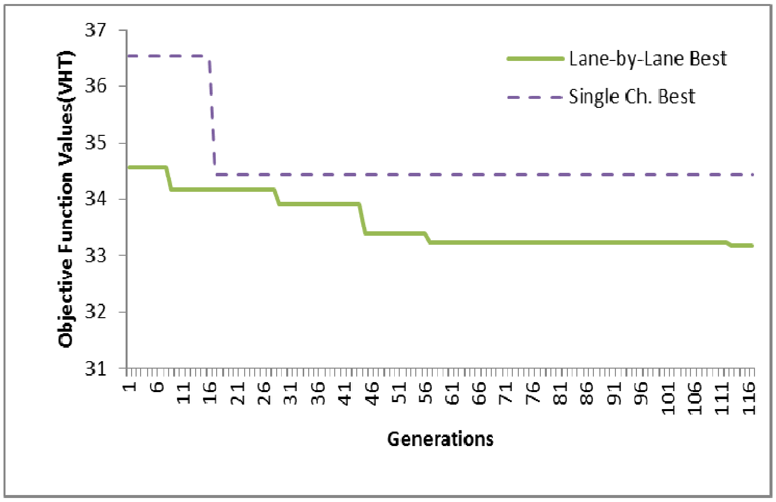
RESULTS

Signal Timing Optimization

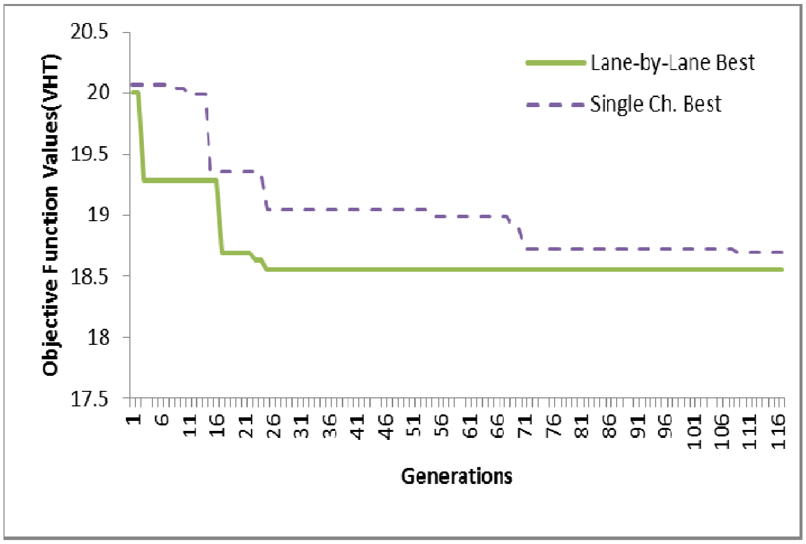
With the GA setting described in the previous section, convergence curves of the GA-based optimization seeking the optimal timing plans for both the single channel (i.e., movement-based) and the lane-by-lane gap-out cases were demonstrated in Figure 6. For all traffic volume cases in Table 2, the GA optimizer found better solutions with the lane-by-lane gap-out case while no significant performance differences were found for the lower volume cases (i.e., 50% and 25% volume cases). It is noted that under the lane-by-lane gap-out control case the GA optimizer quickly converged than the single channel gap-out case in which could indicate the lane-by-lane case has much less variability than the single channel case.



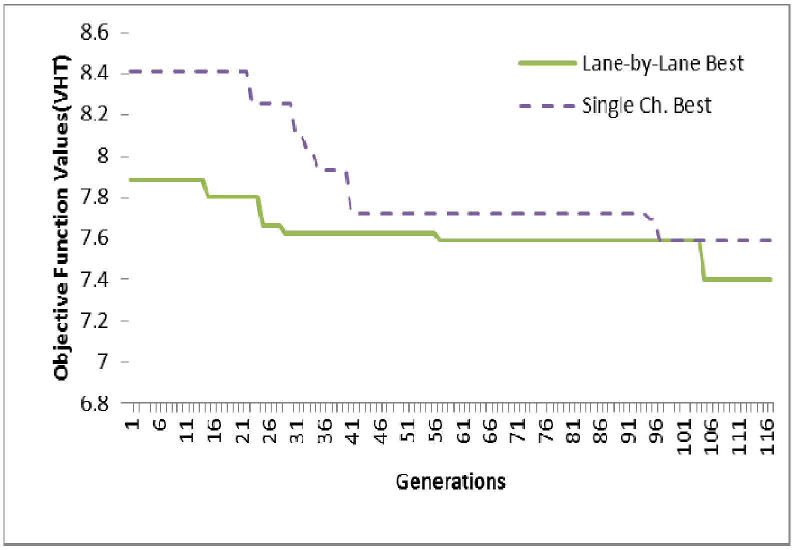
(a) V/C = 1.3 Volume Case



(b) 75% Volume Case



(c) 50% Volume Case



(d) 25% Volume Case

Figure 6. Genetic algorithm convergences for the single channel and the lane-by-lane gap-out cases

Table 3 shows the optimal gap-out times and the max green times obtained by the GA optimizer for the 100% volume case, which showed the most notable benefits of the lane-by-lane control scheme. It is observed that the maximum green times of the lane-by-lane gap-out for the through movement phases serving two lanes (i.e., phases 2&6 and 4&8) in this research are significantly shorter than those of the single channel gap-out. Observing that the gap-out times for both control schemes are not significantly different, longer max green times of the single channel gap-out shown in Table 3 confirms that the single channel gap-out would inevitably prolong the green time to serve approaching traffics on multiple lanes together by extending the green times addressed by previous studies (Tian and Urbanik, 2006; Sharma, 2006). On the other hand, by separately capture the departure of traffics on each lane, the lane-by-lane gap-out enables to be quickly gapped-out by reducing the frequency of the max-out, thereby resulting in shorter maximum green times that can minimize the total delay at the intersection.

Table 3. Optimal Gap-out time and max green time for 100% volume case

Phase	Number Of Lane	Gap-Out Time(Sec)		Max Green (Sec)		Approach Volume
		Lane-by-Lane	Single Channel	Lane-by-Lane	Single Channel	
1	1	5.9	5	7	14	270
5	1	4.7	4.6			183
2	2	2.9	2.8	46	65	1,731
6	2	2.6	2.1			1,650
3	1	3	3.3	10	10	257
7	1	5	4.9			187
4	2	3.5	2.3	10	18	504
8	2	2.1	3.1			618

Given the optimal signal timing data obtained by the GA optimizer for each volume case, the performance of the lane-by-lane gap-out scheme was evaluated by comparing four network-wide mobility measures produced by the single channel gap-out control as displayed in Figure 7. Unlike previous research efforts examining the performance of lane-by-lane gap-out by using green time utilization measure for a certain approach that were collected from the field, this research investigated the impact of the lane-by-lane gap-out on the entire intersection by measuring intersection-wide total travel time and total delay time based on the optimized gap-out and maximum green times under the lane-by-lane as well as the traditional single channel gap-out cases.

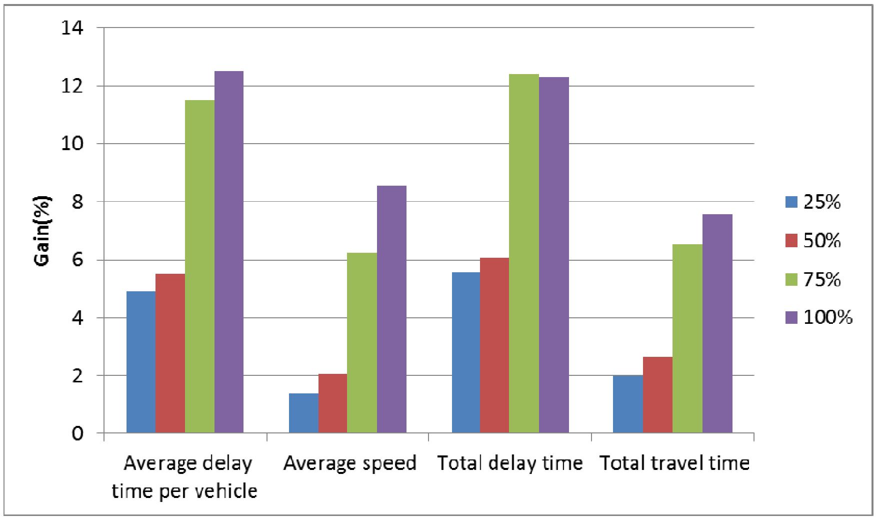


Figure 7. Gains by lane-by-lane gap-out

Overall, the lane-by-lane gap-out improved the intersection by saving average delay time, average speed, total delay time, and total travel time by up to 13%, 9%, 12%, and 8%, respectively. It is noted that the improvements by the lane-by-lane gap-out increased as the traffic volume for the intersection increase; e.g., about 2% of total travel time saving were obtained under the lowest volume case (i.e., 25%

volume case) while approximately 8% of savings were gained with the highest volume case (i.e., 100% volume case). The detailed evaluation results for the four traffic volume cases are summarized in Table 4.

Table 4. Lane-by-lane gap-out evaluation results

Vol. Case	Control Scheme	Measure	Average delay (Sec/Veh)	Average speed (Mile/Hr)	Total delay time (Veh-Hr)	Total travel time (Veh-Hr)
100% (V/C=1.3	Lane-by-Lane	Mean	50.9	14.9	38.1	62.0
		S.D	6.6	1.1	5.2	5.3
	Single Channel	Mean	58.1	13.7	43.5	67.1
		S.D	10.1	1.4	8.2	8.3
	Gain (%)		***12.5***	***8.6***	***12.3***	***7.6***
75% (V/C=1.0)	Lane-by-Lane	Mean	27.5	20.8	15.4	33.4
		S.D	3.5	1.1	2.0	2.2
	Single Channel	Mean	31.1	19.6	17.5	35.7
		S.D	2.4	0.7	1.6	1.8
	Gain (%)		***11.5***	***6.2***	***12.4***	***6.5***
50% (V/C=0.7)	Lane-by-Lane	Mean	19.0	24.2	7.1	19.2
		S.D	0.8	0.4	0.4	0.6
	Single Channel	Mean	20.1	23.7	7.6	19.7
		S.D	1.1	0.5	0.6	0.9
	Gain (%)		***5.5***	***2.1***	***6.1***	***2.6***
25% (V/C=0.4)	Lane-by-Lane	Mean	10.5	29.1	2.0	8.1
		S.D	0.5	0.4	0.1	0.3
	Single Channel	Mean	11.1	28.7	2.1	8.2
		S.D	0.7	0.5	0.2	0.4
	Gain (%)		***4.9***	***1.4***	***5.6****	***2.0****

* Statistically insignificant.

CONCLUDING REMARKS

This research quantified the potential benefits of the lane-by-lane gap-out feature by examining intersection-wide multiple performance measures including total travel time, total delay, average delay, and average speed. Unlike previous research efforts, this research investigated the performance of the lane-by-lane gap-out with the optimized signal timing plan produced by a stochastic heuristic optimization method utilizing a Genetic Algorithm. To this end, the research team developed a simulation-based test-bed incorporating a microscopic traffic simulator, VISSIM, MATLAB-based GA optimizer for traffic signal optimization, and the Vehicle Actuated Programming (VAP) interface for the implementation of the lane-by-lane gap-out scheme in VISSIM.

This research evaluated the performance of the lane-by-lane gap-out under various traffic volume and turning movement conditions by simulating an isolated intersection with optimized maximum green times and gap-out times for each case while assuming that the phase sequences are fixed. It would be desirable to evaluate the effectiveness of the lane-by-lane gap-out by using properly optimized phase sequences in the future. The impact of the lane-by-lane gap-out on the coordinated intersections is also of interest but no relevant research assessed the performance of the lane-by-lane gap-out for the coordinated intersections. Based on all the crucial elements required for the evaluation of the lane-by-lane gap-out, such as the simulation test-bed, GA optimizer, and VAP logic, developed in this research, the benefits of the lane-by-lane gap-out for the coordinated intersections can be precisely examined in the future.

The implementation of the lane-by-lane gap-out in the field is relatively easy and straightforward as it can be quickly performed by rewiring cables connecting the detectors and cabinet and simply adjusting the controller setting. Based on the findings from this research, it is recommended that the lane-by-lane gap-out feature be implemented to improve intersection performance as one of cost-effective intersection improvement techniques.

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