Optimization of Traffic Signal Time and Coordination for Road Network with Oversaturated

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Abstract

The increase in road user in terms of delay on peak hours in Vientiane Capital Lao PDR, intersections in Vientiane Capital demanded a traffic control scheme. Most road condition in Vientiane Capital City were 4 lanes 2 directions, 3.25m inner lane width and 2.75m outer lane (slow down lane) width that's narrow. On the working day, the most of road user need to go ahead and made traffic jam finally. Existing of the traffic signal time and green phases were not matching within the traffic volume on each direction which it was shown in the cycle length in the intersections, such as some green phase was too sort, and other too long that's made a queue. The cases of these problems were bad of traffic control and management system. The Webster Methodology in Traffic Engineering was presented to estimate traffic movement. A queuing system is used to generate the performance of traffic flow. And a Webster theory is applied to calculate the optimal length of each phase of the cycle. The aims of research including of the traffic volume at the intersection, optimization of traffic signal time, signal coordination and traffic management. The optimal cycle length was 100 second, and two-phasing permit better than one-phasing permit, and if improved the existing of traffic signal system and traffic management by linking of traffic signal each intersection to make the traffic condition will be better.

Keyword: Traffic volume, Optimization of Traffic Signal, Signal Coordination

Introduction

Intersections are critical areas in the effective use of streets and highways. In-depth studies show that they are focal point of conflicts and congestion at road crossings. By definition, an intersection is the place where two or more highways meet and provides an area for the cross movement of vehicle traffic (Flaherty CAO, 1976; Craig & Steve, 2008 cited in Chikezie, 2011). The efficiency, speed, cost of operation and capacities of an intersection are dependent upon its design. The primary operational function of an intersection is to permit a change in travel route. Hence, it becomes a point of decision for motorist. Highway designers must recognize the problems of a driver passing through an intersection and make driving as simple as possible by the use of good control scheme and geometric design (Federal Highway Administration Office of Research and Development, 1976; Khanna & Justo, 2001). The essential elements of an intersection are resolving conflicts, providing main core areas, channeling and controlling traffic into clear paths and permitting entry and exit to and from stream safety at correct speeds and angles. As the frequency and severity of conflicts increase, regulation and control become more necessary. To a considerable extent the design of a control scheme for an intersection is covered

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by traffic demands, physical factors, and land use, economic and environmental consideration. The proper compromise is a decision to be made by the designer.

Study Areas

For the purpose of this study the three intersections of study are from Patuxay to Hatsady Rd (S1 = 550m), from Hatsady Rd to Khuvieng Rd (S2 = 155m), and Khuvieng Rd to Samsenthai Rd (S3 = 158m) at Lane Xang Avenue. The intersections are controlled by traffic controll and traffic wardens. Commercial buildings are found very close to the intersections. The map of the study area is shown in figure 1.

The compound nature of the two intersections i.e. S1, S2 and S3 could be seen in the high level of traffic density, traffic conflicts which include merging, diverging and crossing. All these inhibit free movement and thereby reducing the level of service of the intersections. The importance of delay could be looked at in terms of the road users' times. These times in the three intersections are in the form of time wasted by the road users, additional fuel consumed by motor vehicles slowing down and/or stopping and accelerating again, grades which are steeper, additional motor vehicles running cost and traffic accident costs. These have cumulative adverse effect on individual and the government. The government has used on manual control through the traffic wardens (i.e. the peak hours) and the delays in three intersections which are controlled by unco-ordinated traffic wardens. Conflicts between opposing flows of traffic streams cause a major delay. The delay at the three intersections cannot be completely eliminated but can be improved upon (Ogundare, 1987). Thus, a designed traffic signal is to be established to minimize the delays for the critical conditions (a-4 leg and a T - Junction) at these intersections.

Objectives

The objective of this research would be to develop a methodology for calibrating microscopic traffic simulation models using real data. The focus is placed upon the following:

1. explored the traffic volume at the intersections, for a period of 14 hours and counting of the vehicle entering to the intersection every 15 minutes.
2. Classified by 6 vehicle type i.e. motorcycles, cars/pickup/van, mini buses, jumbo/toktok, buses, and light trucks/medium trucks/heavy trucks.
3. Explored the optimization of traffic signal.
4. Signal coordination

Method

The number of vehicles entering the intersections every hour, from each approach, for a period of 14 hours and counting of vehicle every 15 minutes, from each approach, for the peak period in the morning and in the afternoon. Classified by 6 vehicle types such as motorcycles, cars/pickup/van, mini buses, jumbo/toktok, buses, and light trucks/medium trucks/heavy trucks.

Design of Traffic Signal at an intersection

Cycle length of signals

Webster Method, Webster has shown that for a wide range of practical conditions minimum intersection delay is obtained by the equation 1

$$C_0 = \frac{1.5\,L + 5}{1 - \sum_{i=1}^{\emptyset} Y_i} \quad (1)$$

Where

C_o = optimum cycle length (sec)

L = total lost time per cycle (sec)

Y_i = maximum value of the ratio of approach flow to saturation flow for all lane groups using phase i (i.e., q_{ij}/s_j)

Ø = number of phases

q_{ij} = flow on lane groups having the right of way during phase i

s_j = saturation flow on lane group i

Total Lost time

$$l_i = G_{ai} + \tau_i - G_{ei} \quad (2)$$

Where

L_i = lost time for phase i

G_{ai} = actual green time for phase i (not incluid yellow time)

τ_i = yellow for phase i

G_{ei} = effective green time for phase i

$$L = \sum_{i=1}^{\emptyset} l_i + R \quad (3)$$

Where

L = total lost time

R = is the total-red time during the cycle

Allocation of Green times

In general, the total effective green time available per cycle is given by

$$G_{te} = C - L = C - \left(\sum_{i=1}^{\emptyset} l_i + R\right) \quad (4)$$

Where

C = actual cycle length (usually obtained by rounding of Co to the nearest five seconds

G_{te} = total effect green time per cycle

To obtain minimum total delay, the total effective green time should be distributed among the different phase in proportion to their Y values to obtain the effective green time for each phase.

$$G_{ei} = \frac{Y_i}{Y_1 + Y_2 + \cdots Y_i}\; G_{te} \quad (5)$$

And the actual green time for each phase is obtain as

$$G_{a1} = G_{e1} + l_1 - \tau_1$$
$$G_{a2} = G_{e2} + l_2 - \tau_2$$
$$G_{ai} = G_{ei} + l_i - \tau_i$$
$$G_{a\emptyset} = G_{e\emptyset} + l_\emptyset - \tau_\emptyset \quad (6)$$

Minimum Green Times

The minimum green time can be determined by using the HCM expressions given in Eqs. 7, and 8 as below

$$G_p = 3.2 + \frac{L}{S_p} + \left[2.7\frac{N_{ped}}{W_E}\right];\ for\ W_E > 10\ ft\ (3.2\ M) \qquad (7)$$

$$G_p = 3.2 + \frac{L}{S_p} + \left[2.7\ N_{ped}\right];\ for\ W_E < 10\ ft\ (3.2\ M) \qquad (8)$$

Where

G_p = minimum green time (sec)

L = crosswalk length (ft, M)

S_p = average speed of pedestrian, usually taken as 4ft/sec (1.28M/s) assumed to present 15th percentile pedestrian walking speed

3.2 = pedestrian start up time

W_E = effective crosswalk width

N_{ped} = number of pedestrians crossing during an interval

Average delay

Average delay using the Webster's uniform delay formula (UD) given in Eq. 9 or can finding from the chart as below

$$UD = \frac{C(1-(\frac{g}{C})^2)}{2(1-(\frac{v}{s})} \qquad (9)$$

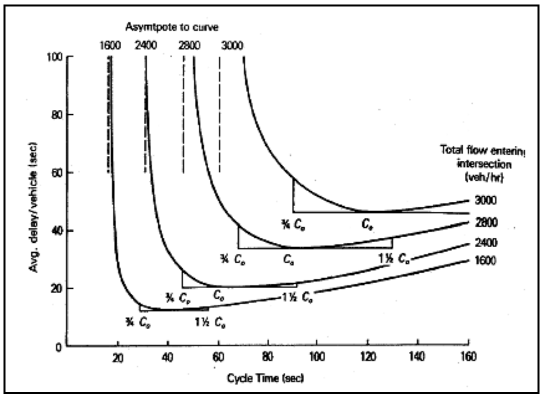


Figure 1 Webster's optimum cycle length

Offsets on a two-way street are interrelated presents one of the most fundamental problems of signal optimization. Note that inspection of a typical time-space diagram yields the obvious conclusion that the offsets in two directions add to one cycle length, for longer blocks, the offsets might add to two (or more) cycle lengths. The ideal offset to be the same as the travel times, this is not always the case. Once the offset is specified in one direction, it is automatically set in the other. The general expression for the two offsets in a link on a two-way street can be written as:

$$t_{1i} + t_{2i} = nC \qquad (10)$$

Where

T_{1i}: offset in direction 1 (link i), sec

T_{2i}: offset in direction 2 (link i), sec

n: integer value
C: cycle length, sec

To have n = 1 (figure 3.22a), $t_{1i} \leq C$; to have n = 2. $C \leq t_{1i} \leq 2C$

Any actual offset can be expressed as the desired "ideal" offset, plus an "error" or "discrepancy" term:

$$t_{actual\ (ij)} = t_{ideal\ (ij)} + e_{ij} \qquad (11)$$

Where j represents the direction and i represents the link. In a number of signal optimization programs that are used for two-way arterials, the objective is to minimize some function of the discrepancies between the actual and ideal offsets.

Analysis

The data collected and analyzed at each intersection are shoulder, median, Drainage widths and number of lanes. A sketch of the intersections is shown in figure 1

Figure 2 Intersections of study

Traffic Volume Data Analysis

The hourly count from 06.30am to 20.30pm was collected and analyzed. The analysis is shown in figures 3(a), (b) and (c). This figure shows 14-hour traffic volume at Lane Xang Avenue (Patuxay to Hatsady Rd (S1 = 550m), from Hatsady Rd to Khuvieng Rd (S2 = 155m), and Khuvieng Rd to Samsenthai Rd (S3 = 158m)).

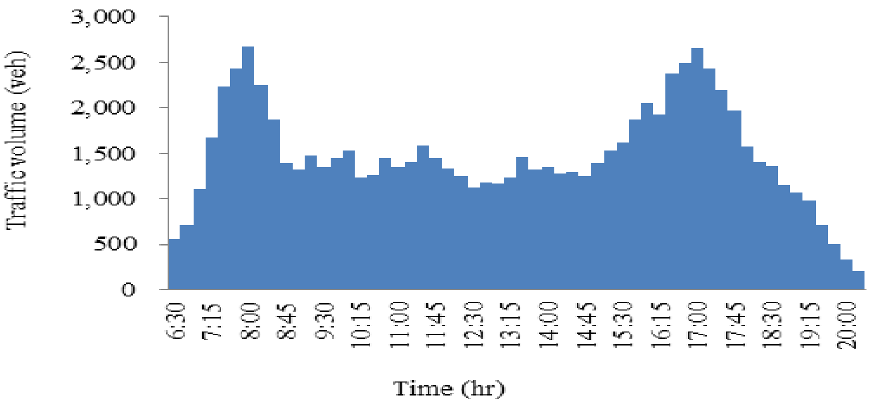


Figure 3 Intersections of study (P_1)

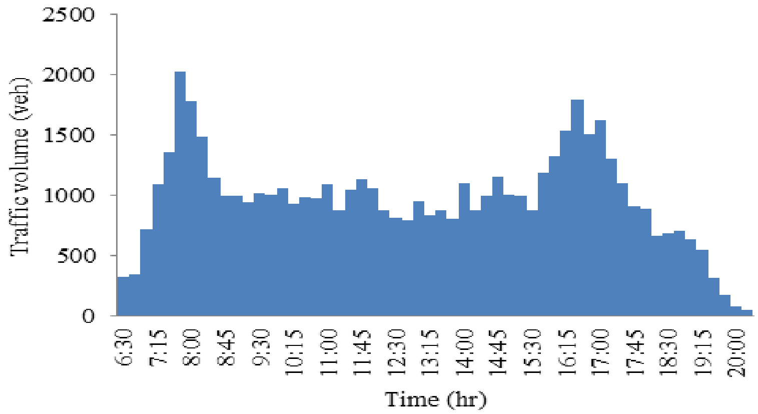


Figure 4 Intersections of study (P_2)

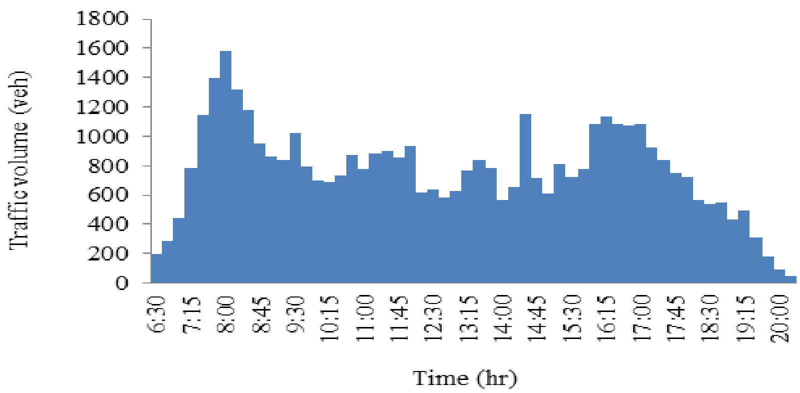


Figure 5 Intersections of study (P_3)

Average Daily Traffic (ADT) of the intersections

The average daily traffic is the number of vehicles that pass a particular point on a roadway during a period of 24 hours consecutive hours averaged over a period of 365 days. The volume collected for 14 hours (V14) in passenger car unit pcu is made use as shown in table 1.

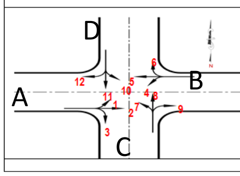
Table 1 This table shows the average Daily Traffic (ADT) of the intersections

P_1: Intersection
V1 = 82,780 veh
ADT =82,780 x 1.12 = 92,714 veh/day
P_2: Intersection
V12 =54,617
ADT =54,617 x 1.12=61,171 veh/day
P_3: Intersection
V3 =42,986
ADT =42,986 x 1.12=48,144 veh/day

Results and Discussion

Traffic volume

From the analysis, it was clear that the three intersections operate at a low level of performance. Hence, the intersections warrant some forms of control scheme for better operation. The peak hour traffic flow was analyzed. The graphic summary of the peak hour traffic flow band at all intersections are shown in figure 3a, 3b, and 3c. And the volumes at P1 on direction 8, 10, 11 are 13,113, 13,059, and 20,968 veh. For the volume at P2 and P3 on directions 2, 5, 11 and 1, 6, 7 are 10,445, 7,980, 9,486 and 11,895, 12,405, and 6,483 respectively.



Location	Direction	Vehicle Class						Total
		Motorbike	Car/pickup/ van	Medium size bus	TukTuk-Jumbo	Bus	Light/heavy truck	
	1	3,162	3,053	49	48	10	9	6,343
	2	2,370	1,188	3	276	2	85	3,960
	3	276	234	0	17	0	18	556
	4	880	1,230	22	6	0	14	2,162
	5	3,913	2,925	3	478	5	452	7,833
	6	655	441	10	11	1	19	1,147
	7	1,409	2,088	8	21	2	20	3,553
	8	5,362	7,441	37	11	9	154	13,113
	9	1,395	1,787	65	28	5	5	3,333
	10	6,976	5,843	111	36	55	26	13,059
	11	10,880	9,860	145	65	1	10	20,968
	12	3,369	3,157	33	73	3	87	6,753
Total		40,647	39,247	486	1,070	93	899	82,780

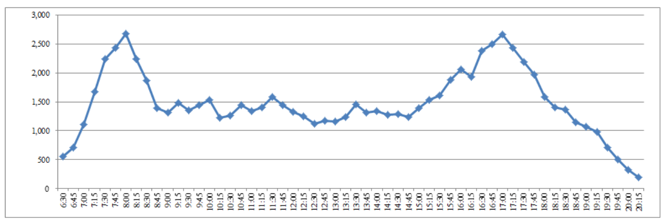
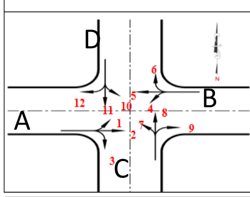


Figure 6 Intersections of study (P_1)



Location	Direction	Vehicle Class						Total
		Motorbike	Car/pickup/van	Medium size bus	TukTuk-Jumbo	Bus	Light/heavy truck	
	1	1,278	1,339	28	25	2	59	2,731
	2	3,833	6,823	79	6	12	144	10,945
	3	1,264	826	56	52	18	12	2,540
	4	1,587	1,295	30	11	0	71	3,007
	5	2,661	5,030	32	2	16	164	7,980
	6	1,010	1,322	16	21	1	16	2,512
	7	506	442	43	15	1	2	1,014
	8	3,936	1,559	244	794	24	32	6,641
	9	748	972	10	6	1	6	1,798
	10	1,568	1,923	8	4	3	53	3,588
	11	5,343	3,404	154	442	40	10	9,486
	12	889	1,430	1	1	2	20	2,375
	Total	24,623	26,365	701	1,379	120	589	54,617

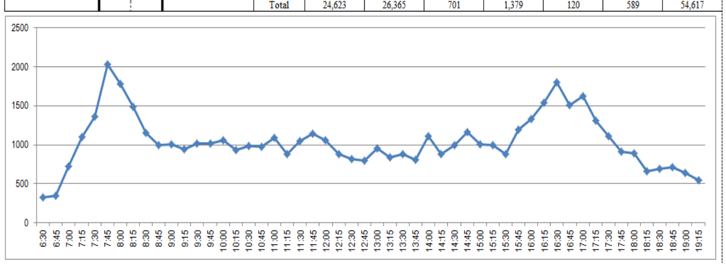
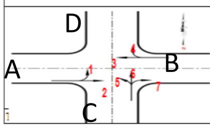


Figure 7 Intersections of study (P_2)



Location	Direction	Vehicle Class						Total
		Motorbike	Car/pickup/van	Medium size bus	TukTuk-Jumbo	Bus	Light/heavy truck	
	1	61	204	19	0	0	3	381
	2	4,773	6,586	117	16	24	211	11,895
	3	2,203	3,833	42	4	11	196	6,315
	4	1,749	3,121	32	6	3	108	5,073
	5	121	166	2	0	0	1	434
	6	5,363	6,523	259	18	56	141	12,405
	7	2,556	3,456	39	34	9	233	6,483
	Total	16,826	23,889	510	78	103	893	42,986

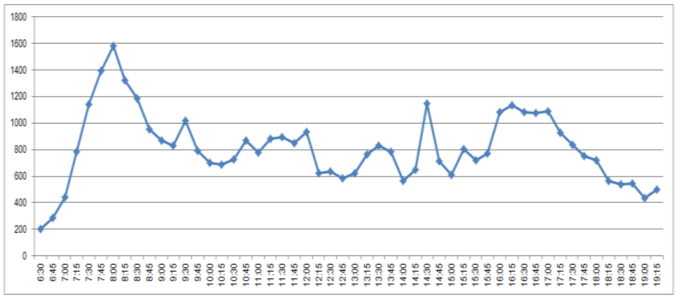


Figure 8 Intersections of study (P_3)

Traffic signal

Cycle length of signals at the intersection

Table 2 traffic volume and direction of vehicle at the intersections

Phase	Lane Group		Saturation flow	
A	1	LT	614	
	2	TH	486	
	3	RT	79	565
B	4	LT	299	
	5	TH	1,053	
	6	RT	126	1,179
C	7	LT	181	
	8	TH	1,066	
	9	RT	238	1,304
D	10	LT	1,493	
	11	TH	3,741.05	
	12	RT	1,028	4,769
			10,404	

Table 3 Signal time for the intersections using the four-phase system

Lane Group	Phase A(EB)		Phase B(WB)		Phase C(SB)		Phase D(NB)	
	1	2	1	2	1	2	1	2
Q_{ij}	614	565	299	1,179	181	1,304	1,493	4,769
S_j	10,404	10,404	10,404	10,404	10,404	10,404	10,404	10,404
Q_{ij}/S_j	0.059	0.113	0.029	0.113	0.017	0.125	0.144	0.458
$Y_{i\,=}$	0.059		0.113		0.125		0.458	

Compute the total lost time

Using Eq 2. Since there is not an all-red phase, that is, R = 0, and there four phase
L = Sum (li) = 4*3.5 = 14 sec, assuming lost time per phase is 3.5 sec

Determine Y_i and sum Y_i

Sum Yi = (0.113+0.113+0.125+0.458) = 0.76

Determine the Optimum cycle length

Using the Webster method, determine suitable signal timing for the intersection using the four-phase system as show below. Using a yellow interval of three seconds and saturation flow given

From Eq.1

$$C = \frac{1.5\,L + 5}{1 - \sum_{i=1}^{\phi} Y_i}$$

$$C = \frac{(1.5\,x\,14) + 5}{1 - 0.76} = 108\ sec$$

Use 100 second as cycle lengths are usually of 5 or 10 seconds

Find the total effective green time

G_{te} = C - L

= (100-14) = 86 sec

The effective time for the phase i obtained by from Eg. 5

$$G_{ei} = \frac{Y_i}{(0.113 + 0.113 + 0.125 + 0.458)} = 86$$

$$= \frac{Y_i}{0.76} = 86$$

Yellow time, $\tau = 3.0\ sec$, the actual green time G_{ai} for each phase is obtained from Eq. 6 as

$$G_{ai} = G_{ei} + l_i - \tau_i$$

Actual green time for phase A

$$G_{aA} = \frac{0.113}{0.76}\ \ 86 + 3.5 - 3 = 13\ sec$$

Actual green time for phase B

$$G_{aB} = \frac{0.113}{0.76}\ \ 86 + 3.5 - 3 = 13\ sec$$

Actual green time for phase C

$$G_{aC} = \frac{0.125}{0.76}\ \ 86 + 3.5 - 3 = 15\ sec$$

Actual green time for phase D

$$G_{aD} = \frac{0.458}{0.76}\ \ 86 + 3.5 - 3 = 52\ sec$$

Using the actual green time for phase A = 15 sec, phase B = 15 sec, phase C = 15 sec, and phase D = 50 sec

Check the minimum green time require for pedestrian crossing. Since W_E < 3.2M, from Eg. 8

- Crosswalk length (Phase A and B, N -S) = 12.0 M
- Crosswalk length (Phase C and D, E -W) = 7.5 M
- Speed limit on each approach = 40 km/h
- Number of pedestrians crossing all approach directions = 10 per interval in each direction

$$G_p = 3.2 + \frac{L}{S_p} + \left[2.7\, N_{ped}\right];\ for\ W_E < 10\ ft\ (3.2\ M) \qquad (8)$$

Minimum time required for (Phase A-B) = 3.2+(12/1.28)+0.27 x 1.28 = 14.7 sec
Minimum time required for (Phase C-D) = 3.2+(7.5/1.28)+0.27 x 1.28 = 11.2 sec

Average delay
From figure 1, the average delay per vehicle is 21 seconds

Summary of the signal time for all phases
Phase A: G = 15 sec, Y = 3 sec, all-R = 82 sec
Phase B: G = 15 sec, Y = 3 sec, all-R = 82 sec
Phase C: G = 15 sec, Y = 3 sec, all-R = 82 sec
Phase D: G = 50 sec, Y = 3 sec, all-R = 47 sec

The existing of cycle length and green phases were very bad situation, firstly, optimal of cycle length each intersection were not related to the traffic volume direction, such as some intersections the green time of cycle were too long, but some intersections were too sort, and the second, the most of phasing permit on one-direction or one-phasing permit. Consider on the existing of traffic signal and research results shown that the two-phase permit was better.

Coordination of Intersections

Assuming no vehicles are queued at the signals, the ideal offsets can be determined if the platoon speed is known. For the purpose of illustration, a desired platoon speed of 40 km/h (11.1 m/s), 50 km/h (13.9 m/sec), and 60 km/h (16.7 m/sec) will be used. The cycle length is 100 sec, and the effective green time at each intersection is 50% of the cycle length, or 50 s. Ideal offsets are computed using Equation 10 and 11and the results are listed in Table 4, 5, and 6 respectively. According to the Lao's regulations of transport, speed limit was 40kph in urban.

Consider on the existing coordination of intersection and research results found that the traffic signal system was not connected within the each intersection or not related, but the actual speed of drivers over than 40kph or up to 60kph, so if improving the traffic management to better way, such as remade the link of all intersections by nonstop of platoon while the platoon from intersection1 reach to intersection2 and so on, the traffic condition will be better as the research results had shown in the table 4, 5 and 6.

Table 4 Ideal Offset (40 km/h)

Signal	Relation to signal	Distance (m)	Avg. speed (km/h)	Ideal offset (sec)
S1	S2	550.0	11.1	49.5
S2	S3	155.0	11.1	14.0
S3	S4	158.0	11.1	14.2

Table 5 Ideal Offset (50 km/h)

Signal	Relation to signal	Distance (m)	Avg. speed (km/h)	Ideal offset (sec)
S1	S2	550.0	13.9	39.6
S2	S3	155.0	13.9	11.2
S3	S4	158.0	13.9	11.4

Table 6 Ideal Offset (60 km/h)

Signal	Relation to signal	Distance (m)	Avg. speed (km/h)	Ideal offset (sec)
S1	S2	550.0	16.7	33.0
S2	S3	155.0	16.7	9.3
S3	S4	158.0	16.7	9.5

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