

Evaluating lane-by-lane gap-out based signal control for isolated intersection under stop-line, single and multiple advance detection systems

Chandan Kancharla¹, Alvaro M. Seco² e Ana Bastos Silva³

Abstract: In isolated intersection's actuated signal control, inductive loop detector layout plays a crucial role in providing the vehicle information to the signal controller. Based on vehicle actuations at the detector, the green time is extended till a pre-defined threshold gap-out occurs. The Federal Highway Administration (FHWA) proposed various guidelines for detector layouts on low-speed and high-speed approaches. This paper proposes single and multiple advance detection schemes for low-speed traffic movements, that utilizes vehicle actuations from advance detectors located upstream of the stop-line, which are able to detect spill-back queues. The proposed detection schemes operate with actuated signal control based on lane-by-lane gap-out criteria. The performance of the proposed schemes is compared with FHWA's stop-line and single advance detection schemes in the VISSIM simulation tool. Results have shown that the proposed single advance detection schemes showed improved performance in reducing travel time delay and average number of stops per vehicle under low volumes while the multiple advance detection scheme performed well under high volumes.

Keywords: Actuated signal control, advance detectors, gap-out, lane-by-lane detection, FHWA, VISSIM.

Resumo: Nos sistemas semaforizados atuados os detetores por indução constituem a forma mais comum para recolha de informação de tráfego. Com base nessa informação o tempo de verde é incrementado sucessivamente até atingir um valor máximo, sendo o processo interrompido quando o intervalo de atuações ultrapassar um valor pré-estabelecido. A Federal Highway Administration (FHWA) propõe vários esquemas para localização dos detetores adaptados a diferentes ambientes rodoviários. Este artigo apresenta propostas de localização de detetores baseados na aplicação de um ou de múltiplos detetores, a montante da entrada. Os esquemas propostos são baseados num sistema de sinais luminosos com funcionamento atuado, onde os incrementos dos tempos de verde são avaliados usando, de forma separada por via de entrada, um intervalo crítico entre veículos sucessivos como critério de referência. O nível de desempenho do sistema foi comparado com o resultante dos esquemas de referência do FHWA baseados em detetores únicos, num caso colocado junto à linha de stop, no outro com localização avançada, recorrendo à plataforma de microsimulação VISSIM. Os resultados comprovam que, face a níveis de procura de tráfego baixos, a utilização de um detetor isolado permite atingir melhor desempenho, traduzido na redução das demoras e do número de paragens por veículo, enquanto para elevados níveis de procura a adoção de múltiplos detetores tende a resultar em melhores resultados.

Palavras-chave: Sinais semaforizados atuados, detetores de avanço, intervalo crítico de extensão, detecção individualizada por via, FHWA, VISSIM.

1. INTRODUCTION

Signalized intersections are an important part of the road transportation system that regulates the traffic flow in urban areas. Correct installation of traffic signals along with proper signal control strategy will minimize delays, stops and fuel consumption for all road users. Traffic signals usually operate in either fixed time or actuated mode or combination of both. The fixed time signal consists of a series of cycle lengths that are fixed in duration. On the other hand, actuated control consists of varied cycle lengths whose intervals are called and extended in response to vehicle detectors. Detection is used to provide real-time information about traffic demand to the controller. The green time of each phase is determined by detector input and corresponding signal control parameters (Koonce, 2008).

In actuated control, minimum green time is provided to every phase to serve the queued-up vehicles from the red part of the cycle, and the green time is either continued until no vehicles are detected over a short gap-out time (or extension time) or extended until the maximum green is reached if the vehicles continue to arrive within the gap-out time. Thus the amount of green times in an actuated control can be flexible between the minimum and maximum green times. Detector layout (i.e., location and size) plays a very important role in passing the vehicle actuation information to the signal controller. The performance of the intersection operation mainly depends on the relationship between the detection layout and the signal controller settings. For optimum performance, the detector layout and signal settings should be balanced to the geometry of the intersection, its traffic volume, and the approach speed. The balancing process consists of adjusting the detector location (with respect to the stop-line), detector length, passage time, and minimum green time for the prevailing conditions (Koonce, 2008).

Many adaptive traffic control systems worldwide use different detection layouts to estimate the state of traffic. SCATS, which is a two-level hierarchical system developed in Australia (Sims and Dobinson, 1980) uses information from vehicle detectors, located in each lane immediately in advance of the stop-line. SCOOT, which is a dynamic, online, real-time method of signal control developed in

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U.K. (Hunt *et al.*, 1982) uses upstream detection to collect its traffic information. SCOOT's upstream detectors are usually installed in the vicinity of the previous upstream intersection to reduce communication costs. MOVA, which is a vehicle actuated signal control system developed by Transport Research Laboratory (TRL), U.K. (DfT, 1997) uses an advance detector layout to provide traffic data to the control logic. Each lane in MOVA system consists of one vehicle detector about 100m before the stop-line, and a second one at approximately 40m. Adaptive Control Software Lite (ACS Lite), which is developed by FHWA in USA uses stop-line detectors (sized from 4 to 70ft or 1.22 to 21m long) to monitor the volume and occupancy on green. On arterial approaches where progression is required, ACS Lite uses advance detectors (6ft×6ft or 1.83m×1.83m size) to monitor cyclic flow profile, to identify platoon arrivals, and use this information for adjustment of offsets to improve progression (Stevanovic, 2010).

The Federal Highways Administration (FHWA), which is a body of expertise in road transportation of the United States Department of Transportation (USDOT), has given guidelines for various detector layouts to be used for a fully actuated signal control for an isolated intersection. The objective of this paper is to analyze various detection layouts and evaluate their performance when applied to an isolated intersection through simulation.

2. BACKGROUND

2.1. Detector layouts

The objective of the detection process is to detect the vehicle's presence and identify gaps in traffic, which, depending on their duration, will lead to the phase being ended or the green being extended. Many authors in the past have proposed detector layout criteria for actuated traffic signal control (Bonneson *et al.*, 1994; Lin, 1985; Hulscher, 1976; Kay *et al.*, 1975).

Bonneson *et al* (2009) states that stop-line detection is a very effective means of ensuring that a waiting queue is given the time it needs to clear the intersection. This type of detection allows the controller to be responsive to the presence of waiting vehicles and to minimize the percentage of cycles that end unnecessarily before the queue has been cleared. However, the major limitation of using only stop-line detection is the gap-out time will be known only maximum allowable headway (MAH) seconds after the vehicle crosses the stop line, causing unnecessary extension of green at the end of each phase.

Koonce (2008) and Bonneson *et al* (2009) have suggested guidelines for the detection design of *low-speed* traffic movements (speeds less than or equal to 56kmph). The main objective of the detection of low-speed traffic movements is "to call a phase and serve the queue while minimizing the delays" (Koonce, 2008). Stop-line detection is used on low-speed approaches because there is less emphasis on protection from the dilemma zone on the approach. According to Lin (1985), the ideal length of the stop-line detection zone is about 24m. This length is very efficient in detecting the end of queue while minimizing the chance of a premature gap-out (which occurs when the unit extension time is too short and the green ends before serving the queue adequately). However, the installation and maintenance of

such a long detector are often cost prohibitive. Hence FHWA has suggested that, the appropriate length of the stop-line detection zone should not be smaller than 6m and the detector should be operated in presence mode (see Figure 1). In a presence mode detection, the actuation starts when the vehicle arrives to the detection zone and ends only after the vehicle leaves the detection zone (Bonneson *et al.*, 2009).

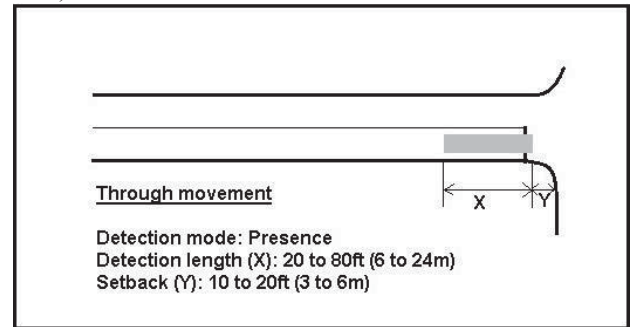


Figura 1. Stop-line detection design for low-speed movement through movement (Bonneson *et al.*, 2009)

Tabela 1. Recommended distance (Z) between stop-line and detector (Koonce, 2008)

85th Percentile Approach Speed, kmph	Distance, Z (m) for MAH 3.0seconds
32	27
40	33
48	40
56	47

If advance detection is used for *low-speed* traffic movements, according to FHWA's guidelines, one 1.83m detector should be located upstream of the stop-line which operates in pulse mode. In pulse mode, the actuation starts and ends with the arrival of the vehicle to the detector (typical pulse actuation is about 0.10 to 0.15 s) (Bonneson *et al.*, 2009). "The location of the advance detector should be such that the travel time from the detector to the stop-line for a vehicle traveling at the 85th percentile speed is equal to the maximum allowable headway (MAH)"(Koonce, 2008). The advantage of such advance detection over stop-line detection is, the unnecessary extension of green time is prevented by a vehicle that has crossed the stop-line. Based on this principle, the recommended location for the detector for different approach speeds is listed in Table 1.

For *high-speed* approaches (speeds greater than 56kmph), the objective of the detection design is to be able to serve the queue at the beginning of green and also to safely terminate the phase during a conflicting call. According to FHWA's guidelines, stop-line detection should be used to clear the queues and multiple upstream detectors should be used to safely terminate the phase (Koonce, 2008; Zimmerman and Bonneson, 2006).

The objective of the work presented here is to test the actuated signal control for an isolated intersection, using the vehicle actuations from stop-line, single and multiple advance detectors. Since FHWA has recommended to use multiple upstream detectors for *high-speed* approaches, this paper focusses only on *low-speed* approaches where no recommendations are made by FHWA to use multiple advance detectors, which it was considered to be a potentially competitive alternative worth being tested.

2.2. Gap-out based signal control

For vehicle detection associated with multiple detectors, two types of traffic detection schemes were seen as current research practice: single-channel detection and lane-by-lane detection (Smaglik *et al.*, 2005; Tian and Urbanik, 2006). A single-channel detection method connects all detectors in all lanes on an approach into a single detection unit and provides a single input to the signal phase. Therefore, when any detector on the approach detects a vehicle, the controller resets the gap-out timer for that phase and the green phase extends. The phase terminates only when the entire approach gaps out. Such a detection scheme may cause unnecessary green extensions based on the desired headway, particularly for the approaches that have more than one lane. In a lane-by-lane detection scheme, each lane is monitored with a separate detector and gap-out timer. Under this method, the green phase terminates only when all the lanes on an approach have *individually* reached the desired gap-out condition (Wang Xuan, 2008).

Tian and Urbanik (2006) presented an example to understand the difference between the single-lane and lane-by-lane gap-out detection schemes. The same kind of example, with different numbers is presented in this paper. Table 2 shows a sample of vehicle detection times and their associated headway gaps on a two-lane approach. Assuming a 3.0s of MAH, when a headway gap is greater than 3.0s, a gap-out condition occurs and the phase terminates.

In case of *single-channel* detection, to determine when the gap-out condition occurs and the resulting green extension time, the vehicle detection times in both lanes are combined and sorted in sequence, and the headway gaps are calculated (see Table 3). The numbers in bold represent the vehicles in Lane 2. For the data shown in Table 3, a gap-out condition would occur in 17.2s when the following headway is 3.5s ($>3.0s$). So the phase would terminate at 17.2s ($14.2 + 3.0$).

Tabela 2. Vehicle detection times and headway gaps on a two-lane approach

Lane-1 Vehicle Detection time (s)	Lane-1 Headway gap (s)	Lane-2 Vehicle Detection time (s)	Lane-2 Headway gap (s)
1.6		1.9	
3.2	1.6	3.8	1.9
5.2	2.0	5.3	1.5
6.8	1.6	7.3	2.0
10.0	3.2) >3.0	8.9	1.6
11.8	1.8	12.7	3.8) >3.0
17.7	5.9	14.2	1.5

Tabela 3. Combined vehicle detection times and headway gaps on a two-lane approach

Combined Vehicle detection Time (s)	Headway Gap (s)	Combined Vehicle detection Time (s)	Headway Gap (s)
1.6		7.3	0.5
1.9	0.3	8.9	1.6
3.2	1.3	10.0	1.1
3.8	0.6	11.8	1.8
5.2	1.4	12.7	0.9
5.3	0.1	14.2	1.5
6.8	1.5	17.7	3.5) >3.0

In case of *lane-by-lane* detection, the headways in each lane are monitored separately by the detectors, and the phase would gap-out when both lanes individually reach the gap-out condition. As shown in Table 2, Lane-1 first reaches gap-out after the vehicle detection at 6.8s when the following headway gap is 3.2s ($>3.0s$), and Lane-2 reaches gap-out after the vehicle detection at 8.9s when the following headway gap is 3.8s ($>3.0s$). Therefore, a gap-out condition would occur at 8.9s, and the phase would terminate at 11.9s ($8.9+3.0$). In this particular example, the lane-by-lane detection results in 5.3s less green extension than the single-channel detection. This could decrease the overall delay of the intersection.

Wang Xuan (2008) analyzed the gap-out logic with single-channel and lane-by-lane detection schemes. Lane-by-lane detection was observed to more easily reach the gap-out condition and provided efficient signal timing solutions. Two scenarios related to the MAH of 2.5 seconds and 3.0 seconds were analyzed. It was found that a 2.5-second MAH was able to produce better intersection performance compared to a 3.0-second MAH under the same vehicle detection scheme.

Smaglik *et al* (2005) also compared the traditional vehicle detection, in which all lanes on an approach are connected to an actuated controller through one amplifier card and input, and lane-by-lane detection, in which each lane is interfaced with the controller through separate amplifier cards and inputs. Various MAH (2.0, 2.5, 3.0, 3.5, and 4.0 seconds) scenarios were tested and concluded that implementation of lane-by-lane detection with 3.0s MAH showed 3 to 5% benefits.

No research has been found in literature investigating the performance of the different detection schemes, using lane-by-lane gap-out signal control criteria. This paper attempts to evaluate two kinds of FHWA's detection schemes: stop-line detection, one advance detector upstream of the stop-line. To achieve better performance compared to those layouts, an alternative multiple advance detection scheme is proposed which consists of two advance detectors upstream of the stop-line.

3. EVALUATION OF VARIOUS DETECTION SCHEMES

This section presents various detection schemes that are used for evaluation through simulation. Note that all the detection schemes that are presented below will be analyzed under the same platform of fully-actuated lane-by-lane gap-out signal timing criteria, assuming MAH of 3.0 seconds.

3.1. FHWA's Stop-line detection scheme

According to Koonce (2008) guidelines, for *low-speed* approaches, the stop-line detection zone length should not be smaller than 6m (see Figure 2a) and the detector should be operating in presence mode. When lane-by-lane detection with gap-out criteria is applied, the green phase for the approach terminates when all lanes have individually reached the desired gap-out (3.0 seconds) condition. The main limitation in this scheme is, the gap-out time will be known, only MAH seconds after the vehicle crosses the stop-line, thereby causing a delay of 3.0 seconds per lane per phase.



Figure 2. FHWA's Detection schemes.

3.2. FHWA's 1.83m single advance detection scheme

According to Koonce (2008) guidelines, for *low-speed* approaches, if an advance detector is used, one 1.83m detector is located upstream of the stop-line. The advance detector should be located such that the travel time from the detector to the stop-line for a vehicle traveling at the 85th percentile speed is equal to the maximum allowable headway (3.0 seconds). In Figure 2b, a 1.83m detector is located at a distance of 40m before the stop-line, assuming the 85th percentile approach speed is 48kmph. Similarly, the location of the advance detector varies for different approach speeds (see Table 1).

In this scheme, minimum green is provided to serve the queued-up vehicles between stop-line and the upstream detector and the green phase is continued till gap-out condition occurs with MAH of 3.0 seconds in individual lanes or maximum green is reached. The advantage of this scheme over stop-line detection scheme is, the gap-out time will be known in advance at the upstream detector and the last vehicle will be able to cross the stop-line when the gap-out period is reached and the phase terminates immediately. The main limitation of this detection layout is, during high-volume and congested situations the queues could extend beyond the advance detector, causing a premature gap-out that will leave a portion of the stopped queue unserved and, thereby, leading to increased delays and possible queue spillback.

3.3. Proposed 6m single advance detection scheme

Similar to the FHWA's single advance detection scheme as in section 3.1, an alternative layout is proposed in this section, using a 6m presence mode detector placed at 40m before the stop-line (see Figure 3a). In this scheme, minimum green is also provided to serve the queued-up vehicles between stop-line and the upstream detector and the green phase is continued till gap-out (MAH 3.0 seconds) condition occurs in individual lanes or maximum green is

reached. The advantage of this scheme over the FHWA's 1.83m advance detection scheme is, due to its long detection zone and presence mode operation, the 6m detector could be able to detect more vehicles and calls for green extension and thereby reducing the occurrences of premature gap-out situation.

3.4. Proposed multiple advance detection scheme

To acquire and utilize more vehicle information, an alternative layout is proposed where one 6m presence mode detector and one 1.83m pulse mode detector are used in each lane upstream of the stop-line (see Figure 3b).

- Detector-1 (6m) is located (based on the average approach speeds) such that, a vehicle after crossing Detector-1 will take at least 3 seconds to cross the Detector-2.
- Detector-2 (1.83m) is located (based on the average approach speeds) such that, a vehicle after crossing Detector-2 will take at least 3 seconds to cross stop-line.

The main advantage of this detection layout is the fact that the 6m detector (due to its presence mode) is long enough to detect the stopped or slow moving queue which is spilled back the 1.83m detector, thereby extends the green interval without causing premature gap-out situation. Once the minimum green period is expired, the 6m detector calls for a green extension until the gap-out condition occurs with MAH of 3.0 seconds on each lane individually. Once gap-out occurs at 6m detectors, the 1.83m detectors are activated and the green time is extended until the gap-out condition occurs with MAH of 3.0 seconds on each lane individually. The lane-by-lane gap-out logic for multiple detection scheme is presented in Figure 4. Since multiple advance detectors are used, more vehicle information is used by the signal controller and hence, it was believed, that this strategy could perform better than both the FHWA's stop-line and single advance detector strategies.

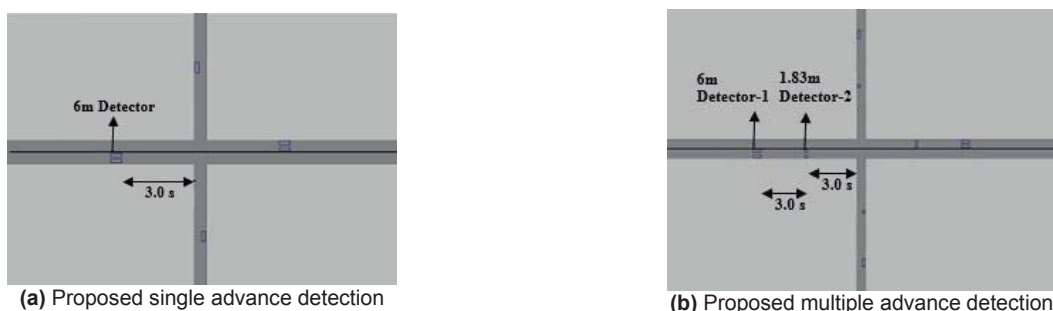


Figure 3. Proposed detection schemes.

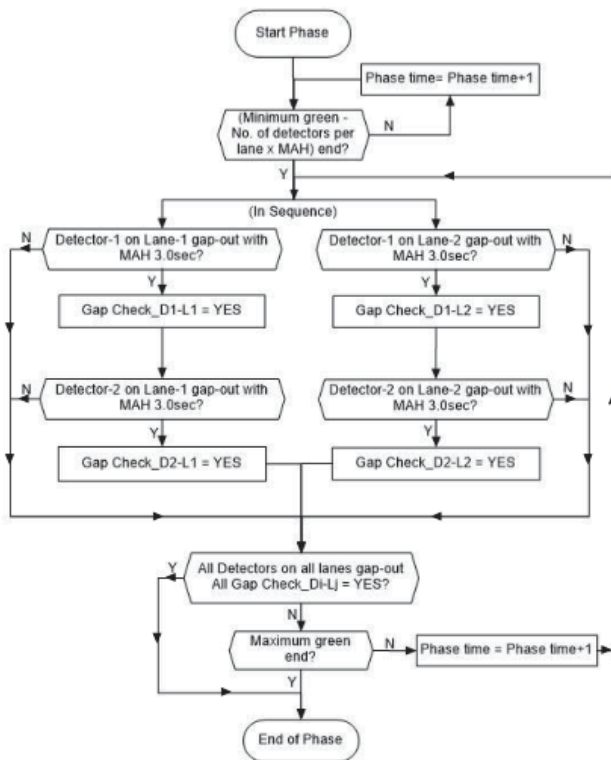


Figure 4. Lane-by-lane gap-out logic for multiple advance detection scheme

A major concern to most agencies installing traffic signals is the increased capital costs associated with any new equipment. According to the costs database of Intelligent transportation system office of USDOT, a 1.83m x 1.83m loop detector costs \$1,100 (ITSJPO, 2014). This is minor in comparison to a cost of \$47,300.00 for a vehicle detection station with 2 lanes in each direction which includes 2 loops per lane (ITSJPO, 2014). All that is required is to customize the loop size according to the proposed layout.

4. SIMULATION TESTS

4.1. Simulation framework

The testing and evaluation of all the detection layouts as mentioned in section 3 is performed on a simple hypothetical four-legged isolated intersection as shown in Figure 5.

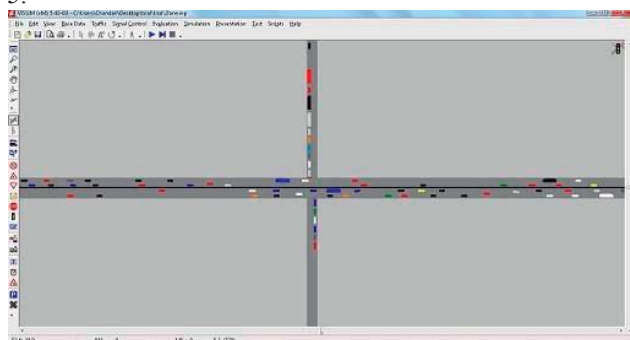


Figure 5. Snapshot of test intersection in VISSIM.

Each approach on the major road has two lanes (1 km long) with one-way through movement only. Each approach on the minor road has one lane (1 km long) with one-way through movement only. The approach width is taken

as 3.5m per lane. Simulation tests were carried in VISSIM 5.40 microscopic simulation software (PTV, 2012). VISSIM allows the users to access the vehicle information from the detectors and manipulate the traffic signal timings via a COM Application Programming Interface (API). The signal timing algorithms with lane-by-lane gap-out criteria for all the four detection layouts were coded in C++ language and were integrated with VISSIM’s COM interface. A simple two-phased timing plan is applied to allow only through movements during the simulation.

Simulation is run for 3900 seconds in which the first 300 seconds is used as warm-up time. The results of various scenarios are based on the average of 10 random seeds. Cars and Heavy vehicles (HV) are used in the simulation. During VISSIM trial simulation runs, using the default calibration parameters values defined in VISSIM, the saturation flow rate for the simulated intersection was found to be 2030 pcu/hr/lane, which was then used to identify the input flows corresponding to the different V/C traffic scenarios. The absolute maximum cycle length was taken as 120sec. Amber time and all-red time was taken as 3 and 2 seconds per phase, respectively. The minimum green for major roads (EB and WB) and minor roads (NB and SB) was taken as 15 and 10 seconds respectively as per the guidelines in Koonce (2008). The maximum green for major and minor roads was taken as the proportion of major and minor road flow, multiplied by the maximum cycle length, after deducing the amber time and all red time. To compare the evaluation results of different detector layouts, travel time delay and average number of stops per vehicle were used as measures of effectiveness. Table 4 presents different sets of input flows for different volume to capacity ratios, which were used in the different analysis scenarios.

Table 4. Input flows for different V/C ratios

V/C	Major road (70% flow)		Minor road (30% flow)	
	East bound (veh/h)	West bound (veh/h)	North bound (veh/h)	South bound (veh/h)
0.4	1040	520	223	112
0.5	1300	650	279	140
0.6	1560	780	335	167
0.7	1820	910	391	195
0.8	2080	1040	446	223
0.9	2340	1170	502	251
1.0	2600	1300	558	279

1. East and West bound approaches has two lanes each. North and South bound approaches has one lane each

4.2. Simulation scenarios and results

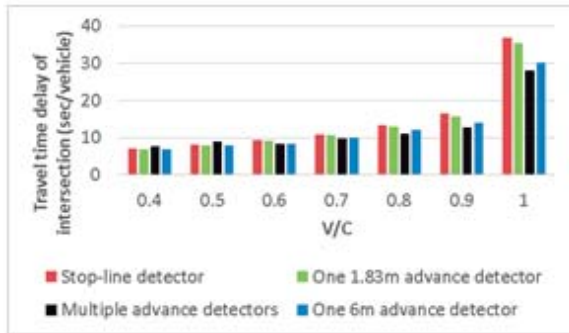
Three sets of scenarios were evaluated in which traffic conditions were varied by varying v/c ratio, varying the proportions of Cars and HV’s in total flow, varying the proportion of traffic flow on major and minor streets, in order to understand whether the relative performance of different detection schemes depends on the network congestion levels.

4.2.1. Variation of volume to capacity ratio

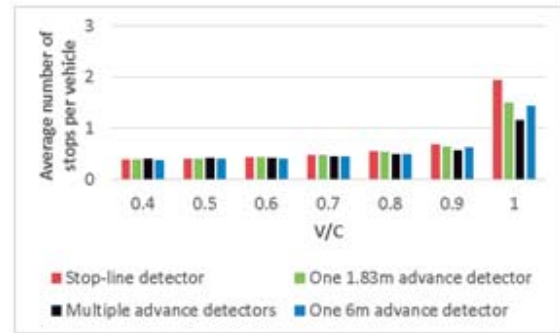
In this scenario, input flow from Table 4 is assigned according to different v/c ratios. The proportion of cars and HV in total flow are kept constant as shown in Table 5. The simulation results of this scenario are shown in Figure 6.

Tabela 5. Variation in volume to capacity ratio for different traffic composition

V/C	Percent Cars in total flow	Car Desired speed (kmph) (Min-Max)	Percent HV's in total flow	HV Desired speed (kmph) (Min-Max)
0.40	90	45-58	10	40-45
0.50	90	45-58	10	40-45
0.60	90	45-58	10	40-45
0.70	90	45-58	10	40-45
0.80	90	45-58	10	40-45
0.90	90	45-58	10	40-45
1.00	90	45-58	10	40-45



(a) Travel time delay vs V/C



(b) Average number of stops per vehicle vs V/C

Figure 6. Variation of V/C ratio.

From the results in Figures 6 it can be observed that, for v/c ratios from 0.60 to 1.0, the multiple advance detection scheme showed reductions in delays, ranging from 9.1% to 20.5%, and reductions in average number of stops per vehicle, ranging from 3.5% to 22.1%, when compared to the 1.83m single advance detection scheme results. When compared to the proposed 6m single advance detection scheme, the multiple advance detection scheme showed reductions in delays between 3% to 6.5% of for v/c ratios from 0.7 to 1.0.

Due to the pre-se 1.83m detectors, the multiple detection scheme clearly took advantage of detecting queued vehicles during high v/c ratios and congestion situations, thus placing more calls for green extension. However, for lower v/c ratios (0.4 and 0.5), the performance of the multiple advance detection scheme was worse when compared to all other detection schemes. At lower v/c ratios, because of low traffic volume and due to the MAH gap-out conditions of both 6m and 1.83m detectors on individual lanes, the travel time delay for the multiple advance detection scheme was higher when compared to all other detection schemes. Further, during low v/c ratios the proposed 6m advance detection scheme has shown better performance over all other schemes.

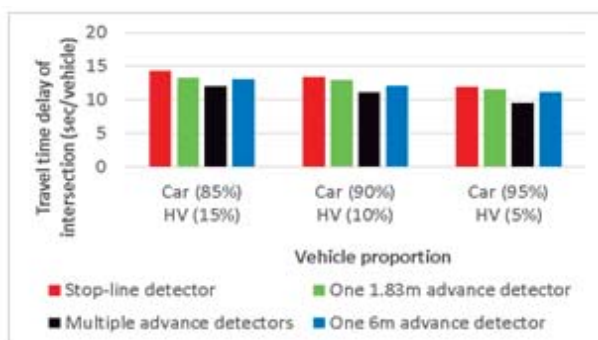
4.2.2. Variation in proportion of type of vehicles in total flow

In this scenario, v/c ratio is kept constant as 0.8 and the proportion of Cars and HV's are varied in the total input flow as shown in Table 6.

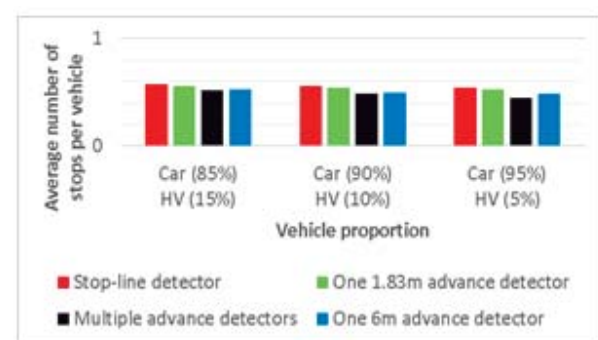
Tabela 6. Variation in vehicle type proportion

V/C	Percent Cars in total flow	Car desired speed (kmph) (Min-Max)	Percent HV's in total flow	HV desired speed (kmph) (Min-Max)
0.80	85	48-58	15	40-45
0.80	90	48-58	10	40-45
0.80	95	48-58	5	40-45

The results show that the higher the proportion of HV's, the higher is the travel time delay and average number of stops per vehicle (see Figure 7). This is because, due to the lower speeds HV's in total flow causes the Cars that are travelling behind them, to reduce their speeds. In this scenario, the multiple advance detection scheme has shown better performance compared to FHWA's stop-line detection, 1.83m single advance detection scheme and the proposed 6m advance detection scheme, with the benefits being higher when the proportion of HV's were low in the total flow. When the HV's proportion was 5% in total flow,



(a) Travel time delay vs Vehicle proportion

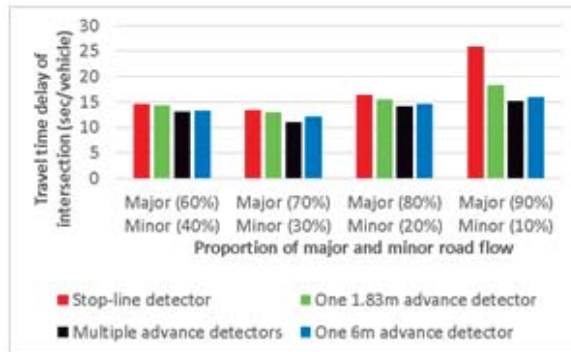


(b) Average number of stops per vehicle vs Vehicle proportion

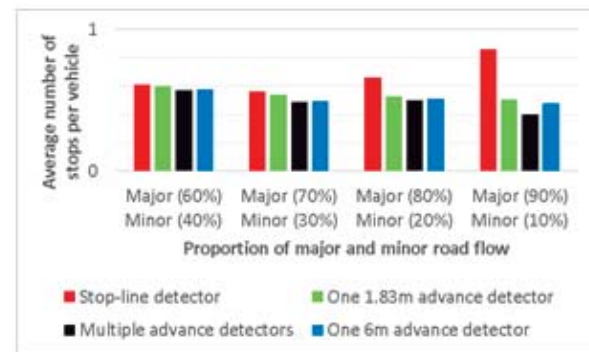
Figure 7. Variation of vehicle proportion

Tabela 7. Variation in major road-minor road flow proportion

Major road flow proportion	Minor road flow proportion	East bound (veh/h)	West bound (veh/h)	North bound (veh/h)	South bound (veh/h)
60%	40%	1787	894	596	298
70%	30%	2080	1040	446	223
80%	20%	2383	1192	298	149
90%	10%	2681	1341	149	75



(a) Travel time delay vs Major and minor road flow proportion



(b) Average number of stops per vehicle vs Major and minor road flow proportion

Figure 8. Variation in proportion of flow on major and minor roads.

multiple advance detection scheme showed 16.9% reduction in travel time delay and 14% reduction in the average number of stops per vehicle compared to the 1.83m single advance detection scheme. For the same case, when compared to the proposed 6m single advance detection scheme, the multiple advance detection scheme showed 13.6% reduction in delay and 7% reduction in the average number of stops per vehicle. In this scenario, since the v/c ratio is taken as 0.8, the multiple advance detection scheme was able to perform better than other schemes by taking the advantage of both 6m and 1.83m detectors in detecting and serving more vehicles.

4.2.3. Variation in proportion of flow on major and minor roads

In this scenario, the flow proportion on major road (EB, WB) and minor road (NB, SB) in total flow is varied as shown in Table 7. The volume to capacity ratio is kept constant as 0.8 and 90% Cars, 10% HV's are assumed in the traffic flow.

The simulation results of this scenario are shown in Figure 8. In this scenario, the multiple advance detection scheme has also shown better performance compared to all other detection schemes with the benefits being higher when the proportion of major road flow is high. When the major road flow proportion was 90%, multiple advance detection scheme showed 17.1% reduction in travel time delay and 21.5% reduction in the average number of stops per vehicle compared to the 1.83m single advance detection scheme. For the same case, when compared to the proposed 6m single advance detection scheme, the multiple advance detection scheme showed 4.2% reduction in delay and 16.8% reduction in the average number of stops per vehicle. However, when the major road flow was 60%, the multiple advance detection scheme showed only 0.4% reduction in delay compared to the 6m advance detection scheme, thus proving to be uneconomical layout.

5. CONCLUSIONS

This paper proposes single and multiple advance detection schemes for low-speed traffic movements, that utilizes vehicle actuations from advance detectors located upstream of the stop-line, which are able to detect spill-back queues. The performance of FHWA's stop-line detection, 1.83m single advance detection, and the proposed 6m single advance detection and multiple advance detection schemes was evaluated using lane-by-lane gap-out based green extension criteria with 3.0 seconds MAH. Different scenarios were tested, including varying v/c ratio, varying the proportion of Cars and HV's in the total flow and varying the proportion of major and minor road flow. During high volume conditions, the multiple detection scheme outperformed all the detection schemes, in reducing travel time delays and average number of stops per vehicle. The multiple detection scheme has utilized the advantage of its 6m long detection zone to detect more vehicles behind the 1.83m detector and to place the green extension calls during the premature gap-out and queue spill-back situations. However, during low volume conditions, the performance of the multiple advance detection scheme was worse compared to all other schemes, while the proposed 6m advance detection scheme has shown the best performance. Hence, the 6m single advance detection scheme was proved to be economically sound when compared to the multiple advance detection scheme under low volume conditions.

Future work will focus on improving the gap-out logic of the multiple advance detection scheme, by placing the 6m detectors 3.0 seconds before the stop-line and 1.83m detectors 6.0 seconds before the stop-line. The 6m presence mode detectors can be used to serve the queued-up vehicles before the stop-line. Once the 6m detectors reach gap-out condition, the 1.83m pulse mode detectors checks for any vehicle actuations and places the call for green extension accordingly. It is believed that this strategy could perform better under low v/c ratios.

The simulation results presented in this paper were performed on a hypothetical intersection, in the German traffic simulator VISSIM, as it allows the users to access the vehicle information from the detectors and manipulate the traffic signal timings via a COM-API interface. The saturation flow rate for the simulated intersection was found to be 2030 pcu/hr/lane using the default calibration parameters values defined in VISSIM. However, in the field, it is not rare to observe different saturation flow rates for each movement at a signalized intersection. Moreover, in VISSIM it is not possible to define saturation flow rates explicitly. The driving behavior parameters have to be changed in order to get a relevant field saturation flow rate. Future work will focus on performing the simulation on real-world intersections, considering more saturation flow rates, calibrating and validating the simulated environments to different local infrastructure, operational and driver behavior conditions, thus enabling an even more comprehensive test of the proposed detection scheme's performance potential.

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