PERFORMANCE OF VEHICLE ACTUATED CONTROL UNDER MIXED TRAFFIC CONDITIONS

Budi Yulianto[1]

Abstract: *It is generally accepted that a fully Vehicle Actuated control (VA) is almost always the most efficient form of traffic signal contr l for an isolated intersection. The successful design of VA control requires the specification of several critical parameters, including detector position and the settings for the timing variables. The major timing variable related to vehicle delay is vehicle extension (Bullen, 1989). This paper describes the examination and evaluation of the erformance of VA control under mixed traffic conditions with particularly high roportion of motorcycles. This includes an investigation of the most appropriate extension time for the VA control that was suitable for mixed traffic. As the proportion of motorcycle in traffic is high, the effect of motorcycles to the performance of the VA control was also investigated. Two schemes were carried out to observe it, namely: sc eme 1 where detector detects all vehicle types (DfT, 2006) and scheme 2 where detec or detects all vehicles types, apart from motorcycles. The simulation program VISSIM was used to examine and analyse the performance of the VA control in term of a rage delay of vehicles at an intersection. The simulation results show that the Vehicle Actuated Controller (VAC) System D using extension time of 1.2 seconds and VAC Extension Principle with detector position of 30 m and extension time of 3.0 se nds produced better performance than the other extension times tested for both schemes. The simulation results indicate that the performance of the VACs with scheme 1 is generally worse than with scheme 2. The performance of the VACs with scheme 1 against 2 tended to reduce significantly as the percentage of motorcycles in traffic increased.*

Keywords: *Actuated Control, Mixed Traffic, Performance, Vehicle.*

1. Introduction

Traffic signal control is a measure that is commonly used at road intersection to minimise vehicular delays. The oldest type of traffic signal control is Fixed Time control (FT). Under FT control, all signal timing parameters including cycle time and splits are predetermined and kept constant. This control usually shows good results in normal traffic conditions, but sometimes FT controls fail to cope with complex, time varying traffic conditions (Kell and Fullerton, 1991; Lee et al, 1994; Trabia and Kaseko, 1996). VA control presents an improvement over FT control. It is responsive to traffic demand as registered by the vehicle actuation detectors on the approaches to the intersection. The main feature of VA control is its ability to adjust the length of green time for a particular stage, and possibly the stage sequence in response to real traffic flow variations. The most common method of VA control is System D and Extension Principle (gap-seeking). VA control has been used widely in most of isolated intersection especially in develop countries due to its performance is better than the FT control.

The VA control was developed based on non-mixed traffic conditions (developed countries), where vehicles move in clearly defined lanes and very low proportion of motorcycles in the traffic. This type of control has not been tested and used at signalised intersection in Indonesia or others developing countries where the traffic streams are heterogeneous consisting of different type of vehicles and with a particularly high proportion (30% - 70%) of motorcycles. Also due to lack of lane

[1] Jurusan Teknik Sipil Fakultas Teknik Universitas Sebe as Maret

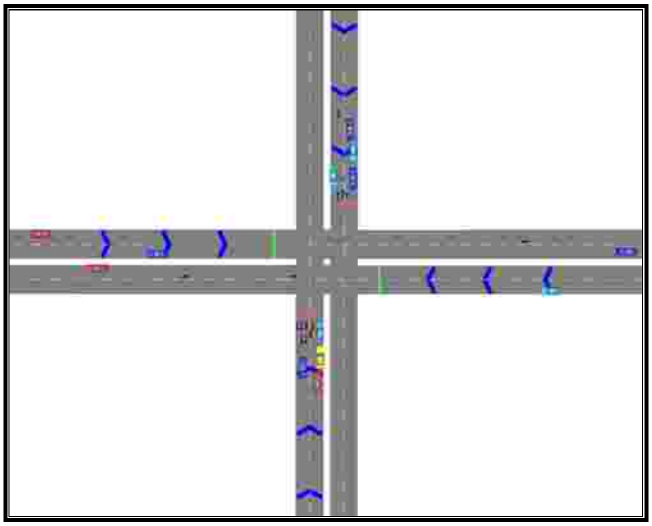

Figure 1. Typical detector configuration of System D at an isolated intersection

discipline, queues at intersections are built up based on the optimum road space utilization which means vehicles can occupy any position across the road based on the available space.

This paper describes the examination and evaluation of the performance of VA control under mixed traffic conditions with particularly high proportion of motorcycles. As the extension time is one of the most critical parameters to affect the overall performance of VA control (Bullen, 1989) therefore an investigation was carried out to find the most appropriate extension time for the VA control that was suitable for mixed traffic. The effect of motorcycles to the performance of the VA control was also investigated.

2. Overview of Traffic Signal Control Strategies

2.1. Vehicle Actuated Control System D

In the United Kingdom, the most commonly used form of control at isolated intersections is VA. VA control is based on the detection of vehicle presence and gaps (McLeod et al, 2004). The most common form of vehicle detection is System D detection. The standard System D has three loop detector positions at 12, 25 and 39 metres from junction. Detector should be able to detect all vehicles, including bicycles (DfT, 2006). Figure 1 shows typical detector configuration of System D at an isolated intersection. The controller operates with respect to vehicle demands and influences the duration of phases. Therefore, vehicles crossing detectors on the approach to the intersection would demand a specific phase. Three parameters must be set on the controller, namely the minimum green time, the extension time and the maximum time (DfT, 2005). When the signals turn green, the phase will run for its minimum green time, to clear vehicles between the stop line and the

Table 1. Traffic composition (%) for cases 1, 2 and 3

Case	MC	CAR	LGV	MGV	HGV	BUS
1 & 2	40.0	45.0	6.0	4.0	2.5	2.5
3	47.2	46.5	3.9	1.4	0.2	0.8

Table 2. Set of traffic volumes (vehicles/hour) for cases 1, 2 and 3

Case	E – W	N - S	Case	E - W	N - S	Case	E - W	N - S
1a ; 2a	1080	1080	1e ; 2e	1080	2520	1i ; 2i	1440	2520
1b ; 2b	1080	1440	1f ; 2f	1440	1440	3	1935 (E)	2071 (N)
1c ; 2c	1080	1800	1g ; 2g	1440	1800		2031 (W)	1848 (S)
1d ;2d	1080	2160	1h ; 2h	1440	2160			

Z detector. The shortest minimum green time normally used is seven seconds. Once the minimum green time has expired, the green time can be extended by vehicles crossing any of the three detectors. The aim of extensions is to allow the vehicle to pass the stop line before the expiry of the green period. The vehicle activating the detectors will extend the phase until there are no more vehicles detected on expiry of the last extension, or until the maximum green time has been reached. The controller will then move onto the next stage in the sequence to serve the next demand.

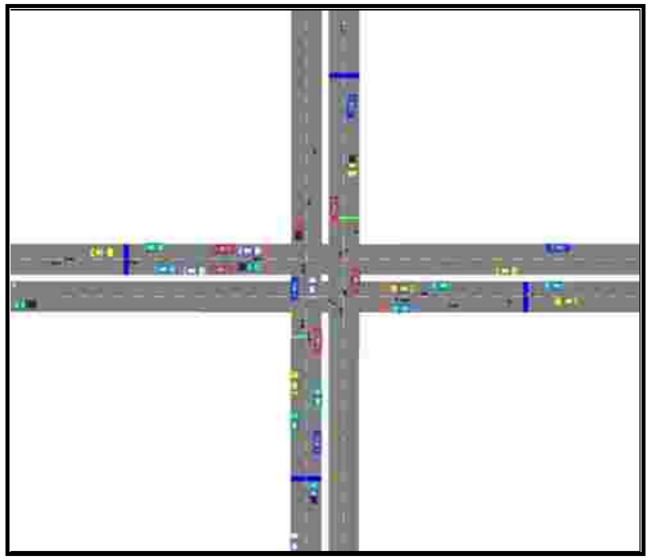

Figure 2. Typical detector configuration of Extension Principle at an isolated intersection

Cases	Average Delay of Vehicles (second)					
	Scheme 1			Scheme 2		
	ET = 1.2	ET = 1.4	ET = 1.6	ET = 1.2	ET = 1.4	ET = 1.6
1a	11.1	11.0*	11.4	10.8*	10.9	10.9
1b	12.7*	13.1	13.5	12.6*	12.7	12.8
1c	15.1	14.8*	15.1	14.8*	14.8	15.4
1d	17.8	17.5	17.5*	17.2*	17.3	17.6
1e	21.9*	24.0	23.2	21.9*	22.1	23.5
1f	15.6	15.5	15.3*	15.5	15.4	15.1*
1g	18.5*	18.7	18.6	18.8	18.7*	18.8
1h	24.1	23.5*	24.2	24.4	23.3*	23.5
1i	32.0*	32.9	32.6	32.4	31.9*	34.1
2a	15.2	14.5*	15.0	14.9	13.5*	13.7
2b	25.1	24.4	24.0*	22.8	22.3	22.0*
2c	24.7*	25.0	24.8	24.3*	24.8	24.7
2d	30.2	30.3	29.6*	29.8*	30.3	29.9
2e	34.8	34.8	34.5*	33.9*	34.2	35.6
2f	21.0*	23.8	22.7	19.4*	20.3	21.7
2g	28.3*	28.7	28.9	28.6	28.2	27.9*
2h	37.8	36.4	34.7*	35.9	35.3*	35.4
2i	45.9*	48.5	48.6	46.8	46.7*	47.9
4	22.8	23.0	22.7*	22.2*	22.6	22.8

ET: Extension Time (seconds)

* : the lowest average delay of vehicles

2.2. Vehicle Actuated Control Extension Principle

The VA control Extension Principle has been used widely at isolated intersection in many countries, especially in the United States of America (Kell and Fullerton, 1991). Under this control, the green time of phase is adjusted based on the extension time and time gap between vehicles crossing the point detector a certain distance from the stop line (D metres). A typical detector configuration of the Extension Principle at an isolated intersection is presented in Figure 2. There are three parameters required by the VA control Extension Principle, namely the minimum green time, the extension time and the maximum green time. A green signal is activated for at least the minimum green time to provide sufficient time for all vehicles potentially stored between the detector and the stop line to enter the intersection. The green interval is extended by resetting the extension time every time an actuation vehicle is recorded after the minimum green time expires. If the detectors record another vehicle within this extension time, the green will be extended again from the time of this actuation, by the length of the extension time. If the time gap (headway) between vehicles becomes greater than this extension time, then this green interval will be terminated before it reaches its

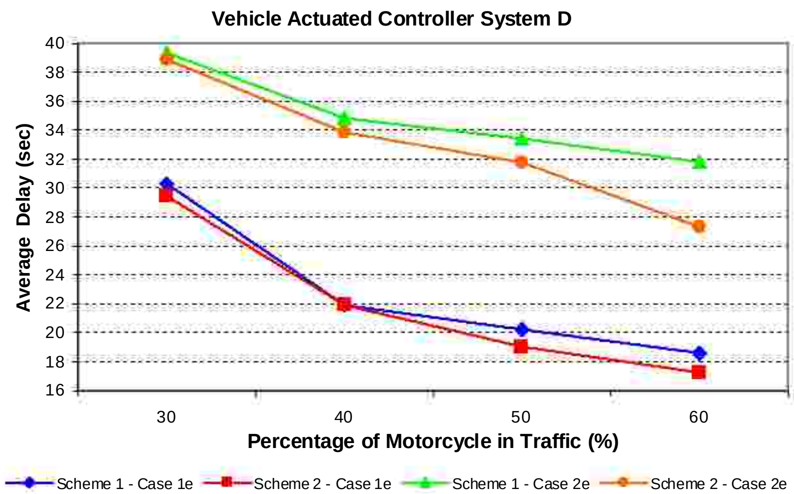

Figure 3. Effect of motorcycles to the VAC System D performance

maximum green value. In such circumstances, where there are no vehicles detected on a particular approach, the controller can skip over that stage and move directly to the next stage in the sequence.

3. Simulation Studies

3.1. Simulation Tool - VISSIM and Vehicle Actuated Programme (VAP) Language

In this simulation studies, VISSIM 4.10 was used to analyse the performance of the Vehicle Actuated Controller (VAC). In order to simulate mixed traffic condition, all vehicle types were modelled individually. The vehicle can occupy any position across the available lane space depend on the safe lateral clearance among vehicles. Motorcycles use inter-vehicular spaces to come to the front of the queue, and fill any lane space available between two vehicles. A motorcycle can squeeze between two vehicles moving side-by-side, or two successive vehicles moving in the same lane.

The signal controller program of the VAC was developed using VAP language. This way, the signal controller program could interact directly with VISSIM via internal signal state generator (Yulianto, 2003).

3.2. Case Study

The performance of the VAC was evaluated in three case studies with different traffic compositions and volumes as follows:

- Case 1. Traffic flow is constant during a one-hour period.
- Case 2. Traffic flow is varies, every 15 minutes the traffic changes.
- Case 3. Traffic flow used is based on real data from Sutomo-Diponegoro signalised intersection in the city of Surabaya-Indonesia.

The traffic composition and set of traffic volume for all case studies are presented in Tables 1 and 2.

3.3. Study Methodology and Results

3.3.1. Vehicle Actuated Controller System D

The VAC System D was developed using VAP language. This controller was analysed on an isolated four-way intersection, East-West and North-South without turning movements as seen in Figure 1. The effect on vehicle delay of variations in extension time was studied for a variety of traffic conditions. The traffic composition and set of traffic volume used for the simulation studies are presented in Tables 1 and 2. To produce the output of average delay of vehicles, each simulation was run for

Distance Between Stop line and Detector (metre)	Minimum Green Time (second)
12	8
18	10
24	12
30	14
40	18

Table 4. Minimum green time as a function of distance

Cases	Average Delay of Vehicles (second)							
	Scheme 1				Scheme 2			
	ET = 3.0	ET = 3.5	ET = 4.0	ET = 4.5	ET = 3.0	ET = 3.5	ET = 4.0	ET = 4.5
1a	11.1*	11.1*	11.1*	11.1*	11.1*	11.1*	11.1*	11.1*
1b	13.5	13.5*	13.5	13.5	12.8	12.9	12.9	12.6*
1c	15.3	15.5	15.6	15.1*	14.9	14.8*	15.1	14.9
1d	18.0	17.9	17.9	17.5*	17.5	17.5	17.4	17.4*
1e	22.1*	22.9	22.8	22.9	22.4	21.8*	22.7	22.7
1f	15.6*	15.6	15.7	15.7	15.7	15.4*	15.4	15.4
1g	18.6*	18.9	19.2	19.6	18.4*	19.1	18.8	19.3
1h	23.2*	24.0	23.4	23.6	23.0*	23.2	23.8	24.1
1i	32.6	32.4	34.9	32.3*	32.6	33.6	32.2*	33.7
2a	16.1*	16.1*	16.1*	16.1*	16.1*	16.1*	16.1*	16.1*
2b	23.5*	24.8	25.0	24.2	23.8*	24.1	24.8	24.3
2c	25.1	25.0	24.9*	25.5	24.9	24.8	24.5*	26.0
2d	29.7	30.3	29.5*	30.2	29.5	30.4	28.3*	30.0
2e	34.5	34.1*	34.8	35.0	33.7*	34.8	35.2	34.7
2f	23.1	22.1*	25.0	25.1	21.7	20.6*	21.4	23.2
2g	27.9*	29.5	29.0	28.8	28.5	29.0	27.9*	28.8
2h	35.6	35.2*	39.0	35.9	35.5*	36.5	35.8	36.4
2i	48.3	47.3	45.7*	47.1	47.3	47.7	46.9*	46.9*
Real	22.6*	22.9	23.4	22.7	21.8*	22.3	22.3	22.8

ET: Extension Time (seconds)
* : the lowest average delay of vehicles

approximately one-hour. The minimum green time for each phase was 7.0 seconds. An extension value of 1.4 - 1.5 or 1.6 seconds is often used for System D; this value will provide a useful gap change for most junctions (Simmonite, 2005). In order to obtain the most appropriate extension time for mixed traffic with a high proportion of motorcycles, the extension time of 1.2, 1.4 and 1.6 seconds will be tested for comparison. In this study, the maximum green time for each phase was determined by calculating the green time at FT control and multiplying by a factor of 1.5 (Roess, et al, 1998).

The effect of motorcycles to the performance of the VAC System D was also investigated. Two schemes were carried out to observe it, namely:

- Scheme 1. Detector detects all vehicle types (DfT, 2006).
- Scheme 2. Detector detects all vehicle types, apart from motorcycles.

Table 3. The average delay of vehicles at the intersection in one-hour simulation time for the VAC System D with different extension time

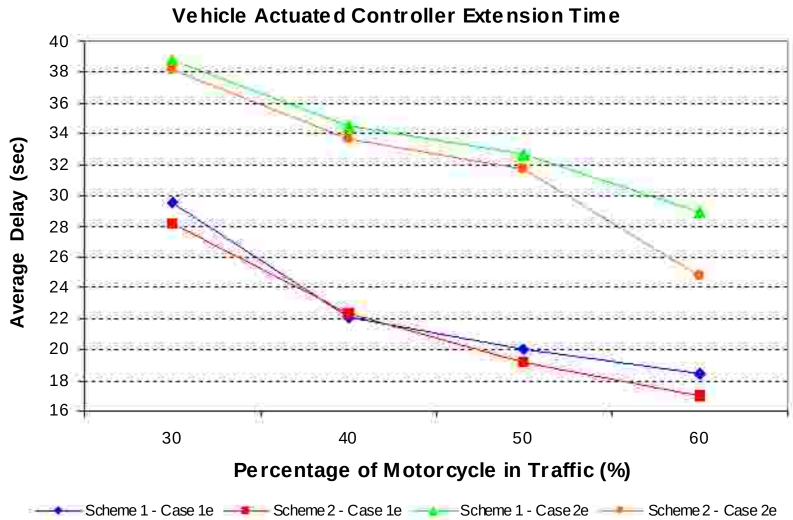

Figure 4. Effect of motorcycles to VAC Extension Principle performance

Table 3 illustrates the simulation results of the VAC System D with different extension time with schemes 1 and 2, in terms of the average delay of vehicles at the intersection in one-hour simulation time, for different case studies. The simulation results show that generally, the VAC System D using extension time of 1.2 seconds produces better performance than using extension time of 1.4 and 1.6 seconds for both schemes.

The difference in average delay between schemes 1 and 2 is small, typically less than 1 second. In general, the average delay of scheme 2 is lower than the average delay of scheme 1. To see the effect of motorcycle on the performance of the VAC System D, simulation runs were carried out with different percentages of motorcycles in traffic, namely 30%, 40%, 50% and 60%. Cases 1e and 2e were used for the case study. Figure 3 shows average delay varies with percentage of motorcycle in traffic. The difference in average delay between schemes 1 and 2 tended to increase as the percentage of motorcycles in traffic increased. The average delay of scheme 2 is lower than the average delay of scheme 1 for all cases.

3.3.2. Vehicle Actuated Controller Extension Principle

The VAC Extension Principle was developed using VAP language and analysed on an isolated intersection, East-West and North-South without turning movements as seen in Figure 2. The extension time is a function of detector position (Bullen, 1989). In order to obtain a good performance of the VAC Extension Principle, various extension times were tested for different detector locations. The detector locations used were 12, 18, 24, 30 and 40 metres from junction (Kell and Fullerton, 1991; Roess, et al, 1998). The extension time of 3.0, 3.5, 4.0 and 4.5 seconds were tested for comparison on each detector location. Simulation runs for a variety of traffic conditions were carried out similar to that in Section 3.3.1. The minimum green time for various detector locations were used as seen in Table 4 (Kell and Fullerton, 1991; Roess, et al, 1998). The calculation of the maximum green time was similar to that in Section 3.3.1. Two schemes were made to see the effect of motorcycles to the performance of the VAC Extension Principle.

Table 5. The average delay of vehicles at the intersection in one-hour simulation time for the VAC Extension Principle with detector position of 30 m and different extension time

The simulation results show that the VAC Extension Principle with detector position of

30 metres and extension time of 3.0 seconds produces the lowest average delay in most cases. Table 5 shows the average delay of vehicles at the intersection in one-hour simulation time for the VAC Extension Principle with detector position of 30 metres and different extension time. In general, the controller with extension time of 3.0 seconds produces better performance than using others extension times for both schemes. This finding is slightly shorter than that in current practice where the extension time for detector position of 30 metres is 3.5 seconds (Roess et al, 1989).

The simulation results indicate that the difference average delay between schemes 1 and 2 is small, generally less than 1 second. The average delay of scheme 2 is lower than the average delay of scheme 1 in most cases. Similar to that in case the VAC System D, a number of simulation runs were carried out with different percentages of motorcycles in the traffic, to observe the effect of motorcycles on the performance of the VAC Extension Principle. The simulation results reveal that the difference in average delay between the schemes 1 and 2 tended to increase as the percentage of motorcycles in the traffic increased (see Figure 4). In general, the average delay of scheme 2 is lower than the average delay of scheme 1.

3.3. Conclusions

The performance of the VAC depends on several critical parameters including the detector position and the settings for the timing variables. In this study, the analysis of traffic delay at an actuated traffic signal as it relates to detector position and the setting for vehicle extension was carried out. The simulation results show that the VAC System D using extension time of 1.2 seconds and VAC Extension Principle with detector position of 30 m and extension time of 3.0 seconds produced better performance. The finding of this study is similar to that in Bullen (1989), where the VAC Extension Principle with detector location of 30 m gave the best

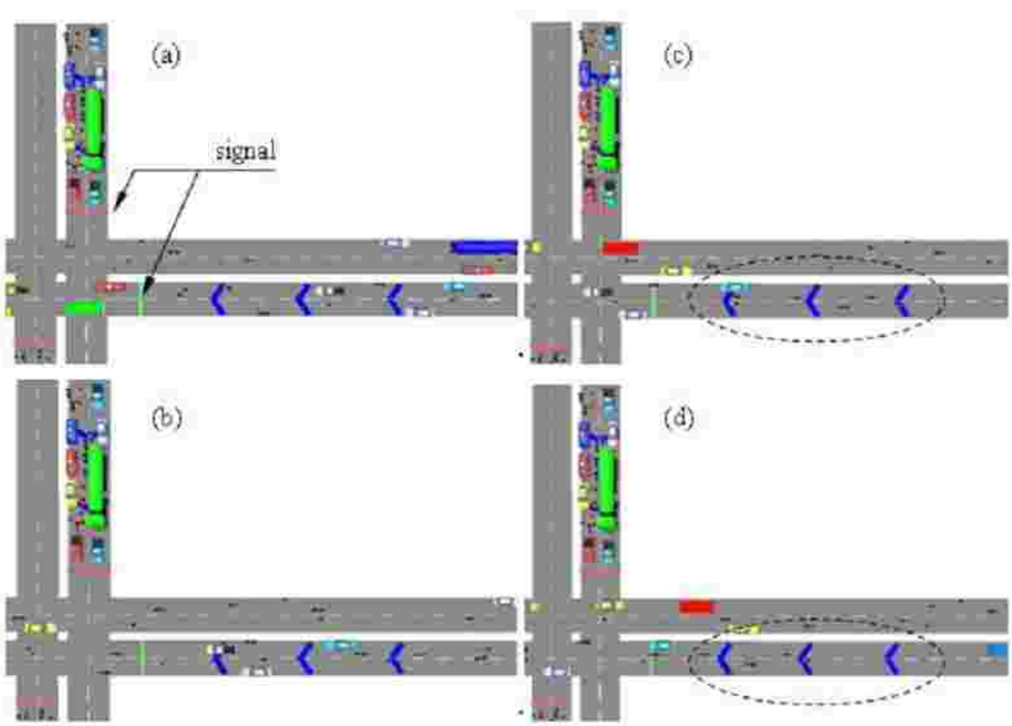

Figure 5. Time gap within the VAC System D

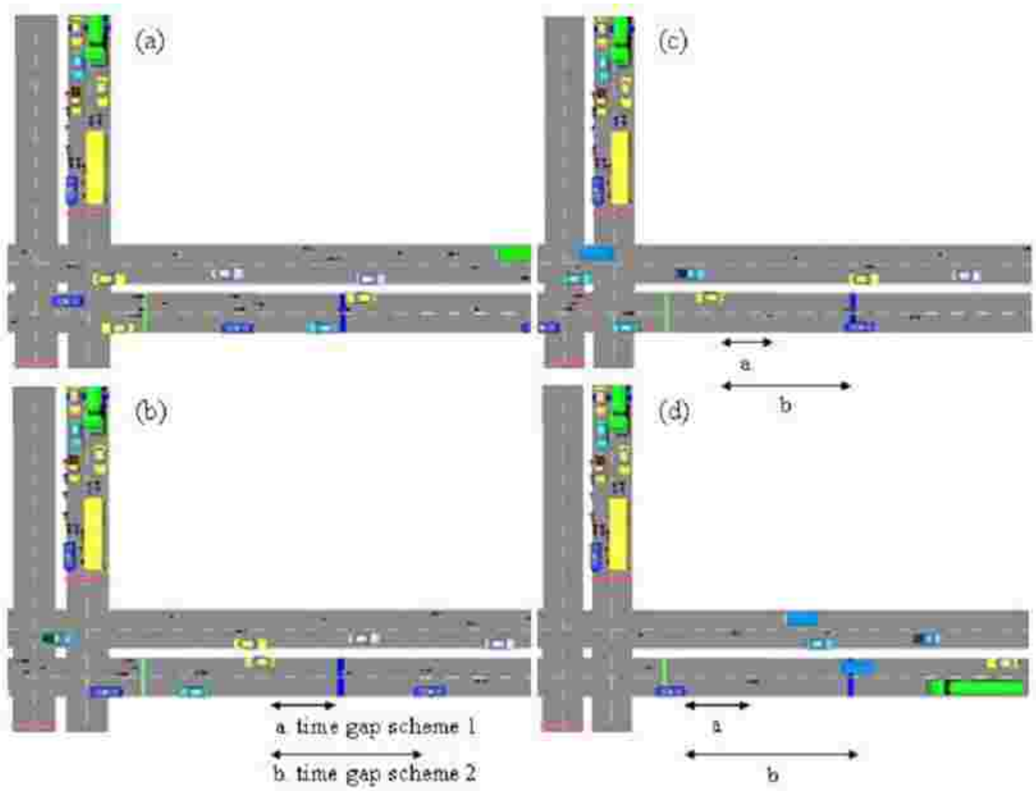

Figure 6. Time gap within the VAC Extension Principle

controller performance in term of average delay. Generally, it is recommended that the extension time should be set as short as practical to give snappy signal operation (Bullen, 1989; Kell and Fullerton, 1991). The results of these studies of the extension time show the consistency with this recommendation.

The effect of motorcycles on the performance of the VAC System D and VAC Extension Principle were also investigated. The simulation results indicate that the performance of the controllers with scheme 1 is worse than with scheme 2. The difference in average delay between schemes 1 and 2 tended to increase as the percentage of motorcycles in traffic increased. The reason why the scheme 1 is worse than scheme 2 can be explained as follows. The existence of motorcycles in traffic cause the gaps between vehicles to become shorter, due to motorcycle being able to move into any position across the available lane and squeeze between two vehicles moving side-by-side or two successive vehicles moving in the same lane. These phenomena cause the controller to extend the green time inefficiently when traffic is flowing at considerably less than full saturation rate.

Simulation studies show those facts as seen in Figures 5 and 6 that with scheme 1 the controller extends the green time continuously, due to the time gap between vehicles always being lower than the extension time, until it reaches its maximum green time value. The green time adjusted by the controller is long and inefficient. This, therefore, leads to increased delay of vehicles.

In case of the VAC System D, with scheme 1 the controller keeps extending the green time as long as the detector still detects vehicles (including motorcycles) during the extension time (see elliptical dash in Figures 5c and 5d). This will be not the case with scheme 2 where the detector does not detect motorcycles. With this scheme, the controller will terminate the green time as soon as the detectors do not detect any vehicle on the expiry of the last extension. Thus, the green time will be adjusted as efficiently as possible by the controller.

In case of the VAC Extension Principle, the time gap between vehicles with scheme 1 is shorter than with scheme 2. With scheme 1, the controller tends to adjust the green time inefficiently. For example as seen in Figures 6b to 6d, the controller continue to extend the green time due to the time gap (a) being lower than the extension time. This may not occur with scheme 2, in which the controller will terminate the green time due to the time gap (b) being greater than the extension time.

With scheme 1, the higher percentage of motorcycle in traffic more higher the probability of short gaps produced by the detector. This then caused the controller to more frequently adjust its green time inefficiently.

Reference

Bullen, A.G.R. (1989) Effects of Actuated Signal Settings and Detector Placement on Vehicle Delay, Transportation Research Record 1244, pp. 32-38.

DfT (2005) TR 2500: Specification for Traffic Signal Controller, Department for Transport, London.

DfT (2006) General Principles of Traffic Control by Light Signals Part 2 of 4, Traffic Advisory Leaflet 1/06, Department for Transport, London.

Kell, J.H., Fullerton, I.J. (1991) Manual of Traffic Signal Design – Chapter 7: Detectors, Institute of Transportation Engineers, Prentice Hall, Englewood Cliffs, New Jersey.

Lee, J.H., Lee, K.M., Leekwang, H. (1994) Fuzzy Controller for Intersection Group, International IEEE/IAS Conference on Industrial Automation and Control, Taipei, Taiwan pp. 376-382.

McLeod, F.N., Hounsell, N.B, Rajbhandari, B. (2004) Improving Traffic Signal Control for Pedestrians, 12th IEE International Conference on Road Transport Information and Control, April, pp. 268-277.

Roess, R.P., McShane, W.R., Prassas, E.S. (1998) Traffic Engineering, Prentice-Hall Inc., New Jersey.

Simmonite, B. (2005) An Introduction to Traffic Signals, JCT Consultancy Ltd.

Trabia, M.B., Kaseko, M.S. (1996) A Fuzzy Logic Controller for a Traffic Signal, IASTED International Conference on Applications of Control and Robotics, pp. 117-122, Orlando, Florida, January 1996.

Yulianto, B. (2003) Application of Fuzzy Logic to Traffic Signal Control Under Mixed Traffic Conditions, Traffic Engineering and Control, International Journal of Traffic Management and Transportation Planning, Vol.44, No. 9, November, pp. 332-336.