Effects of ITS Technology in Reducing Traffic Pollution and Fuel Consumption from Intersection Congestion

Weeradej CHEEWAPATTANANUWONG
Director of Data Warehouse and Service,
Department of Rural Roads,
Ministry of Transportation,
Bangkok, 10400, Thailand
E-mail: weeradej146@gmail.com

Pichai TANEERANANON
Professor,
Department of Civil Engineering,
Faculty of Engineering,
Prince of Songkla University,
Songkhla, 90110, Thailand
E-mail: 2007tao@gmail.com

Abstract: The impact of the extreme traffic congestion especially in Bangkok's Suburb has many serious consequences including road crashes at intersections caused by drivers' disobedience of the sub-optimally controlled traffic signals; the excessive waste of fuel from the long delay and very low speed during peak hours; and the air and noise pollution which have adverse effects on the health of Bangkok citizens, especially those living nearby or using highly congested intersections. This paper describes the authors' continued efforts to address the challenge of mitigating the congestion, traffic pollution and fuel consumption. A before and after study of fuel consumption of a typical passenger car, the average speed, the level of air and noise pollutions in terms of CO, PM_{10}, L_{10} using the authors' developed ITS technology and predictive models are presented. The results show that fuel consumption and pollution levels have improved after the installation of the ITS system.

Key Words: *traffic congestion**,** air pollution, fuel consumption*

1. INTRODUCTION

Traffic congestion in big cities has become a global challenge. Bangkok has been mentioned as one of the most congested cities in the 2012 BBC report, BBC (2012). The consequences of the extreme Bangkok traffic congestion are well known. They include road crashes at intersections caused by drivers' disobedience of the sub-optimally controlled traffic signals; the excessive waste of fuel from the long delay and very low speed during peak hours; and the air and noise pollution which have adverse effects on the health of Bangkok citizens. Many researchers have attempted to put a cost on the congestion in Bangkok, among them include a study by Shibata who put the total annual social costs of congestion including motor vehicle fuel consumption, time loss, and health damage at 59.13 billion Baht（$US 1,847 million), Shibata (2013). It seems he used the 1995 traffic and population data for the estimate. A recent review of Bangkok traffic congestion put the figure at 200 billion Baht (US$ 6,667 million), OTHPF (2012). It is clear that the congestion challenge needs to be addressed by all available measures including engineering. The authors has over the past years developed an ITS technology to address Bangkok congestion. A description of the system is briefly described in the next section together with its previous applications in intersection crash reduction. The focus of the paper is on the study of traffic pollution (air and noise) and fuel consumption after the application of the technology.

In previous studies, the authors show that after the installation of the ITS technology, the number of accidents especially those relating to disobedience of traffic signal, speeding and lane changing at intersection decrease dramatically. The follow-up show that there were 3 crashes from drunk driving, but none from violation against traffic law, Cheewapattananuwong *et al.* (2011), Cheewapattananuwong and Taneerananon (2012). Figure 1 shows a typical crash from speeding and abrupt lane changing prior to the application of the technology.

Figure1. Road crash caused by abrupt lane changing lane speeding

The next section gives a description of the ITS technology which has been shown to be effective in reducing intersection delay and giving out warning to drivers not to break the traffic rules.

2. **THE ITS TECHNOLOGY**

2.1 The Adaptive Traffic Signalization and Application to Red Light Running

The development of classified vehicle count and the management of traffic phasing and cycle times from image sensing camera have been carried out over the past 5 years. Moreover, the results of the times and number of phases are 150 seconds and 3 phases for the 3- leg and 90 seconds and 2 phases (local people prefer driving under these phases) for the 4- leg intersection respectively. The use of open source – coding from the http://ubaa.net/shared/processing/opencv/-website allows passing vehicles to be detected and counted when they pass through a rectangular box or a virtual loop. Processes of the system entails;

- Decoding from MPEG4
- Noise Reduction and Image Enhancement Techniques
- Tracking Vehicles on the Foreground / Background (FG/BG) detection by the deleted images between FG and BG

Figure 2.FG and BG and Vehicles on FG Detection Technique

Other components of the system include Blob Entering Detection Techniques, Virtual Detector, whose role is to function as a loop detector as well as a traffic volume and classified vehicle counter using java script- computer language. During peak hour, headways of vehicles passing through the virtual loop are within 5 seconds and the characteristic of traffic flow is steady state –steady flow. Therefore, the cycle times is extended up to maximum green times which are obtained from the calculation using the software SIDRA and Synchro, SIDRA (2000) and Synchro (2003). For two adjacent intersections, the offset times -phase or green wave –phase are proposed for the vehicles passing from one intersection to the other. The offset times were calculated based on the method of ARRB - Australian Road Research Board, ARRB (1989). More details are described in Cheewapattananuwong and Taneerananon (2012).

2.2 The Image Sensing Concept and Application to Controlling Speed and Lane Changing Behavior

Coordinate (x,y) is evaluated from the pixels frame by frame in the avi.file. In addition, the process of angle and length calibration is also taken into consideration. The calculation of speed depends on the time-frame. Moreover, the reference points of coordinates (x_1,y_1) and (x_2,y_2) (as shown in Figure 3) are marked as the standard length (1 meter) in the software. The VDO frames are applied with the Blob functions and the first and last frames are checked for the positions and length**.** In case of time frame, the absolute values of (t_2-t_1) which are more than threshold values (checking status of moving vehicle) are taken into account.

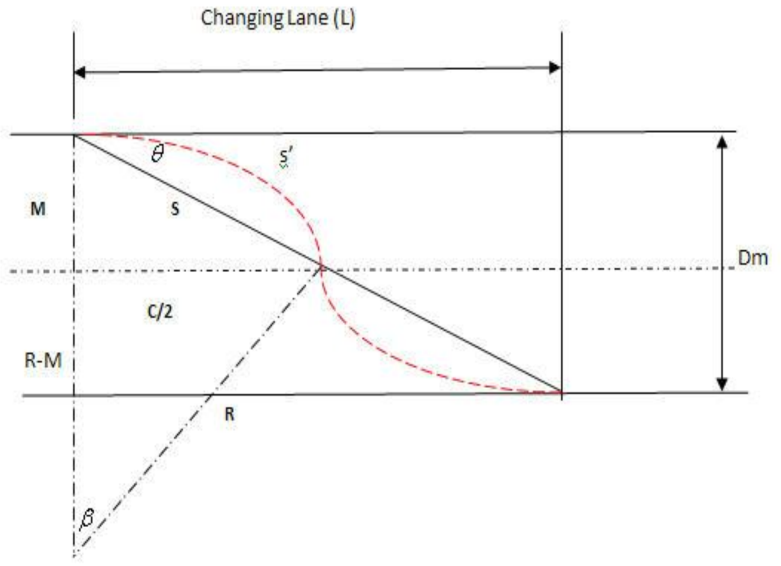

Figure 3.Two Circulars represent the Changing Lane Part of vehicle

The virtual loop at the camera has three functions: to do classified traffic count, to check the angle of vehicle movement while changing lane, and to measure the gap of vehicles and speed. The traffic flow images from CCTV are classified and sent signals to a server (New Traffic Signalization – Software) which can then evaluate the optimum signal phases and cycle times for the traffic light at the intersections. Moreover, the virtual loop concept and the traffic synchronization with offset time concept are taken into account. As the vehicle length and height can cause errors in the classified results; corrective steps need to be made as described in Cheewapattananuwong *et.al* (2011), and Cheewapattananuwong and Taneerananon (2012). In the near future, the vehicle classification and the new traffic signalization software will be applied in the Embedded Card of CCTVs. Therefore, the cost of system will decrease owing to the reduction of encoding and decoding equipments.

2.3 The Hybrid Model

The model is built on traffic engineering concept, speed and lane changing behavior control concept, traffic pollution concept and fuel consumption concept. The integrated system is essential part of the ITS system. The 5 software concepts are as follows:

1. Classified Count and PCU by Image Sensing
2. Traffic Management and Adaptive Traffic Signalization
3. Controlled Speed and Changing Lane
4. Traffic Pollution such as, Noise and Air Pollution
5. Fuel Consumption

The whole systems are further described in Figures 4 and 5.

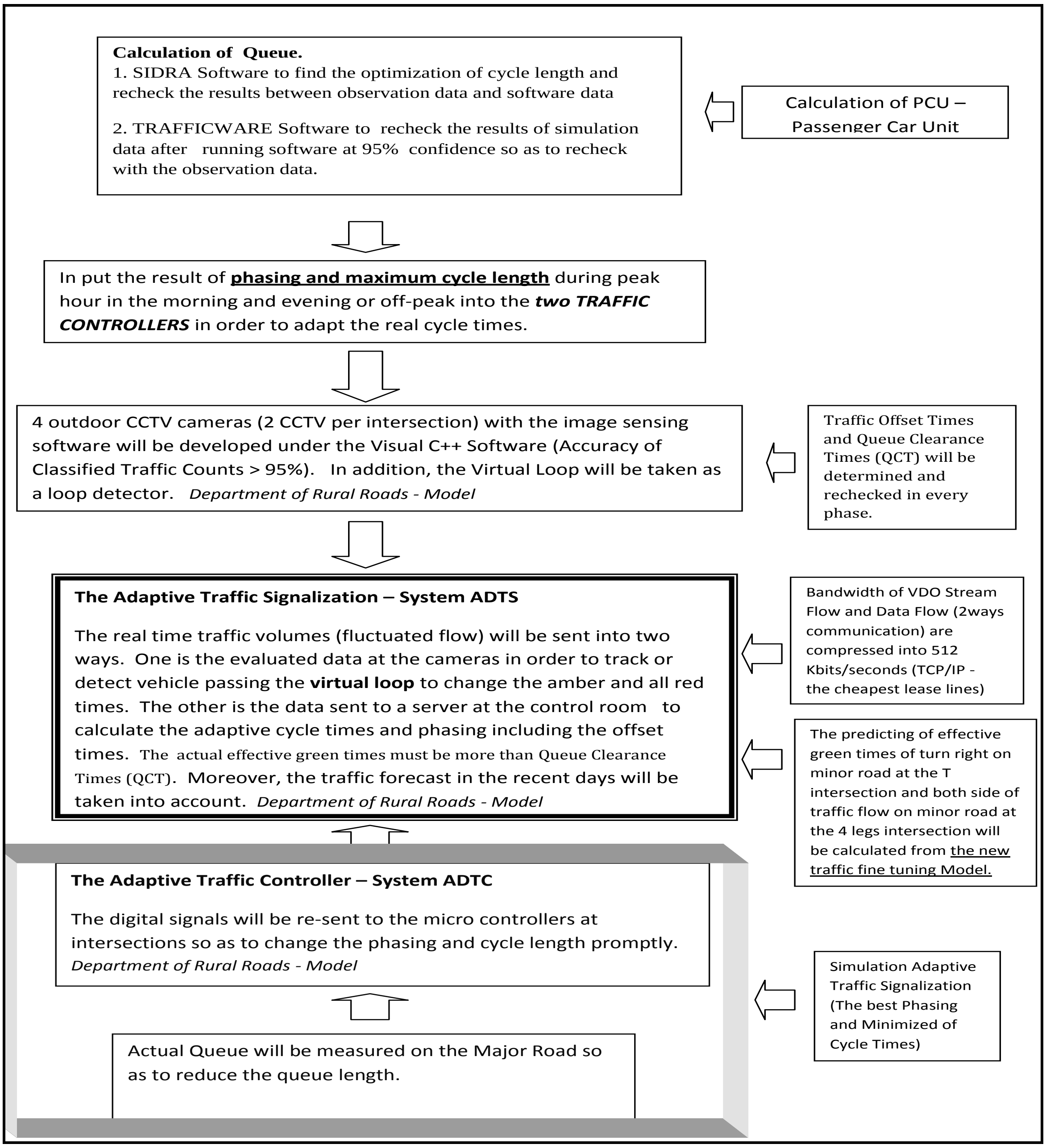

Figure 4.Adaptive Traffic Signalization Model (ADTC)

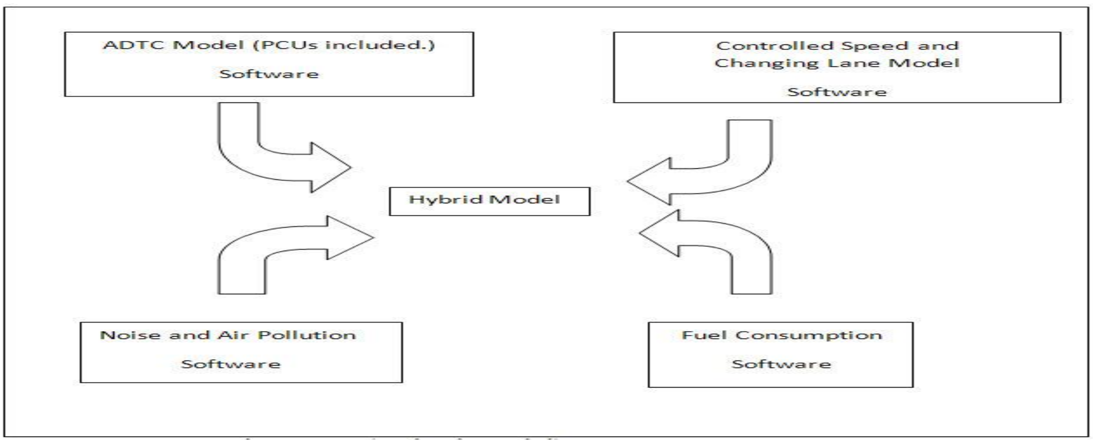

Figure 5.Hybrid Model

The system is composed of several elements such as, Adaptive Traffic Signalization Diagram, CCTV Cameras, Router, M-Peg4 Encoder, IP Converter, Telecommunication Line, and Virtual Loop Detector Concepts, PCU Factor, and Optimum Phasing and Cycle Times. Furthermore, the 5- developed software were applied and evaluated for the traffic systems in the pilot intersections.

2.4 Engineering Concepts used in the System

The following concepts are used in the development of the software to apply in the ITS technology. They are presented in the following 9 equations, Cheewapattananuwong and Taneerananon (2012).

2.4.1 PCU Concept

$$PCU_x = \frac{q_{car} - \ldots / (WL)}{q_x - \ldots / (WL)} \quad (1)$$

Where,

$PCUx$: Passenger Car Unit for x vehicle
$q_{car-\ldots}$: Traffic flow rate (number of PC's per hour) of PC following PC or PC following other types of vehicles
$q_{x-\ldots}$: Traffic flow rate (number of vehicles per hour) of other types of vehicles following other types of vehicles
WL : Lane width per direction

PCU formula is used to calculate traffic volumes to input into aaSIDRA and Synchro programs. The calculated PCU are 1.00 for Passenger Car, 0.70 for Motorcycle, 2.07 for Light Truck, 3.16 for Bus, and 3.82 for Truck. These PCU will be calculated with traffic volumes so as to *input in* SIDRA and Synchro.

2.4.2 Arrival Rate (PCU-M/min) and Average Headway concepts

In case of Arrival Rate (PCU-M/min), the standard lengths of each type of vehicle of vehicles are 2.5 m for MC, 6.0 m for private car, 12.0 m for van, 15.0 m for bus, and 12.0 for truck.

$$Ave.Spac. = \lambda * Ave.Hw \quad (2)$$

Where,

$Ave.\ Spac.$: Average Spacing (m)
λ : Arrival Rate (PCU-M/min)
$Ave.\ Hw$: Average Headway (min/PCU)

$$Ave.Speed = \frac{Ave.Spac.}{Ave.Hw.} \quad (3)$$

Where,

$Ave.Speed$: Average Speed (km/hr)

Ave.Spac. : Average Spacing
Ave.Hw : Average Headway

2.4.3 Stopping Sight Distance Concept

The Stopping Sight Distance - SSD Values from the equation (4) are based on the AASHTO's Standard (1994). If the average spacing is greater than SSD, drivers will drive their vehicles safely while changing lane.

$$SSD = 0.278 \times v_f \times t + 0.039 \times \frac{v_f^2}{a} \tag{4}$$

Where,

v_f : final speed of changing lane of vehicle (m/s)
a : the acceleration (m/s^2)

$$a = \frac{v_f - v_s}{t_f - t_s} \tag{5}$$

Where,

v_s : the starting vehicle speed for changing lane (m/s)
t_s and t_f : the start and final times for changing lane (seconds)
t : the perception time which is assumed to be 2.5 seconds in this analysis.

2.4.4 Speed Density Concept

Salter, R.J. (1982) suggests that the speed density relationship is of the form,

$$Q_{max} = (d_j * v_f) / 4$$
$$Q = v_f * d - (v_f / d_j) * d \,\hat{}\, 2$$
$$v = v_f - (v_f / d_j) * d \tag{6-8}$$

Where,

Q_{max} : the maximum flow rate per lane
v_f : the free speed
d_j : the jam density; when stationary, vehicles are spaced at an average distance headway of 4.578 metres. Thus, the jam density is 436.87 veh/km, 2veh* (1000 m/km / 4.578 m)
d : the density
v : the space mean speed

The results of calculations are shown in Table 1 and 2.

2.4.5 Queue Clearance Times (QCT) Concept

The authors have developed a new ITS technique based on the philosophy of sufficiency economy as expounded by the king of Thailand with budget saving and innovation in mind. The new ITS technology is elaborated further. PCU equivalent are calculated for traffic volumes and used for input in SIDRA and Synchro. Calculation of cycle times and phasing are used for the optimization of cycle times and identification of the best phasing. Traffic factors during peak hours including delay and queue are measured on the main road (inbound direction). After completing the calculation of actual red time, the QCT (queue clearance times –rechecking actual effective green times as shown in Figure 6) are considered. QCT (Synchro version6, 1993-2005) is calculated as:

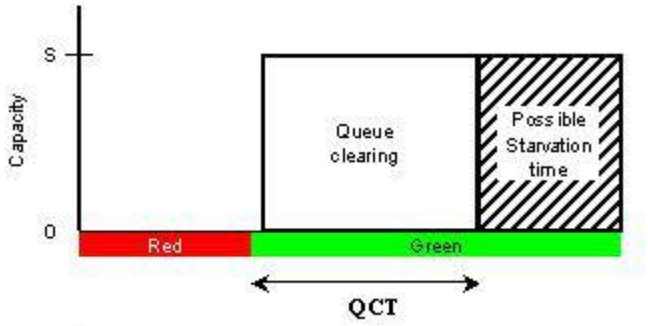

Figure 6. QCT Diagram within the Effective Green Times
(Source: Synchro version6, 1993-2005)

$$\text{QCT} = \text{SLT} + \left(\frac{(\text{PCU} - \text{eff.gr.t / lane})}{(\text{Sat Flow / lane} - \text{PCU} - \text{eff.gr.t / lane})} \right) * (\text{CLT} + \text{ART} + \text{SLT}) \quad (9)$$

Where,

Startup Lost Times (SLT) : 2.5 sec.
Traffic volumes, PCU at effective green times per lane or PCU-eff.gr.t/lane : x
Saturation flow per lane (Sat flow /lane) : 42 PCU per lane
Clearance lost times (CLT) : 3 sec.
Actual all red times (ART) : 5 sec.

Cycle times at the T and four- leg intersections decrease dramatically due to the triggers. The triggers of virtual loop detect vehicles passing through them within 5 seconds (from the calibrated headway during peak hour), otherwise the loops will signalize the controller to promptly switch from green to red phase. As a result, the displayed effective green times of each direction at the two intersections are substantially less than the maximum effective green times of the maximum cycle times as calculated by from SIDRA or Synchro. The flowchart for the adaptive traffic signalization is shown in Figures 4 and 5 (as presented above). From the results of DRR's Model, an optimization of cycle times is proposed as described in the evaluation section.

3 Results

Table 1 shows the recorded data for 1 minute interval from the Image Sensing Software. The data are analyzed to obtain the arrival rate, spacing length, headway, and average speed. Table 2 shows traffic volumes in PCU/hr/lane, free speed, density and space mean speed.

Table 1.Recorded data from the CCTVs shown the arrival rate, spacing length, headway, and average speed for one minute interval

Time	Turn Right					Thrugh					Turn Left					
	Mc	Car	Bus	LT	HT	Mc	Car	Bus	LT	HT	Mc	Car	Bus	LT	HT	Sum
15:05	4	3	0	0	0	2	0	0	0	0	1	1	0	0	0	11
15:06	0	4	0	0	0	1	0	0	0	0	1	0	0	0	0	6
15:07	0	3	0	0	0	0	1	0	0	0	0	2	0	0	0	6
15:08	1	1	0	0	0	1	1	0	0	0	1	3	0	0	0	8
15:09	0	4	0	0	0	1	1	0	0	0	0	2	0	0	0	8
15:10	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	5
15:12	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
15:13	3	2	0	0	0	1	0	0	1	0	0	2	0	0	0	9
15:14	2	3	0	0	0	1	0	0	0	0	0	1	0	0	0	7
15:15	2	2	0	0	0	3	0	0	0	0	2	0	0	0	0	9
15:16	1	2	0	0	2	1	0	0	0	0	1	0	0	0	0	7
15:18	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	3
15:19	1	3	0	0	0	0	0	0	0	0	0	2	0	0	0	6
15:20	3	2	0	0	0	4	0	0	0	0	0	0	0	0	0	9
15:21	1	2	0	0	0	2	1	0	0	0	0	0	0	0	0	6
15:22	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	5
15:23	2	4	0	0	0	0	0	0	0	0	0	3	0	0	0	9
15:24	0	2	0	0	0	3	2	0	0	0	0	0	0	0	0	7

Time	sum Arrival Rate λ PCU-M/min	Arrival Rate λ PCU/min	PCU	Average Headway min/Pcu	Average Spacing M	SSD M	Average Speed KPH
15:05	36.25	8.90	8.90	0.11	4.073	4.19	**5.38**
15:06	27.50	5.40	5.40	0.19	5.093	2.70	**3.59**
15:07	36.00	6.00	6.00	0.17	6.000	3.30	**4.32**
15:08	35.25	7.10	7.10	0.14	4.965	3.59	**4.67**
15:09	43.75	7.70	7.70	0.13	5.682	4.21	**5.40**
15:10	17.25	4.10	4.10	0.24	4.207	1.84	**2.51**
15:12	7.75	1.70	1.70	0.59	4.559	0.77	**1.08**
15:13	62.05	8.87	8.87	0.11	6.995	5.56	**6.92**
15:14	29.25	6.10	6.10	0.16	4.795	2.99	**3.95**
15:15	24.25	6.90	6.90	0.14	3.514	2.98	**3.94**
15:16	108.93	11.74	11.74	0.09	9.279	9.30	**10.76**
15:18	13.75	2.70	2.70	0.37	5.093	1.30	**1.80**
15:19	31.75	5.70	5.70	0.18	5.570	3.00	**3.96**
15:20	24.25	6.90	6.90	0.14	3.514	2.98	**3.94**
15:21	23.25	5.10	5.10	0.20	4.559	2.41	**3.23**
15:22	21.50	4.40	4.40	0.23	4.886	2.13	**2.87**
15:23	45.50	8.40	8.40	0.12	5.417	4.52	**5.75**
15:24	29.25	6.10	6.10	0.16	4.795	2.99	**3.95**

Table2. Capacity, Traffic Volumes, Free speed, Density, and Space Mean Speed

Volumes ,Q (PCU/hr/lane)	Volume ,Q_{max} (PCU/hr/lane)	free speed vf (km/hr)	the density d (PCU/km)	Space mean speed v (km/hr)
622	622	12	169.19	7.35
20	622	12	3.36	11.91
264	622	12	49.64	10.64
5	622	12	0.83	11.98
1	622	12	0.17	12.00

3.1 Minimized- effective green times

The ITS system was applied to two adjacent intersections in Bangkok. The results show that cycle times at the 3 and 4 Legs Intersections decrease dramatically due to the triggers. The triggers of virtual loop detect the vehicles passing the loop within 7-15 seconds. If no vehicle passes the loop after 15 seconds, they will send signal to the controller to change the state from green to red times promptly. This matter is further elaborated in the next diagram. Table 3 shows the minimized- effective green times of each approach of the intersections and the figures focus on the triggers. Virtual loops are still detecting vehicles and the effective green times of each direction at the two intersections as shown on display are substantially lower than the maximum effective green times of maximum cycle times. Furthermore, the results of real time traffic data collection such as, cycle times, phases, green times, QCT, and traffic flows are given in Table 3. From this Table, it can be observed that the effective green times and cycle times decrease substantially when compared to the optimum cycle times. Moreover, the QCT is close to or lower than the real green times. Figures 7, 8 and 9 show when the phase at each intersection was synchronized, using the calculated offset time of 34 seconds; the queue length of vehicles was substantially reduced.

Table 3.Minimized- effective green times of each approach of the two adjacent intersections (cycle times are substantially lower than maximum cycle times as calculated by aaSIDRA and Synchro).

T Intersection				4 Legs Intersection				T Intersection		4 Legs Intersection	
								150 seconds Maximum of Cycle Times		90 seconds Maximum of Cycle Times	
Phasing	Seconds	Traffic Volumes Average PCU	QCT Recheck	Phasing	Seconds	Traffic Volumes Average PCU	QCT recheck	Cycle Times	Total PCU	Cycle Times	Total PCU
ph T-T	30	49	17	ph LT-LT	29	49	17				
ph M R	18	39	11	ph Mi LTR	20	41	13	73	134	49	90
ph Mi R	25	46	15								
ph T-T	34	51	18	ph LT-LT	8	20	6				
ph M R	18	39	11	ph Mi LTR	20	41	13	75	134	28	62
ph Mi R	23	45	14								
ph T-T	30	49	17	ph LT-LT	33	50	18				
ph M R	14	33	9	ph Mi LTR	20	41	13	67	127	53	92
ph Mi R	23	45	14								
ph T-T	23	45	14	ph LT-LT	35	51	18				
ph M R	20	41	13	ph Mi LTR	10	25	7	66	130	45	76
ph Mi R	23	45	14								
ph T-T	19	40	12	ph LT-LT	21	42	13				
ph M R	25	46	15	ph Mi LTR	13	31	9	67	131	34	74
ph Mi R	23	45	14								
ph T-T	18	39	11	ph LT-LT	17	37	11				
ph M R	21	42	13	ph Mi LTR	12	29	8	58	121	29	67
ph Mi R	19	40	12								
ph T-T	13	31	9	ph LT-LT	55	39	11				
ph M R	46	48	16	ph Mi LTR	7	18	5	82	123	62	57
ph Mi R	23	45	14								
ph T-T	15	34	10	ph LT-LT	18	39	11				
ph M R	14	33	9	ph Mi LTR	15	34	10	41	96	33	73
ph Mi R	12	29	8								

The movements at the 3-leg intersection are in 6 directions, 2 movements of left turn directions are free flow. In case of the 4- leg intersection, there are 10 directions and two of them are left turn –free flow or un-prohibited. The Normal Phases and Offset Phase are presented in the following part.

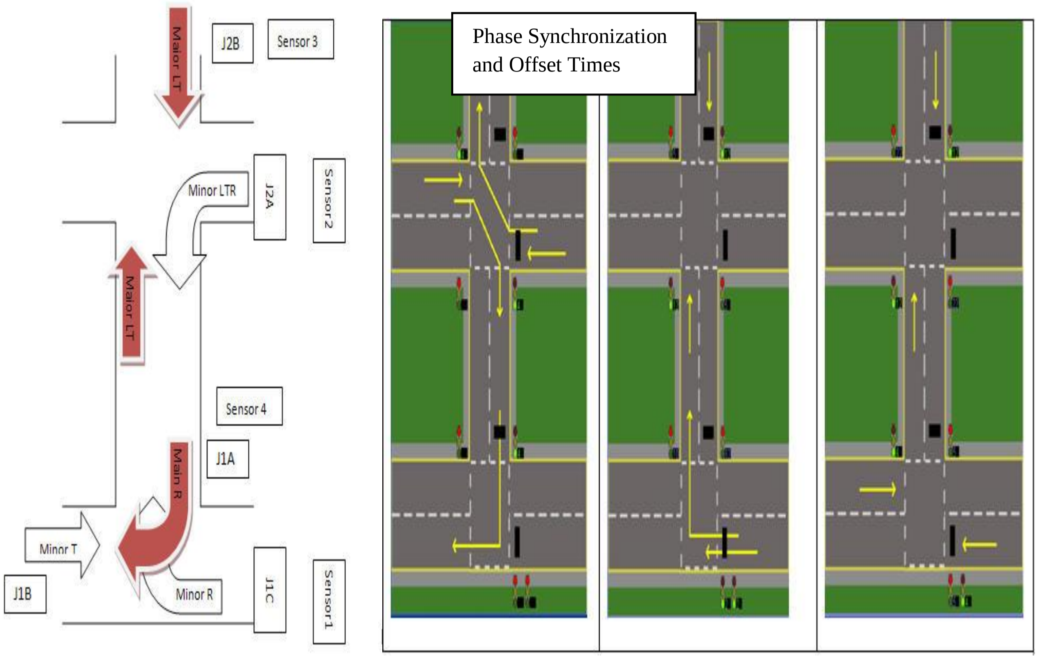

Figure 7.Sensors or virtual loops – locations and Phasing

There are 3 phases at the 3- leg intersection and cycle times are varied based on the traffic volumes at different period of times. **During peak hour, headways of vehicles passing through the virtual loop are within 5 seconds** and the characteristic of traffic flow is steady state –steady flow therefore, the cycle times is extended up to maximum green times of J1-A,B, and C (output from calculation of SIDRA (2000) and Synchro (2003)). In case of the 4-leg intersection, phases of J2-A and B are also the same as the J1A, B, and C’s concepts. The offset times -phase or green wave –phase are proposed for the vehicles passing from one intersection to the other intersection such as, the group of direction flow of J2-B phase and J1-A phase, the group of J1-C Phase and J2-B, and the group of J2-A and J1-A. The offset times as mentioned before were calculated based on the method of ARRB - Australian Road Research Board, ARRB (1989). In the case of J2-B and J2-A to J1-A direction, 34 seconds of offset times was taken into consideration and it was subtracted with the amber and all red times (7 seconds). Therefore, 27 seconds of offset times are proposed for the green wave phase. As for J1-C to J2-B direction, the 28 seconds comes from the difference values of 34 seconds (offset times) and 6 seconds (3 seconds -amber times and 3 seconds –all red times).

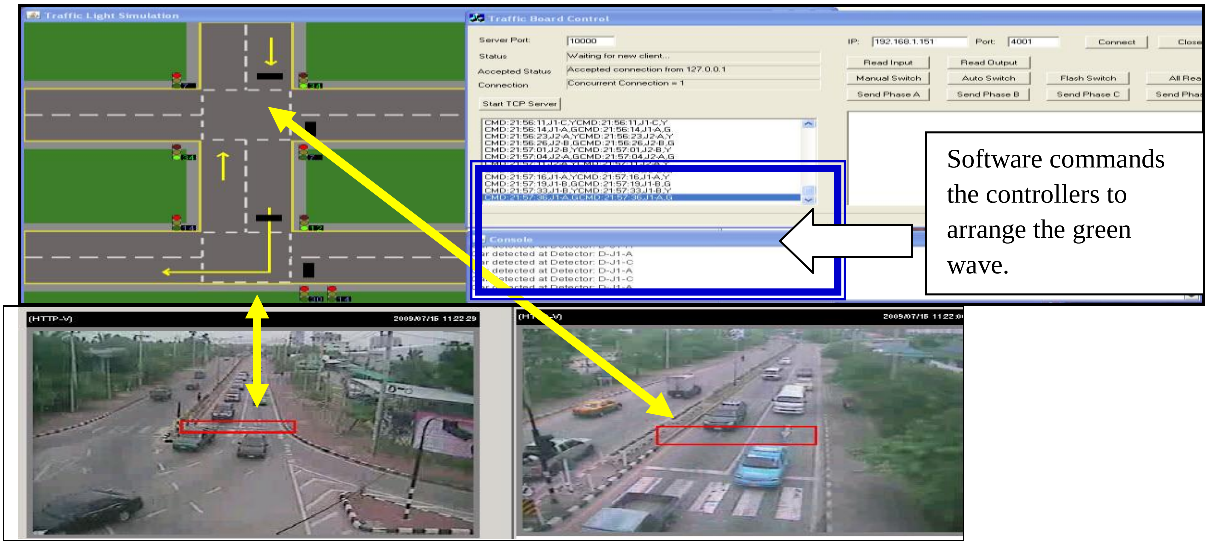

Figure 8.Reduction of queue length by synchronization producing Green Wave phase

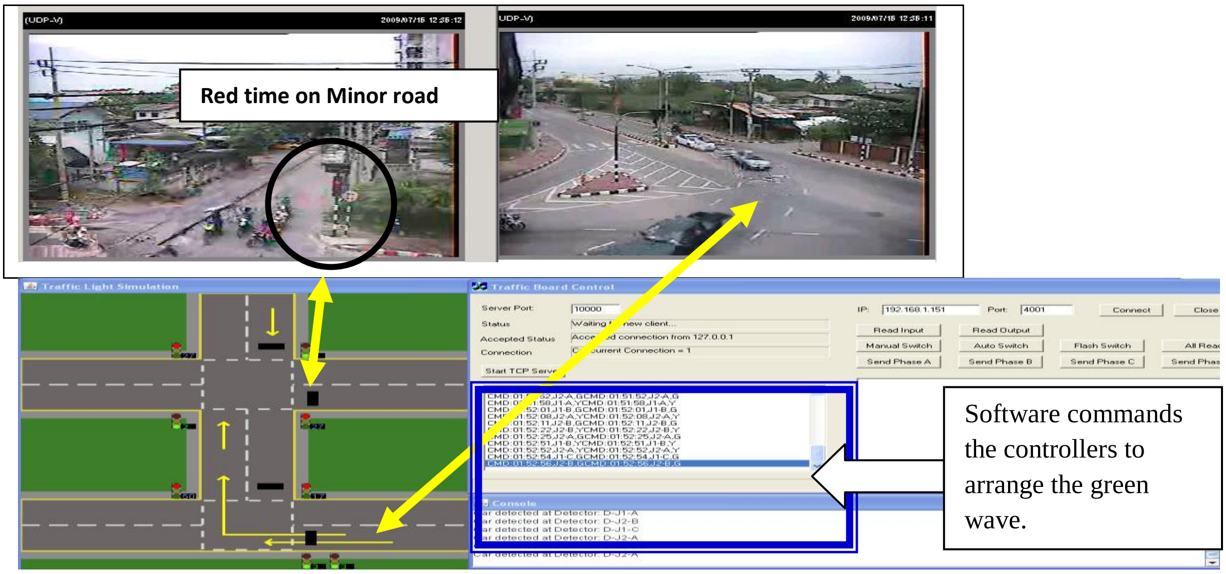

Figure 9.Reduction of queue length by synchronization resulting in Green Wave phase

The green wave as presented in the blue box above was calculated by the Adaptive Traffic Signalization Software in the control room.

As a result, queue length at two intersections decrease substantially as presented below;

- Cycle Times at the 3 legs intersection vary from 13 seconds (7+6) to 150 seconds and those at the 4 legs intersection vary from 14 seconds (7+7) to 90 seconds. Moreover, the number of phases at the 3 and 4 legs intersection are 3 and 2 respectively.
- Queue Lengths at the 3 legs intersection varies from 0 to 125 meters and those at the 4 legs intersection vary from 0 to 155 meters.

Therefore, the effective green times or cycle times decrease dramatically. This leads to the reduction in travel times for road users and resulting in reduced fuel consumption and cost.

3.2 Traffic Pollution
3.2.1 Traffic Noise Pollution

The calculation of traffic noise was based on the Transport and Road Research Laboratory and the Department of Transport (UK Department of Transport - Welsh Office, 1988). The predictions of noise levels in the case study - intersections were calculated by the methods of UK DOT (1988). The noise assessment criterion is 70 dB(A)-Leq 24 hrs. This value is from the Department of Pollution Control, Thailand. Thus, L_{10} is equal to 73 dB(A). This is due to the fact that L_{10} is equal to the addition of both Leq dB(A) and 3 dB(A) ,RTA(1993). As a result, the predicted noise from the Method of DOT (1988) and the developed model from the image sensing's data are the same owing to the fit comparative values of the relative coefficients factors as described below. Figure 10 shows the set-up of data collection.

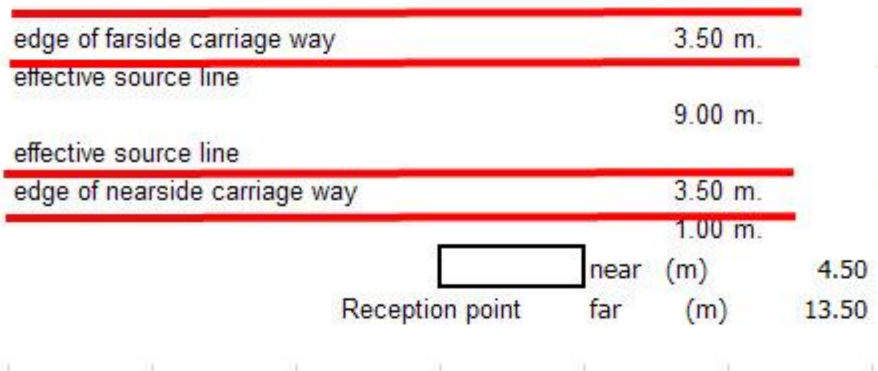

Figure 10.The collected data - location of noise and air pollution

Evaluated Data from the image sensing cameras

Noise – L_{10} (1 hr) based on Traffic Volumes

$$(\text{Noise} - \text{dB (A)}) = 635.3 + 0.0003473*(\text{Traffic Vol.})^2 - 0.8815*(\text{Traffic Vol.}) \quad (10)$$

R^2 Goodness of fit and Correlation Coefficient = 1.000

Where,

Traffic Vol. : Traffic Volumes in PCU/Hr

Noise – L_{10} (1 hr) based on Speed

$$(\text{Noise} - \text{dB (A)}) = 85.98 + 0.01315*\text{Speed}^2 - 0.7305*\text{Speed} \quad (11)$$

R^2 Goodness of fit and Correlation Coefficient = 1.000

Where,

Speed : Speed in Km/Hr

Noise – L_{10} (1 hr) based on Traffic Volumes and Speed

$$(\text{Noise - dB (A)}) = 4.609*\text{Speed} + 0.7867*(\text{Traffic Vol.}) - 1050 \quad (12)$$

R^2 Goodness of fit and Correlation Coefficient = 1.000

It is seen that only speed has the effect on the predicting noise – equation. Details of the results are illustrated in Table 6.

3.2.2 Traffic Air Pollution

The values of EU standard emissions for Passenger Car for CO and PM_{10} have decreased significantly from 1995 to 2011 as shown in Table 4. For the present study, the existing CO and PM_{10} data in 2012 were measured at the study intersections. The equations of emission of CO and PM_{10} were developed as presented below.
The EU has developed Air Pollution Emission standards since 1995. The EU Emission Standards for the period 1995 to 2011 are presented in the following Tables.

Table 4.EU Emission Standard used in Thailand during 1995 to 2011

	Comparison of EURO Stadard during 1995 - 2010 Year	CO PPM	Δ%	Δ1995–2011%	PM10 mg/m^3/24hr	Δ%	Δ1995–2011%
	1995	4.00	-0.25		0.54	-0.06	
EURO 1	1996	3.00	-0.08		0.51	-0.31	
	1997	2.75	-0.18		0.35	-0.14	
	1998	2.25	0.02		0.3	-0.33	
	1999	2.30	-0.02		0.2	-0.05	
EURO 2	2000	2.25	-0.11		0.19	-0.05	
	2001	2.00	-0.05		0.18	0.00	
	2002	1.90	0.05		0.18	-0.11	
	2003	2.00	-0.13	62.50	0.16	0.13	73.15
	2004	1.75	-0.09		0.18	-0.17	
	2005	1.60	-0.06		0.15	0.07	
	2006	1.50	0.00		0.16	-0.06	
	2007	1.50	0.00		0.15	-0.03	
EURO3	2008	1.50	0.00		0.145	0.00	
	2009	1.50	0.00		0.145	0.00	
	2010	1.50	0.00		0.145	0.00	
	2011	1.50	0.00		0.145	0.00	

Source: Pollution Control Department Thailand (2012)

Table 5.The Collected Environmental Data at the Intersection during 14 – 16 November 2012

Collected Pollution Data 3 – Day (Peak Hour)	2012				
	Traffic Volumes (PCU/Hr/Direction)	Speed (Km/hr)	CO (PPM)	PM_{10} (mg/m^3/24hr)	Noise (dB(A))
1		33.78	4.27	13.08	-
2		21.83	3.09	14.82	-
3		10.00	2.78	16.66	79.6
Peak Hour : 17:00 – 18:00			Standard CO	Standard PM_{10}	Standard Noise
			30.00	120.00	73.0

Source: Pollution Control Department Thailand (2013)

3.2.2.1 CO Prediction

CO based on Traffic Volumes

$$CO = 93.02 + 5.444e\text{-}13*(\text{Traffic Volumes})^4 - 0.04414*(\text{Traffic Volumes}) \quad (13)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

Where,

CO : Carbon Monoxide, PPM/hr

Traffic Vol.: Traffic Volumes, PCU/Hr

CO based on Speed

$$CO = 2.841 + 4.649e^{-5}*Speed^3 - 0.01075*Speed \quad (14)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

Where,

Speed : Speed in Km/Hr

CO based on Traffic Volumes and Speed

$$CO = 1.059*Speed + 0.08255*(\text{Traffic Volumes}) - 235.3 \quad (15)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

3.2.2.2 PM_{10} Prediction

PM$_{10}$ based on Traffic Volumes

$$PM_{10}\ (\mu g/m^3/24hr) = 0.009547*(Traffic\ Volumes) + 7.066^{e-14}*(Traffic\ Volumes)^4 - 12.76 - 1.06^{e-31}*(Traffic\ Volumes)^9 \quad (16)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

Where,
PM_{10} : µg/m^3/24hr
Traffic Vol.: Traffic Volumes, PCU/Hr

PM$_{10}$ based on Speed

$$PM_{10}\ (mg/m^3/24hr) = 17.54 + 5.049^{e-5}*Speed^3 + 8.891^{e-7}*Speed^4 - 0.0401*Speed - 1.515^{e-11}*Speed^6 - 1.017^{e-9}*Speed^5 - 0.005383*Speed^2$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

Where,
PM_{10} : µg/m^3/24hr
Speed : Speed in Km/Hr

PM$_{10}$ based on Traffic Volumes and Speed

$$PM_{10}\ (\mu g/m^3/24hr) = 18.32 - 5.942^{e-5}*(Traffic\ Volumes)*Speed - 0.0002516*Speed^2 \quad (18)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.000

Table 6 focuses on the comparison between Before and After Situation under the standard of air pollution such as, CO, PM_{10}, and Noise (L_{10}) when stopping or idling and going situation at the intersection. The Standards are 30 ppm./hr for CO, 120 µg/m^3/24hr for PM_{10} and 73.0 -dB(A) for Noise, respectively .

Table 6. Air and Noise Pollution Levels Before and After Situation at the Intersections

Time	Before Improvement Average Speed Km/Hr	After Improvement Average Speed Km/Hr	Before Improvement **CO** ppm/hr 30 ppm/hr	After Improvement **CO** ppm/hr 30 ppm/hr	Before Improvement PM10 mg/m^3/24hr 120 mg/m^3/24hr	After Improvement PM10 mg/m^3/24hr 120 mg/m^3/24hr	Before Improvement Noise dB(A) 73.0 dB(A)	After Improvement Noise dB(A) 73.0 dB(A)
15:05	3.00	5.38	2.81	2.79	17.37	17.18	83.9	82.4
15:06	3.00	3.59	2.81	2.80	17.37	17.33	83.9	83.5
15:07	3.00	4.32	2.81	2.80	17.37	17.27	83.9	83.1
15:08	3.00	4.67	2.81	2.80	17.37	17.24	83.9	82.9
15:09	3.00	5.40	2.81	2.79	17.37	17.18	83.9	82.4
15:10	3.00	2.51	2.81	2.81	17.37	17.41	83.9	84.2
15:12	3.00	1.08	2.81	2.83	17.37	17.49	83.9	85.2
15:13	3.00	6.92	2.81	2.78	17.37	17.02	83.9	81.6
15:14	3.00	3.95	2.81	2.80	17.37	17.30	83.9	83.3
15:15	3.00	3.94	2.81	2.80	17.37	17.30	83.9	83.3
15:16	3.00	10.76	2.81	2.78	17.37	16.56	83.9	79.6
15:18	3.00	1.80	2.81	2.82	17.37	17.45	83.9	84.7
15:19	3.00	3.96	2.81	2.80	17.37	17.30	83.9	83.3
15:20	3.00	3.94	2.81	2.80	17.37	17.30	83.9	83.3
15:21	3.00	3.23	2.81	2.81	17.37	17.36	83.9	83.8
15:22	3.00	2.87	2.81	2.81	17.37	17.38	83.9	84.0
15:23	3.00	5.75	2.81	2.79	17.37	17.14	83.9	82.2
15:24	3.00	3.95	2.81	2.80	17.37	17.30	83.9	83.3
15:25	3.00	3.58	2.81	2.80	17.37	17.33	83.9	83.5
15:27	3.00	5.37	2.81	2.79	17.37	17.18	83.9	82.4
15:28	3.00	1.07	2.81	2.83	17.37	17.49	83.9	85.2
15:29	3.00	4.31	2.81	2.80	17.37	17.27	83.9	83.1
15:30	3.00	4.30	2.81	2.80	17.37	17.27	83.9	83.1
15:31	3.00	3.23	2.81	2.81	17.37	17.36	83.9	83.8
15:32	3.00	3.95	2.81	2.80	17.37	17.30	83.9	83.3
15:34	3.00	2.15	2.81	2.82	17.37	17.43	83.9	84.5
15:35	3.00	5.74	2.81	2.79	17.37	17.14	83.9	82.2
15:36	3.00	5.74	2.81	2.79	17.37	17.14	83.9	82.2
15:37	3.00	5.73	2.81	2.79	17.37	17.14	83.9	82.2
15:38	3.00	4.66	2.81	2.80	17.37	17.24	83.9	82.9
15:39	3.00	4.30	2.81	2.80	17.37	17.27	83.9	83.1
15:41	3.00	5.01	2.81	2.79	17.37	17.21	83.9	82.7
15:42	3.00	1.43	2.81	2.83	17.37	17.47	83.9	85.0
15:43	3.00	5.73	2.81	2.79	17.37	17.14	83.9	82.2
15:44	3.00	6.20	2.81	2.79	17.37	17.10	83.9	82.0
15:45	3.00	5.37	2.81	2.79	17.37	17.18	83.9	82.4
15:46	3.00	1.79	2.81	2.82	17.37	17.45	83.9	84.7
15:48	3.00	5.03	2.81	2.79	17.37	17.21	83.9	82.6

From the Table, it can be seen that CO and PM_{10} Level and Noise Level have improved from the "before" situation levels. This is due to the fact that the speed has generally improved to over 3 km/hr.

3.3 Fuel Consumption

The fuel consumption model was developed to test the impact of the ITS system installation. There are three models of popular passenger cars (4 wheels) in Thailand with engine capacity of 1.6 L, 1.8 L, and 2.0L. For the pilot study the testing length was 3 km., the speed data were collected from zero to 80 kph, and the fuel consumption (L/100 km) was measured and displayed by the speedometer. From the collected data, the following fuel consumption equations were formulated for different engine capacity.

$$F=21.94-0.2699*S-0.05226S^{2}+0.002685*S^{3}-5.401e^{-5}*S^{4}+5.069e^{-7}*S^{5}-1.843e^{-9}*S^{6} \quad <2000\ cc \qquad (19)$$

$$F=19.21+0.1414*\max(S.65.12)-\frac{0.66}{\tanh(S-14.64)}-\max(1.713+\sqrt{(0.1338+S)},\min(S,23.4)-2.121) \qquad (20)$$

Where,

F : the Fuel Consumption (L/100 km)

S : Speed (km/h)

The correlation coefficients for the equations are 0.984 and 0.992, respectively. Table 7 shows the before and after situation of fuel consumption for passenger car of <2,000 cc and >2,000 cc.

Table 7. Comparison of Fuel Consumption Before and After Traffic Improvement

Time	Before Situation			After Situation		
	Average Speed KPH	l/100 km >2000 cc	l/100 km <2000 cc	Average Speed KPH	l/100 km >2000 cc	l/100 km <2000 cc
15:05	3.00	25.595	20.728	5.38	25.017	19.351
15:06	3.00	25.595	20.728	3.59	25.434	20.411
15:07	3.00	25.595	20.728	4.32	25.255	19.997
15:08	3.00	25.595	20.728	4.67	25.173	19.788
15:09	3.00	25.595	20.728	5.40	25.013	19.340
15:10	3.00	25.595	20.728	2.51	25.739	20.973
15:11	3.00	25.595	20.728	1.08	26.265	21.592
15:12	3.00	25.595	20.728	6.92	24.283	18.346
15:13	3.00	25.595	20.728	3.95	25.344	20.211
15:14	3.00	25.595	20.728	3.94	25.347	20.218
15:15	3.00	25.595	20.728	10.76	20.437	15.675
15:16	3.00	25.595	20.728	1.80	25.975	21.301
15:17	3.00	25.595	20.728	3.96	25.342	20.207
15:18	3.00	25.595	20.728	3.94	25.347	20.218
15:19	3.00	25.595	20.728	3.23	25.531	20.607
15:20	3.00	25.595	20.728	2.87	25.631	20.793
15:21	3.00	25.595	20.728	5.75	24.938	19.112
15:22	3.00	25.595	20.728	3.95	25.344	20.211
15:23	3.00	25.595	20.728	3.58	25.437	20.417
15:24	3.00	25.595	20.728	5.37	25.018	19.355

From the Table7, The fuel consumption levels of Passenger Car with capacity > 2,000 cc and <2,000 cc show significant reduction after the ITS improvement. The summation of fuel consumption cost with engine > 2,000 cc and <2,000 cc (before and after improvement) are 3,863.88 Baht/Kilometer and 3,473.57 Baht/Kilometer, respectively. Moreover, the percentage differences of fuel consumption for cars with engine >2,000 cc and <2,000 cc (before and after situation) are 8.408 and 12.736, respectively.

4. CONCLUSIONS

Extreme traffic congestion in Bangkok has several serious impacts including road crashes, time loss, traffic pollution and wasteful fuel consumption at intersections. In order to address the challenge effectively, the authors conducted studies into the causes of congestion and its consequences. In the study, it was found that the main causes of the problems are red light running, speeding, poor lane changing behavior caused by long delay at intersections. The authors have developed and tested an ITS technology system which comprises of an adaptive traffic signalization, changing lane and speeding model linked with VMS, and new software. The installation of the new system has been shown to be effective in reducing the number of these traffic violations especially, the number of red light running, speeding and poor lane changing vehicle has dropped significantly resulting in the decreasing number of crashes at the intersections. As part of the continuing development and testing of the technology, comparison study of noise and air pollution in terms of CO, PM_{10} and fuel consumption before and after application of the technology were conducted. The results show that the technology has positive impact in reducing the adverse effects of congestion. In addition, the researchers have developed a new set of equations for use by Thai traffic engineers in the study of environmental impact from traffic congestion at intersections based on the Stop and Go conditions.

REFERENCES

aaSIDRA-Full version 1.0.6.145, Traffic Engineering Software, 2000.

Akcelik, R., Research Report, Traffic Signals: capacity and timing analysis, *ARRB 123*, Fourth Reprint: 1989, pp. 89 -95, 1989.

BBC (2012) http://www.bbc.co.uk/news/magazine-19716687 Accessed March 2013.

Cheewapattananuwong, W. and Samuel, S. Study of Traffic Impact during Construction of Infrastructure in Bangkok, *Thesis of M.Eng.Sec., New South Wales University* (1996).

Cheewapattananuwong, W., Taneerananon, P. and Nakatsuji, T. Mitigating Traffic Congestion and Accidents in Thailand with Intelligent Transportation System Technology, *Transportation Research Record: Journal of the Transportation Research Board, No. 2239, Transportation Research Board of the National Academies, Washington, D.C., 2011*, pp. 41–55. DOI: 10.3141/2239-06. TRB Publishers (2011).

Cheewapattananuwong, W. and Taneerananon, P. Remedy Traffic Accidents at Intersection Through the Use of ITS Technology, *Asian Transport Study Vol.2 (2012) No.2*, pp. 178-193. Released: September 15, 2012.

Department of Transport (Welsh Office), Calculation of Road Traffic Noise, *Her Majesty's Stationary Office, London*, 1988.

http://ubaa.net/shared/processing/opencv/ , open source website

Office of Thai Health Promotion Fund. A Study of Thailand 2522 land Traffic Act. Final Report, 2012.

Pollution Control Department, Thailand. EU Emission Standard in Thailand during 1995 to 2011, *Successful Air Quality Control Programs in Thailand*, 2012.

Pollution Control Department, Thailand. The Decreasing of Air Pollution of EU – Emission Standard from 1995 to 2011, *Air Quality Control Report in Thailand*, 2013.

Shibata, T. (2013) *http://www.tku.ac.jp/kiyou/contents/economics/257/079_shibatatokue.pdf* Accessed March 2013.

Salter, R. J. (1982). Simulation of Delays and Queue Lengths: at Over-Saturated Priority Highway Junctions. *Australian Road Research*, Vol. 12. No.4.

Trafficware Synchro 6, Traffic Engineering and Simulation Software, 2003.