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A Real-Time Image Processing Technology for Mitigating Traffic Impacts at Intersections

交差点での交通インパクトを改善するためのリアルタイム画像処理技術

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ABSTRACT

This research presents the result of a pilot study using the author's innovative real-time image processing technology to reduce intersection traffic impacts including road crashes, air pollution and excessive fuel consumption which arose as a result of long intersection delays. Implementation of the new technology has resulted in substantial reductions in the number of traffic crashes, traffic pollution and vehicle fuel consumption at these intersections.

The overall objective of this study is to develop a new and innovative ITS technology for addressing traffic impacts at signalized intersections caused by long delays; these impacts include intersection traffic crashes, traffic pollutions and wasteful fuel consumption. Specific objectives are *to study the optimization of cycle times* under traffic synchronization, queue length, initial speed and final speed during lane changing lane associated with the existing traffic signal control at the two adjacent intersections, *to study drivers' behaviour at intersection*, such as red light running, speed and dangerous lane changing with the objective of reducing the number of crashes, *to develop an ITS technology* including video image sensing device and new software for capturing vehicles passing an intersection and capable of counting 5 vehicle types for use in the calculation of PCU from new model,the technology also include the concept of trigger of virtual loop detector which can help to reduce the cycle times and improve the associated traffic control by traffic synchronization together with another software. As a result, the intersection traffic impact such as speeding and lane changing behaviour are mitigated, *to study the effects of the implemented ITS technology on traffic impacts* at the case study intersections including the reduction in number of traffic crashes, reduced level of traffic pollution and reduced fuel consumption and *to study and produce a new hardware* (Interface Card) for use with a traffic controller which can link the developed software with any traffic controllers in Thailand.

This research is useful for Thai drivers as they can benefit from reduced travel times and fewer accidents after the complete installation of the ITS Technology. In addition, the researcher has 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. In case of fuel consumption, the amount of fuel consumption between before and after situation decrease substantially. Recommendations for future study focus on the use of high quality CCTVs for monitoring of drivers' use of mobile phones while driving using the Image Sensing Software, and the use of laser projected on water sprayed screen while crossing the roadway.

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INTRODUCTION

1.1 BACKGROUND

The United Nation (UN) Decade of Action for Road Safety 2011-2020 calls for a significant reduction in the global number of road deaths by the end of the decade. In addition, World Health Organization (WHO) and UN regional commissions, in cooperation with other partners in the United Nations Road Safety Collaboration and other stakeholders have developed a Global Plan for the Decade of Action for Road Safety 2011-2020. In the plan, five major categories or "pillars" of activities are proposed: road safety management; safer roads and mobility; safer vehicles; safer road users; and post crash response (www.who.int/roadsafety/decade of action/ plan/ en/index.html, 2012). Within this global picture, Thailand has been facing a challenging situation; it has one of the highest road fatality rates in the world. According to the 2013 WHO global status report on road safety which lists the 2010 data, the fatality rate per one hundred thousand population for Thailand stood at 38.1 (26,312 deaths), compared to 5.2 for Japan (6,625 deaths), Australia 6.1 (1,363 deaths) and Malaysia 25.0 (7,085 deaths) (WHO, 2013). Significant numbers of road traffic fatalities and injuries can be prevented by addressing the leading causes, which include excess speed, lack of seat-belt and child restraint use, drinking and driving, lack of helmet use by riders on two-wheel and three-wheel motorized vehicles, poorly designed and inadequately maintained roads, unsafe infrastructure and vehicles, and inadequate trauma care (UN Resolutions/ sept_2011_sg_report_en.pdf, p.3, 2011). It is the unsafe infrastructure and poor drivers' behaviour that this thesis seeks to address.

Traffic volumes at many intersections in suburban Bangkok, Thailand, are at saturation level; this saturation creates long delays, which lead to driver frustration. The fixed time of many existing traffic controllers in suburban Bangkok has exacerbated the situation. The queuing drivers become even more frustrated when they see an approach with few vehicles getting more green time than necessary; the long cycle times further aggravate the situation, especially when drivers are in a rush. A common cycle time is often set for all periods. Phases and cycle times of these intersections are not designed for traffic synchronization and adaptive signalization. Several drivers try to speed through the intersection during the dilemma times to avoid long delays. In addition, there are several black spots at the intersections (Department of Highways, 2000). In this study, existing vehicle actuated traffic controllers with an innovation of interface card and the new traffic image sensing software integrated with new traffic management software applied with CCTVs (analog cameras) are taken into consideration. The software optimizes phase and cycle times and can adapt to real-time traffic volumes.

The use of ITS enforcement for Red Light Running (RLR) or after implementation of RLR leads to the motivated motorists for driving, especially the lane changing behaviors. Moreover, the most of drivers make decisions to change their lane to another lane so as to be close the stop line of intersection or drivers prefer moving their vehicles to the shortest queue length from the stop line of intersection. This causes the traffic accidents at the intersections. In this research, the new image sensing software is developed to track the vehicle-lane changing part, to count the number of lane changing of drivers' behavior, and to check the controlled speed. Furthermore, the tracking signal will be sent the imperative or commanding messages to Variable Message Sign (VMS) in order to compel the nonfeasance from motorists.

The traffic signalizations or non-synchronization at two intersections have an influence on the travel times of traffickers. Besides, the speeding of upstream vehicles after green times at the intersection has an effect on the downstream vehicles of another intersection, thus it leads to the rear end collision. The new concepts to remedy of this situations will be developed two software to apply for the ITS Technology; one is to control speed of vehicles and the other is to do the green wave or traffic synchronization.

Fuel Consumption and air as well as traffic noise pollution have adverse effects on the road users cost and the health of Bangkok citizens, especially those living nearby or using highly congested intersections. This led to an increased prevalence of respiratory symptoms and frequent coughing or phlegm (Karita et al., 2004). The researcher will apply the new ITS Technology so as to mitigate these situations. Furthermore, the evaluated data will be also reported in each period time by VMS.

1.2 PROBLEM STATEMENT

In case of traffic engineering, RLR, Lane changing, Adaptive Traffic Signalization and speeding have effects on the road users in Thailand. In addition, the fuel emission and environmental aspects have an influence on people living near the intersections. The current traffic control systems in Thailand cannot deal with those problems adequately. More advance system should be developed as criticized below:

1.2.1 Current Traffic Control System in Thailand

Most of Traffic Controllers in Thailand are Fixed Time Traffic Signalization. They lead to traffic accidents at intersections in Thailand. These crashes are caused by drivers' frustration because of long intersection delays. Without police or other forms of enforcement, the long delays have led to road crashes caused by drivers' disobedience of traffic signals and dangerous driving manoeuvres in an effort to beat the signal so as to avoid the long delay. This is owing to the fact that some drivers will not wait for the green times when there are no vehicles approaching the intersection, thus Red Light Running (RLR) will occur. In addition, drivers will try to change lane so as to be close to the stop line.

Some Traffic Signalization Systems are Vehicle Actuated (VA) which uses magnetic loop detectors embedded in pavement. The traffic accidents somewhat decrease, however they increase again when the pavement is damaged (Cheewapattananuwong, et al., 2001). This is due to the fact that heavy vehicles carry the over-standard weigh and they lead to the damage of pavement and magnetic loop detectors. Other Signalized Systems are applied by ultrasonic detectors. They were installed in Chiang-mai and Phuket; as a result they are useful to remedy traffic situations in these provinces (Sakakibara, et al., 2005). However, the cost of installed this system is higher than the system as mentioned before due to the extra cost of putting up several posts for ultrasonic sensors for checking the queue length.

In case of traffic signal control system by image processing method with Virtual Loop Detector (VLD), which have been installed in Bangkok, Chiang-Mai and Phuket. This system can solve the traffic problems (Jansuwan and Narupiti, 2005); however they cannot check Lane Changing Behaviours of Thai Drivers and cannot display information on the Variable Message Sign (VMS) in order to warn drivers. Moreover, the cost of this system is higher than the magnetic loop detectors-system. Therefore, the road agencies, especially Department of Highways and Department of Rural Roads cannot afford to use this system nationwide. In case of the application of the existing ITS System for wider area, it is not easy and takes more times to develop the synchronization with other intersections by Software Development Kit (SDK). Moreover, the system especially, VLD cannot do two functions of Loop Detectors. One is the measurement Headway of each vehicle. The other is a ticker as a loop detector on pavement.

As regards Lane Changing in previous studies, Starting Speed of Lane Changing (V_s) and Final Speed of Lane Changing (V_f) have not been measured in these studies. The classified counts of vehicles especially, TUK-TUKS, and SAMLAW (Tricycle) or Low Speed-Vehicles have never been taken into account. In addition, there are several studies on the daily evaluation of fuel consumption and environmental emission assessment. However, few studies on the environmental assessment especially, concerning CO and $PM_{10,}$ have collected these data in 5 seconds interval. Of the few CCTVs for Image Sensing deployed, only Fixed Cameras were used.

1.2.2 New ITS Technologies

In response to the shortfalls mentioned in section 1.2.1, the Development of Image Sensing Technique including CCTVs Concepts, Intelligent Transport System (ITS) technologies, and an Interface Card will be taken into consideration as described below;

<u>Image Sensing Concepts</u>:

1) A Development of Software (Visual C^{++}) for traffic classified counts and traffic signalization.

   They are two functions of Virtual Loop Detectors; one is applied for traffic classified counts, such as five types of vehicles (TUK-TUKS and SAMLAW (Tricycle). Furthermore, Noise Reduction Technique and Zero Lux. Camera will be taken into account. The other is applied for the tracking of vehicles when approaching to the intersection and for the checking of headway within the appropriate times to change the green stage to yellow and red stage (if the headway of vehicles come under the steady stage/steady flow, the proposed green times will be the maximum of green times of cycle length.

2) A Development of Software (Visual C^{++}) for lane changing model.

   Lane Changing-Vehicle Path for geometrical design, such as the tracking of the vehicle in terms of angle of lane changing θ, average spacing M and average length of Lane changing L is taken into consideration. Speed of vehicles is obtained by evaluating two-point locations of vehicle; this leads to speed of a vehicle approaching an intersection. For instance, starting speed of lane changing ν_s, final speed of lane changing $\nu_{f,}$,Critical SSD, Lane Changing Length and Breaking Distance are taken into account.

ITS Technology Concepts:

1) *Isolated Intersection using Traffic Management (Normal Phase) on the main or minor road by installed a CCTV (Pan, Tilt, Zoom-PTZ)*; vehicles are tracked for Lane Changing and Speed. In addition, the traffic headway within 5 seconds (from the data collection before applied ITS Technology) is provided for the adaptive traffic signalization at the intersection.
2) *Two Intersection using Traffic Synchronization* (Additional Phase) during the upstream, the vehicles at the first intersection come to the second intersection and it takes about 34 seconds for the offset times or Green Wave, in fact the offset times are usually lower than 34 seconds due to the management of traffic queue length at the second intersection. Moreover, the cycle lengths are also lower than the maximum cycle length as calculated from SIDRA and Trafficware.
2) *Develop the Traffic Synchronization Software*; there are two functions of the software, one is the traffic simulation of two intersections, the second is the link sensor-real time data from the CCTVs. Furthermore, the other intersections in the wider areas can be linked by the Developed Traffic Synchronization Software, however, the spacing of both intersections must not exceed 500 metres. The developed software can be plugged into an innovative card or an interface card for all traffic controllers in Thailand.
3) *Passenger Car Unit (PCU) Left (Vehicle in Queue-Software from 2)*; the traffic volumes in a queue have been collected since 2010 and the PCU Lefts based on the Green times at the second intersection plus the offset times are not more than 95 seconds. In case of the new PCU Concept, it is found the new empirical formula is useful for Thai Engineers.
4) *New Software to link the traffic data (of speeding vehicles) to a Variable Message Sign (VMS); Sizes of VMS are calculated under the criteria of Geometrical Design. In addition, the sizes of VMS's software are developed by the researcher.*
5) *Both Fuel Consumption and the Environmental Emission Assessment* are predicted for each minute (minute based assessment).

An Interface Card; a new innovation is created for the applied ITS system, the card can be used by all the traffic controllers installed by Departments of Highways and Rural Roads in Thailand. This will save the budget for traffic controllers. The interface card can transfer the data from the command line to every traffic controller nationwide.

1.3 RESEARCH OBJECTIVES

The objective of this study is to develop a new adaptive real-time traffic control system based on the image processing technology for mitigating traffic impacts at intersections. It deals with the traffic impacts of traffic safety, traffic congestion, air pollution and fuel consumption. In the adaptive system, it consists of one hardware system of interface which is compatible with most of traffic controllers in Thailand and some new software for Traffic Classified Count (TCC), Traffic Synchronization and Simulation (TSS), Virtual Loop Detectors (VLD), Enforcing Speed (ES) and Lane Changing Monitoring (LCM).

The study proposes a method for dealing with intersection traffic situation and accidents. To remedy traffic accidents, the new ITS technologies will be applied, these include: new equipment such as, CCTVs (PTZ) and the five newly developed, such as 1) *An Interface Card* which can be used with other traffic controllers in Thailand, 2) *Image sensing software* capable of performing classified traffic counts of 5 vehicle types (TCC) including TUK-TUKS and SAMLAW and traffic volumes-simulation and planning at each intersection, 3) *Software of headway measurements within 5 seconds which serves as a trigger* when vehicles approach the intersections (TSS1), 4) *Traffic synchronization and simulation software* (TSS2) capable of managing the offset time-phase or Green Wave Phase by simulation and real-time monitoring, 5) The Virtual Loop Detector (VLD) which supplies data to *the Software for lane changing monitoring* (LCM) and 6) *the Software for monitoring speeding or Enforcing Speed* (ES). Furthermore, *New Software to link vehicle speeding data (over controlled speed) to VMS*; Sizes of VMS are calculated under the criteria of Geometrical Design (AASHTO, 2001). *The various sizes of VMS's software* are also developed by the researcher.

In case of mitigating the negative traffic impacts of road crashes based on "the Vision Zero Concepts", comparison is made between before and after of the traffic situation after the application of ITS technology, especially the parameters compared include the queue length (number of PCU left in the queue), the number of accidents from the RLR (Red Light Running), the speed of vehicles approaching to the intersection and the prohibition of vehicle lane changing.

As for the study of Environmental Problems and Wasteful Fuel Consumption, the objectives of this research aspects are to calculate traffic noise based on the model of U.K. Transport and Road Research Laboratory and the Department of Transport, to verify the impact of the implemented ITS technology on emission using the author's previously developed emission model for CO and PM_{10}, to develop 3 fuel consumption models for popular passenger cars in Thailand with engine capacity of 1.6 L, 1.8 L and 2.0 L and to compare the traffic impacts before and after the installation of the ITS technology in terms of the level of traffic noise, CO, PM_{10} and fuel consumption under a minute based assessment.

1.4 SCOPE AND LIMITATION

The case study intersections comprise two intersections, 460 meters apart, located in the suburb of Bangkok. Crash data from January 2005 to October 2011 were used to analyze the causes of crashes at both intersections. The major causes of accidents were drivers' disobedience of traffic laws and malfunction of the equipments. The traffic accidents were caused by Red Light Running (RLR), Speeding and Lane Changing when approaching the intersections. The researcher sets out to remedy the traffic situations by developing 4 major types of Image Sensing Software, a major type of Traffic Synchronization and Simulation Software, 2 minor types of Software for Transmitting Signal Command to VMS and for Determining Sizes of Letter in VMS, and a new innovative interface card for traffic controller. The functions of the software are further described:

1) An innovated image sensing software can perform Traffic Classified Counts of 5vehicle types (TCC) including the Para-Transit TUK-TUKS and SAMLAW.
2) It serves as a trigger on the Virtual Loop Detector (VLD) within 5 seconds of headways when vehicles approaching the isolated intersection (TSS1).
3) It applies for Lane Changing Monitoring (LCM).
4) It can monitor speeding or Enforcing Speed (ES).
5) Traffic Synchronization and Simulation software (TSS2) is able to manage the offset time-phase or green wave phase by traffic simulation classified counting and real-time monitoring.
6) Software for detecting speeding-signal transfers the signal to the VMS.
7) Software for modeling the size of letters in VMS determines the appropriate size of letters for display in VMS when vehicles approaching the intersection.
8) A new innovative Interface Card is produced for the applications of signal command interfacing among TCC, TSS1, LCM, ES and TSS2 Software and Servers with the Existing Traffic Controllers (Excluding Solid-State Traffic Controller and including Micro-Processor Traffic Controller).

In summary, the seven innovations in software and a new hardware innovation can be applied for most intersections in Thailand. To field-test the efficacy of these innovations, an isolated intersection and a site with two adjacent intersections will be used to test these software and concepts and the hardware, in order to verify their capability in mitigating intersection traffic problems in Thailand.

Moreover, a new PCU Concept will be derived, which will be useful for Thai Engineers. The existing environmental situations, especially the one-minute based assessment of CO, PM_{10} Level and Noise

Pollution Level have an influence on the road users and people living near the intersections. The pollution models will be proposed using collected data and statistical methods. For the case of Fuel Consumption, the new model will also be illustrated as based on the one-minute based assessment and the data of license plates of registered vehicles, especially cars and other 4- wheel vehicles. Finally, the 7 software, hardware, a new PCU Concept, the prediction of CO, PM_{10} Level and Noise Pollution Level will be combined into the HYBRID ITS System.

1.5 DISSERTATION ORGANIZATION

The remaining chapters of this dissertation are organized as follows. **Chapter 2** summarizes the literature review concerning this study including image sensing and telecommunication techniques, such as Specification of CCTVs, Tracking and Detection of Virtual Loop Detector for Classified Count of Vehicles, Trigger Signal, Lane Changing and Speeding, Noise Reduction and Image. Enhancement Techniques, Fine Tuning Parameters and Calibration, Telecommunication Techniques and Data Collection, Traffic Signalization Techniques for example, PCU (Passenger Car Unit), Optimum Cycle Times and Phasing for Vehicles Actuated (VA) signal control, Traffic Synchronization (Offset Times) and Rechecking of Traffic Cycle Times and Phasing, Lane Changing and Controlled Speed Techniques for instance, Geometrical Design for Lane Changing and Geometrical Design for Over Speeding, Environmental and Fuel Consumption Techniques, such as Traffic Noise, Air Emission Models and Fuel Consumption Models.

Chapter 3 presents Methodologies focusing the study of Traffic Signalization Techniques, e.g., PCU (Passenger Car Unit), Optimum Cycle Times and Phasing for Vehicles Actuated (VA), Traffic Synchronization (Offset Times), Rechecking Traffic Cycle Times and Phasing. Lane Changing and Controlled Speed Techniques, such as Geometrical Design for Lane Changing , Geometrical Design for Over Speeding and Evaluated Data linking of the Warning Messages to VMS – Variable Message Sign, Environmental and Fuel Consumption Techniques, for instance, Traffic Noise, Air Emission Models and Fuel Consumption Models, Image Sensing Techniques, e.g., Specification of CCTVs, Open Source of Coding in the developed software, Tracking and Detection of Virtual Loop Detector, Classified Count of Vehicles, Lane Changing and Speeding and Environmental and Fuel Consumption, Telecommunication Techniques for example, RGB – Red Green and Blue, Noise Reduction and Image Enhancement, Electrical and Coding Equipment, Interface Card for Plug-In with All Traffic Controllers in Thailand, System Integration (SI), Functions of CCTVs complied with Software (a.4 and a.5), Data Collection (SQL – Structured Query Language) and Evaluated Traffic Data Commanding to Traffic Controller and Traffic Control Centre.

Chapter 4 describes Data Collection relating to the Study Site (Case Study Intersections), for including, Road Conditions, Traffic Situations, Traffic Accidents, Traffic Pollution and Fuel Consumption. Data Collection, such as Devices and Measurement System, Data Collection Times Periods and Structured Query Language (SQL), Field Implementation e.g., Software and Equipment for Traffic Signalization and Synchronization, Software and Equipment for Vehicle Lane Changing and Speeding, Software for Vehicles Emission and Fuel Consumption.

Chapter 5 explains the installation and implementation of hardware as well as Software Developed System in the research**,** Numerical Implementation**,** such as Traffic Signalization, Traffic Synchronization (offset times), Rechecking Traffic Signal Cycle Times and Phasing, Lane Changing and Controlled Speed, Telecommunication System, Field Implementation, e.g., Software and Equipment for Traffic Signalization and Synchronization, Software and Equipment for Vehicle Lane Changing and Speeding Maneuvers.

Chapter 6 illustrates the Traffic Signal Synchronization in terms of the Applied ITS Technologies, such as Road Conditions, Traffic Situations and Traffic Accidents, Fitting Empirical Equations provide Traffic Signalization and Synchronization and Evaluation Results.

Chapter 7 points to the Lane Changing and Speeding briefing to After Applied ITS Techniques for example, Road Conditions, Traffic Situations, and Traffic Accidents, Fitting Empirical Equations, for instance, Traffic Lane Changing and Speeding and Evaluation Results.

Chapter 8 presents the Traffic Emission and Fuel Consumption for instance, Applied ITS Technologies, Traffic Pollution, Fuel Consumption, Fitting Empirical Equations, e.g., Traffic Emission and Fuel Consumption and Evaluation Results.

Chapter 9 shows the Conclusions focusing on Research Contributions to improvement in Road Conditions, Traffic Situations, Traffic Accidents, Traffic Pollution and Fuel Consumption as well as recommendations for Future Research.

Chapter

2

LITERATURE REVIEW

2.1 IMAGE SENSING AND TELECOMMUNICATION TECHNIQUES

There are several topics to focus on this section, such as Specification of CCTVs, Tracking and Detection of Virtual Loop Detector for Classified Count of Vehicles, Trigger Signal, Lane Changing and Controlled Speed, Noise Reduction and Image Enhancement Techniques, Fine Tuning Parameters and Calibration, Telecommunication Techniques and Data Collection.

2.1.1 Specification of CCTVs

There are two types of CCTVs for Image Sensing as summarized in **Table 2.1**:

Table 2.1 Compared Specifications between CMOS (Complementary Metal Oxide Semiconductor) and CCD (Charge Couple Devices). Source: Holland (2012)

Parameter	**CMOS**	**CCD**
# pixels	5 - 8 Megapixels	8 – 16 Megapixels
Pixel size	1.4 – 1.7 μm	10 – 15 μm
Imaging area	15 mm^2 (5M)	3775 mm^2 (16M)
Technology	130 nm CMOS	2.5 μm CCD
Illumination	Back illumination	Back illumination
Optical thickness	~ 3 μm	10 – 250 μm
Peak QE	~ 55% (color filter)	~ 90 – 95%
Operating temp	Up to 50°C	-100°C – -140°C
Dark current	20 – 30 e-/pixel/sec	Few e-/pixel/hr
Read noise	~ 2 e-	~ 2-5 e-
Full well	~ 4500 e-	~ 200,000 e- (15 μm)

Axis Communications AB (2010) stated that Ordinary CMOS chips were used for imaging purposes, however the image quality was poor due to their inferior light sensitivity. Modern CMOS sensors used a more specialized technology and the quality and light sensitivity of the sensors had rapidly increased in recent years. The CMOS chip incorporated amplifiers and A/D-converters, which lowered the cost for cameras since it contained all the logics needed to produce an image. Every CMOS pixel contained conversion electronics. Compared to CCD sensors, CMOS sensors had better integration possibilities and more functions. However, this addition of circuitry inside the chip led to a risk of more structured noise, such as stripes and other patterns. CMOS sensors had a faster readout, lower power consumption, higher noise immunity, and a smaller system size.

As shown in **Table 2.2**, 2seetv Ltd (2010) presented that operating under the PAL system produced 25 frames per second (fps) and the maximum rate was recorded. It was usually not necessary to record at the highest rate as the human eye is able to detect a frame rate of no greater than about 12fps. In addition, most applications producing a recording rate of 3 or 6 fps were adequate. The following Table shows a guide for choosing the appropriate frame rate for the application.

Table 2.2 A guide to different applications. Source: 2seetv Ltd (2010)

Application	Typical Recording Rates (Frames per Sec)
Car Parking, external people movement	0.5-2fps
Office, shop	2fps
Money counting	3.5-7.5fps
Traffic monitoring	5-25fps

2.1.2 Image Sensing Techniques, Tracking and Detection for Traffic Control

Image Sensing Technique: Menon (2005) proposed that all the image processing for the visible light cameras were done using grayscale images. The background image was capable of adapting to the current lighting conditions. Zheng et al. (2006) advised that the signal cycle failure (or overflow) was an interrupted traffic condition in which a number of queued vehicles were unable to depart due to insufficient capacity during a signal cycle. Furthermore, an algorithm for traffic signal cycle failure detection used a video image processing (the frame rate was from 24 frames per second (fps) to 30 fps.) that was implemented using Microsoft Visual C#. Rosenbaum et al. (2010) stated that a road traffic monitoring solution based on an airborne wide area camera system was developed. An image processing chain for real-time traffic data extraction from high resolution aerial image sequences (a frame rate of up to 3 Hz and recorded at a flight height of 1500 m) with automatic methods was taken into account.

Bucher et al. (2003) studied that the high level preprocessing features, the whole domain specific processing, i.e., the vehicle segmentation, the tracking and intermediate hypotheses evaluation, as well as the lane detection, were computed within 10ms as presented in **Figure 2.1**.

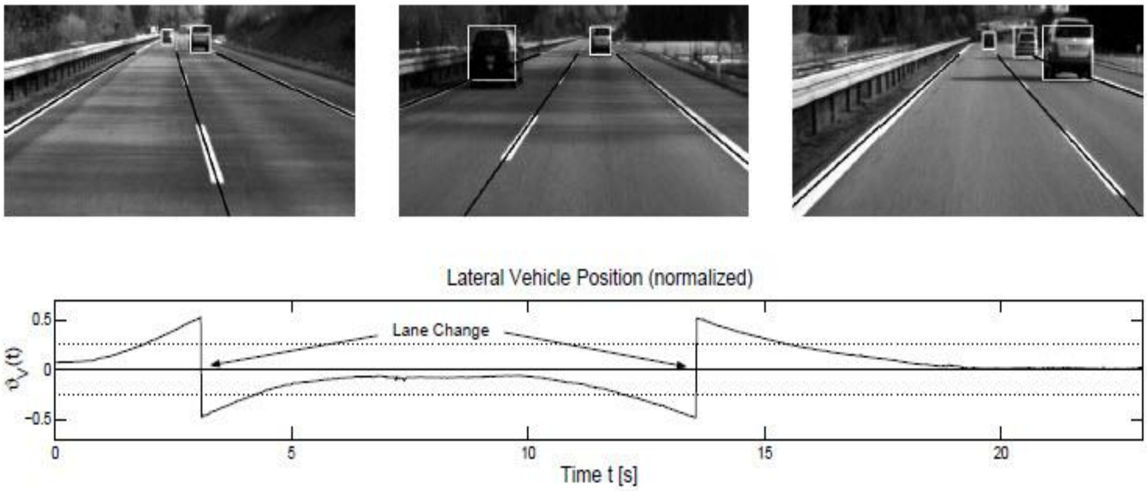


Figure 2.1 Results of the image processing system tested on a sequence of 1440 images (24 seconds, 60Hz). The plot showed the normalized lateral vehicle offset with respect to the middle of the current lane. The images were taken at t = 2:4s, t = 11:5s and t = 19:5s.
Source: Bucher et al., (2003)

Choudekar et al. (2011) recommended that the image sequence was analyzed using digital image processing for vehicle detection, and according to traffic conditions on the road traffic light was able to be controlled. Jain et al. (2012) informed that a simple image processing algorithm was used to estimate traffic density and the specific segments operating at low-capacity levels for long time periods. Niksaz (2012) proposed that there were three primary morphological functions; erosion, dilation and hit-or-miss, respectively. After subtraction, certainly some additional points on the image were left and these parts from the additional points had been removed. Furthermore, the objects on the image resulting from subtraction were removed and then interior and border areas of mark cars in the image resulting from subtraction had been traced. Gupta et al. (2013) proposed that *Matlab* was a high level language and included high-level functions for two-dimensional and three-dimensional data visualization, image processing, and animation. Image processing was also referred for processing of a 2D picture by a computer for example, a (x, y) with as the amplitude (e.g. brightness) of the image at the real coordinate position (x, y).

<u>Image Sensing for Traffic Signalization:</u> Sensor selection and data processing were dependent on the application and algorithm selected to support the application. Arterial signal control was applied with Urban Traffic Control Systems (UTCS), Critical Intersection Control (CIC), Sydney Coordinated Adaptive Traffic System (SCATS) and SCOOT (Klein, 2002). Video Imaging Vehicle Detectors (VIVDs) were used to replace ultrasonic vehicle detectors as a new means of vehicle counting and average velocity measurement by a camera covering multiple lanes. Right-turn control meant a traffic

light control system in which the presence of vehicles in the right-turn lane of an intersection was detected and the right turn green light was turned off when right-turning vehicles were no longer detected. Moreover, time to confirm that no vehicle was following (green time extension per vehicle was approx. 3 seconds) was required after every vehicle detection period (Anzai et al., 2000).

The vehicle location (Floating Car Data) was an efficient way to collect real-time traffic information. In addition, more accurate and relevant real-time traffic information led to a lot of improvements in many areas, such as Congestion reduction, Traffic queue detection, Dynamic network traffic control, and Reducing fuel consumption (Leduc, 2008). Approaching for the traffic congestion detection in time series of airborne optical digital camera images was proposed. Methods were based on the estimation of the average vehicle speed on road segments (Palubinskas et al., 2009).

Zheng et al., (2006) advised that the signal cycle failure (or overflow) was an interrupted traffic condition in which a number of queued vehicles were unable to depart due to insufficient capacity during a signal cycle. Furthermore, an algorithm for traffic signal cycle failure detection used a video image processing (the frame rate was from 24 frames per second (fps) to 30 fps.) that was implemented using Microsoft Visual C# as shown in **Figure 2.2**.

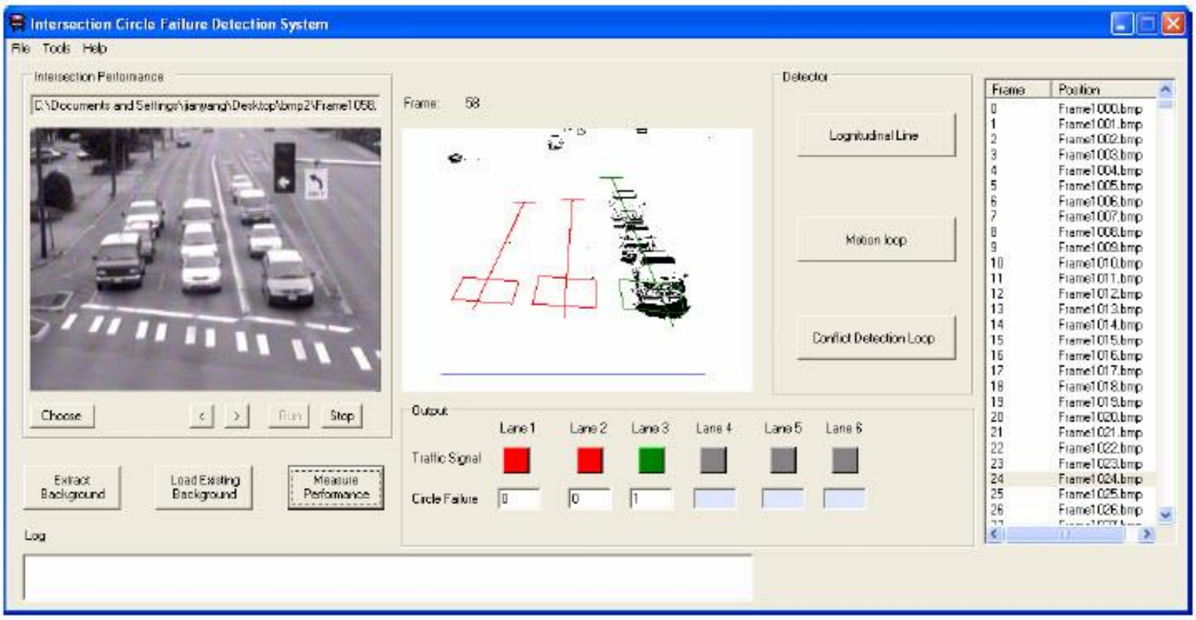


Figure 2.2 A snapshot of the user interface. Source: Zheng et al., (2006)

The application of ITS Technology by CCTV of the Royal Thai Police for improvement of traffic flow including an image-sensing concept for adaptive synchronization have been used to detect traffic data. This data has been collected and processed at Traffic Command and Control center. The locations of the camera were near stop line looking at the approach to the intersection. A maximum of 4 lanes for traffic volume collection and a maximum of 2 lanes of queue length measurements were covered under a camera. Data regarding traffic volume, vehicle type, speed, and image (still picture) data were sent back to the center via ADSL lease line. The system was designed to optimize the communication rate and thus the 256 kbps line was sufficient for the linkage between each roadside camera and the center. The traffic data (volume, speed, queue length) transmission was set to every 5 minutes, while the image data was sent every 1 minute (Narupiti et al., 2012).

Traffic load computation for real-time traffic signal control system as well as the need of hour was taken into consideration in order to make road traffic decent, safe, time saving and fuel conserving. A model counted the traffic load by some parameters such as edge detection, histogram equalization, labeling and removing the noise with the help of median filter. The load computed was then used to control the traffic signals (Gupta et al., 2013).

Image Sensing for Lane Changing: The development of appropriate techniques for robust lane detection, object classification, tracking, and representation of task relevant objects was taken into account. Concentrate was focused on image processing as the main source of relevant object information, representation and fusion of data arose from different sensors, and behavior planning and generation as a basis for autonomous driving (Bucher et al., 2003). The performance of vehicle segmentation and evaluation based on performance of incident detection were performed by using the video images at the same locations inside the roadway tunnels. Especially, the system was able to detect the incident by detecting lane changing behavior against a stalled vehicle. In addition, the behaviors were correctly detected because vehicle trajectories were extracted successfully by following the precisely segmented vehicles (Kamijo and Inoue, 2007).

Liu and Yamazaki (2010) researched that the detection of the vehicle speed, two images covering the same area with a time lag, were needed. Firstly, an overlap area from two consecutive images was extracted to obtain two images over the same area. Geometric distortions between two images existed due to the perspective projection of an aerial camera. Hence, registration for the pairs of images was conducted using 8 ground control points. The two images in a pair after registration had different pixel sizes. Therefore, the images were arranged to the same pixel size by image mosaicing. Visual speed detection was first carried out to obtain reference data by overlapping the second image to the first one. The speed can be detected by measuring the difference of vehicle’s outline, as shown in **Figure 2.3**. Then, the speed and moving direction of vehicles were detected automatically by matching the databases for the two consecutive images using the parameters of order, direction, size and distance.

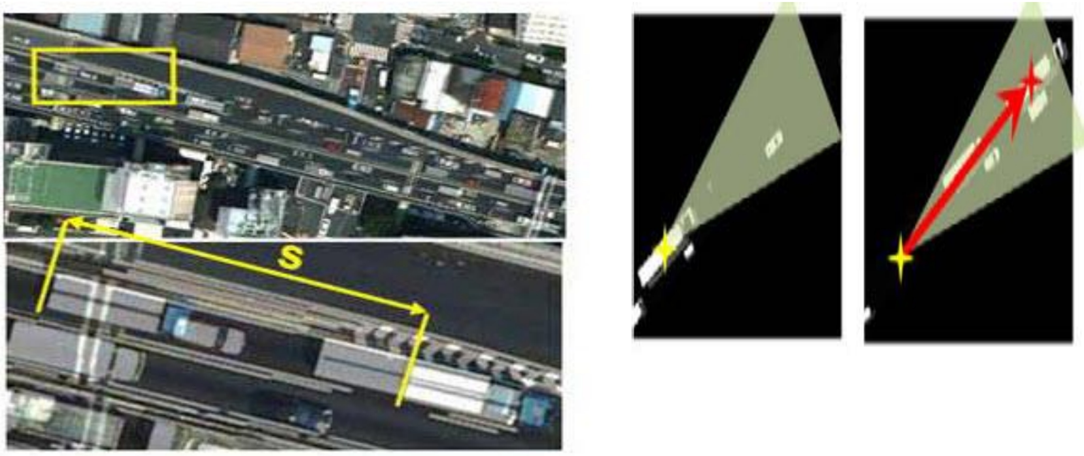


Figure 2.3 Visual speed detection by overlapping two images and Condition of matching the same vehicle. Source: Liu and Yamazaki (2010)

The proposed approach was based on the combination of various techniques: change detection, image processing and incorporation of a priori information such as road network, information about vehicles and roads and finally a traffic model. Moreover, image processing techniques were applied to derive the relevant vehicle density in the finalized changed image. The average vehicle velocity on the road segment was able to be derived (Palubinskas et al., 2009). Driver assistance functions used of the lane structure represented by lane borders and lane markings that were analyzed. Lane analysis was performed on the road region to remove road pixels. Only lane markings were the interests for the lane detection process (Somasundaram et al., 2011).

2.1.3 Noise Reduction and Image Enhancement Techniques

The adaptive image enhancement filtering algorithm was developed using genetic algorithms and implemented on the specific board. For degraded image from unknown noise type, proposed filter system was able to generate optimal combination of filter set, sequent order, and their parameters. The experimental results presented that the proposed system was superior in noise reduction, contrast enhancement, and blurring. With the successful implementation of noise adaptive filter, degraded image from unknown noise was enhanced successfully.

TechSource Systems (2005) described that one of the most basic ways to enhance an image was to change its *brightness* and its *contrast*, and this was done by working with the image's histogram. By stretching the color distribution, equalizing the distribution of colors to use the full range, and adjusting the scaling of the colors were taken into consideration. The separation of an object from its background was the way to the *thresholding* technique. In addition, subtraction, multiplication and division of a number of different image processing techniques were implemented by the addition and multiplication an image contrast increase facilitating the edge detection process. In other words, the subtraction and division changes were detected from one image to another.

2.1.4 Fine Tuning of Parameters and Calibration for Image Sensing

Loose (1999) advised that the self-calibration concept, implemented in each sensor pixel, decreased the overall fixed pattern to a standard deviation (rms.) of less than 4% of an intensity decade. A significant reduction by a factor of more than 20 rms. was not calibrated. The slope variations, was calculated from the individual pixel slopes averaged over 3 decades, amounting to less than 1% per decade. The slope variations increased in the lowermost decade (the fixed pattern at an intensity of 10mW/m2 rise to 8.5% of a decade). Another disadvantage of the realized self-calibrating photoreceptor was the large pixel size of 24*24 m^2.

Grammatikopoulos et al. (2002) commented that the calibration process and the accuracy had to be evaluated with an Ordinary Video Camera (frame size: 640 x 512). For the purpose, 10 frames from different sites were first used to estimate camera height. To measure by tape with an estimated accuracy of ±2 cm was taken into consideration and **Table 2.3** shows the Lane width accuracy from 30 frames.

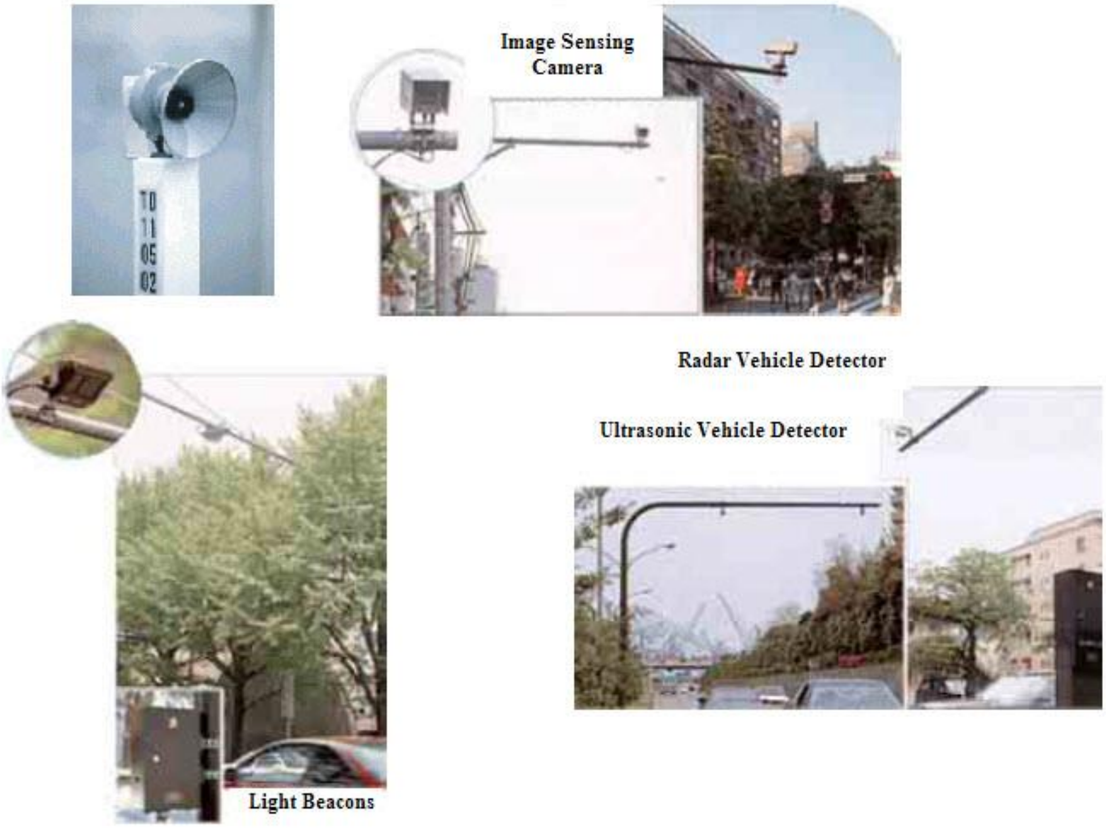
Table 2.3 Lane Width Accuracy from 30 Frames**.** Source: Grammatikopoulos et al. (2002)

Mean Difference (d) cm	RMS Difference (r) cm	Standard Deviation (σ) cm
2.3	4.7	3.8

Satisfactory measurements of lane width were expected to have accuracy (r) better than 5 cm (the largest RMS difference was 7.1 cm), while lane widths typically differed in steps of 25 cm. Image measuring errors and small uncorrected parts of x -tilts, causing perspective distortions, were considered as the main sources of inaccuracy, as expressed in the repeatability s of measurement. Obviously, an averaged width from more than one estimate per frame was generally expected to be closer to ground truth. With a camera, reliable measurements were possible within a depth range of about 10–25 m in front of the vehicle.

2.1.5 Telecommunication Techniques

Hollborn (2002) concluded that the roadside traffic sensors collected the traffic information. Additionally, helicopters, patrol cars and police motorcycles supervised the street network and sent their information to the control center. Moreover, the 110 Communication Command Centers were directly connected. Police stations, police boxes and television cameras completed the collection of traffic information. The traffic control center received the various information data about traffic conditions, such as traffic volumes, congestion lengths and travel times. Various vehicle detectors were in use, including ultrasonic, infrared (optical beacons), radar, loop vehicle detectors and image sensing cameras. The most common devices used in Japan were the ultrasonic vehicle detector as reported in **Picture 2.1**.



Picture 2.1 the Detectors installed in Japan. Source: Hollborn (2002)

Virginia Department of Transportation (VDOT) (2008) proposed that a number of communication approaches were available for the CCTV system. Different infrastructures were discussed below.

<u>Fiber:</u> An agency-owned fiber network had nearly unlimited bandwidth and enabled multiple cameras to be controlled on a network line. VDOT would own any new fiber and would be responsible for installing the fiber and maintaining the fiber and related equipment (including line-break repairs), and in exchange would have guaranteed exclusive use of the VDOT fiber network. Once fiber was provided along a corridor, VDOT could splice future cameras into the network on the existing fiber line. This method provided the greatest possible bandwidth and thus maximized possible video quality as well as the number of cameras and other ITS devices that were able to be installed on a network segment.

Telephone Line: Regular twisted-pair copper wire DS-0 telephone lines were used for ITS data transmission. However, it was not suited for CCTV cameras since its maximum bandwidth was 64 kilobits per second (kbps).

Leased Lines: A line was created through the digital multiplexing of 24 DS-0 telephone lines on a single twisted-pair copper wire. Leased Line was able to provide 1.544 Mbps of upload and download bandwidth for a single CCTV camera. These lines were leased from a commercial telecom provider such as Verizon with typical monthly costs of approximately $300 per line. They did not require VDOT to obtain right-of-way or install and maintain communication lines and equipment. They were ideal for isolated cameras in rural areas and those outside the planned fiber network expansion/coverage.

Digital Subscriber Lines (DSL): DSL services, regardless of the particular DSL variation, generally allowed download bandwidth to 3 Mbps and upload bandwidth to 384 kbps. DSL circuits were generally less expensive than leased line but were limited to a three-mile range from the nearest telecommunications provider Central Office (CO) or fiber optic digital loop carrier (DLC) cabinet. DSL generally entailed an internet connection. Like other leased lines, DSL was a commercial service provided by telecom companies for $80 to $100 monthly per connection.

Wireless Broadband: A number of broadband wireless technologies existed with the commercial service provided by telephone companies. At the time, these services were based on third-generation cellular technology with bandwidth averaging 700 kbps download and 144 kbps upload. Pricing for these services had tended to range from $60 to $80 per month for unlimited use with each device, but Verizon had begun charging monthly fees for overall use in excess of 5 GB and other providers followed suit. Even accounting for the low upload bandwidth, connecting a camera through this network for round-the-clock daily use would exceed the 5 GB monthly cap by tens to hundreds of GB per month, resulting in extreme fees. However, for temporary installations using portable cameras wireless broadband was the most convenient connection method since it did not require a fixed, immovable connection. Video quality limitations due to bandwidth availability for wireless broadband should loosen in the near future with the deployment of fourth generation wireless technologies, such as Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution of the Universal Mobile Telecommunications System (LTE). The first of these technologies expected to be available in the NRO’s area was WiMAX, which Sprint had indicated would be available in late 2008. Competing wireless carriers selected the LTE cellular technology, with Verizon’s LTE network expected to deploy in 2010.

2.2 TRAFFIC SIGNALIZATION TECHNIQUES

2.2.1 Data Collection for Traffic Control

Transportation Research Board (2005) commended that the systems were presumed compliant with the traffic management data dictionary (TMDD). However, the separate projects approached the procurement and installation stages of their implementation. The data-naming conventions used in one system were incompatible with widely used database software employed by the other jurisdiction; those conventions, while popular, had not been considered as an essential functional characteristic of the first system. Regardless of the value of the TMDD standard, expectations for the extent of its contribution to achieving interoperability appeared to have been inflated. In general, any substantial effort to train potential users encouraged the use of the TMDD and other ITS standards appeared premature until there were demonstrations of their effectiveness. Bearing on these matters were the efforts to develop the ITS Data Registry (ITS DR), an online database of the data concepts defined and used in ITS standards that were developed with USDOT support. The ITS DR was not an ITS standard. The ITS DR was intended to promote uniformity of data concepts from one standard to another and reuse of previously developed data concepts, and thereby to be a means for encouraging harmonization of standards across all applications areas.

Leduc (2008) commented that the richness of road traffic data collection sources had grown substantially. The combination of traditional on-road sensors with floating car data techniques provided high quality traffic data in real-time that was utilized by all the transportation actors. On the one hand, fixed detectors' capabilities were limited owing to important installation and maintenance costs and their poor road network coverage which was typically restricted to well known congestion zones, such as sticking on highways, tunnels or bridges. On the other hand, collecting traffic data from tracking cellular phone or GPS was technologically feasible and seemed to be a very cost-effective alternative. If current trends continued, the transportation actors would get huge benefits from the combination of fixed/mobile traffic measurements in a wide range of domains.
U.S. Department of Transportation (USDOT) (2011) stated that there were several applications of collected data as shown below:

Mobility Applications: the applications intended to enhance mobility and system management by capturing better information on road conditions (such as congestion, physical road deterioration, and weather), improving system performance, and supporting mobile transactions. Mobility applications encompassed two complementary roadmaps; one was the real-time Data Capture and Management focused specifically on data capture and communication between users. The other was the Dynamic

Mobility Applications focused on supporting development of the applications that made use of data to improve performance of surface transportation systems.

Environmental Applications: the applications intended to reduce the environmental impact of surface transportation, these applications both generated and captured environmentally relevant real-time transportation data and used this data to create actionable information, supported and facilitated "green" transportation choices for users and operators (to provide "green" transportation alternatives or options) for system operators (to receive detailed, real-time information on vehicle location, speed, and other operating conditions to improve system operation), and for vehicle owners and drivers (to advise on how to optimize the vehicle's operation and maintenance for maximum fuel efficiency).

2.2.2 PCU (Passenger Car Unit)

Several accepted methods have been used to find the PCUs since 1965 such as, the American Highway Capacity Manual (1965), Hasan and Rehan Karim (1993), Tiwari et al. (2000), Vien et al. (2006) etc. These Concepts will be applied to the New PCU Model so as to calculate the optimum cycle times and phasing for Vehicle Actuated (VA).

Highway Capacity Manual (U.S.A) Model: The term “passenger car equivalent” (PCE) was introduced in 1965. Highway Capacity Manual in the U.S.A. defined it as “the number of passenger cars was placed in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions”. Passenger Car Equivalent (PCE) values of HCM (2000) and percent of trucks/buses and Recreational Vehicles (RV) were accounted for HV effect on capacity (Ahmed, 2010). Furthermore, PCE value (under congested conditions) was more than 9% HV presence and was found to be 1.76, which was higher than the HCM 2000-recommended value of 1.5 for level freeway sections. In addition, since various microscopic models exist for the simulation of traffic flow, several micro simulations software packages were reviewed for feasibility in calculating PCEs. Bloomberg and Dale (2000) observed that overall CORSIM and VISSIM traffic engineering software were more similar than they were different (Marlina, 2012).

Japan International Cooperation Agency (JICA) Model: The PCE values derived in their research were then used but with slight adjustment in the JICA study (2002) by the Royal Thai Police and Municipality of Chiang Mai, Thailand to design and analyze signalized intersections as shown in **Table 2.4**. However, at the moment, these values may not be representative of rural and suburban traffic conditions in Thailand. Therefore, it was necessary to acquire more realistic PCE values with respect to Thai road conditions.

Table 2.4 PCE values for signalized intersections according to JICA study compared with Webster values**.** Source: JICA (2002) and Webster (1966)

Vehicle categories	JICA Study (2002)	Webster (1966)
Passenger cars and Pickup	1.00	1.00
Motorcycles	0.33	0.33
Light lorries 6 wheels, Van	2.00	1.75
Heavy Truck or Trailer	3.00	2.25
Buses	2.50	1.75

Hasan and Rehan Karim (Malaysia) Model: Other similar researches were conducted in Malaysia. One of the most prominent researches was conducted by Hasan and Rehan Karim (1993) on PCE values of through vehicles under Malaysian conditions. In their research, they found that for heavy vehicle categories, the values obtained were lower than the values recommended by Webster. The PCE value of Motorcycles was 0.35.

Leong Lee Vien, Wan Hashim Wan Ibrahim, and Ahmad Farhan Mohd Sadullah (Malaysia) Model: In the research, the headway ration method, which was initially proposed by Leong Lee Vien, Wan Hashim Wan Ibrahim, and Ahmad Farhan Mohd Sadullah, was applied in PCE values in 2008. The researcher collected the data by recording details of vehicle departures with event-recording equipment. The inter-vehicle time headways were calculated by measuring the elapsed time between the crossing of the stop line by the rear axle of the vehicle preceding it and the crossing of the stop line by the following vehicle. Brown and Ogden (1988) derived the corrective factor (C) by using the least square method as presented below:

$$\text{Corrector} = \frac{abcd(w - x - y - z)}{abc + abd + acd + bcd} \quad (2.1)$$

Where *a* was the number of headways when car is following car, *b* was when car is following type X vehicle, *c* was when type X vehicle is following car, *d* was when type X vehicle is following type X vehicle, *w* was the mean headways when car is following car, *x* was when car is following type X vehicle, *y* was when type X vehicle is following car and *z* was when type X vehicle is following type X vehicle. These relationships were presented in **Figure 2.4**.

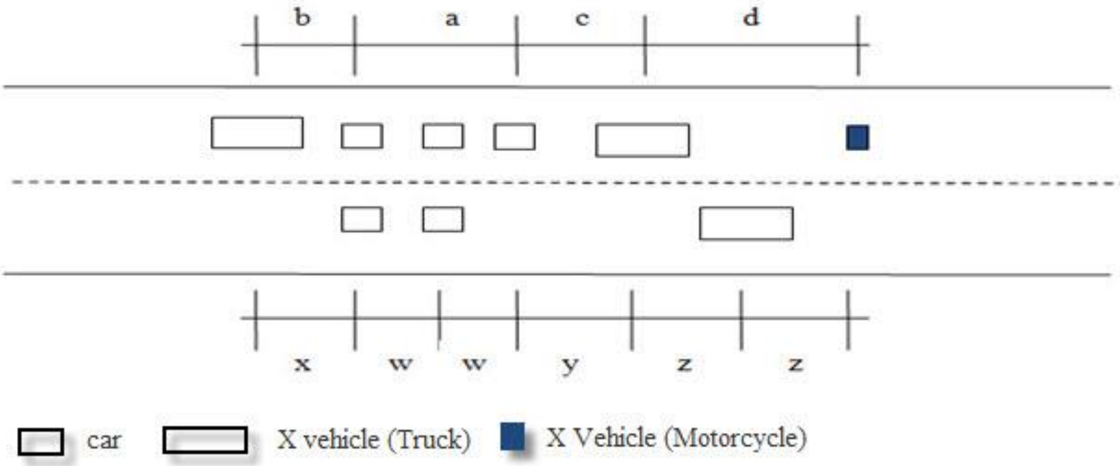


Figure 2.4 Features of car and vehicle type X on the case study section

Furthermore, the adjustment headways for car and other vehicles were taken into account. Adjustments were then made to the raw data using the following equations:

Adjusted mean headways when car is following car:

$$\bar{h}_{A(c-c)} = U - \frac{C}{\text{Number of headways car following car}} \tag{2.2}$$

Adjusted mean headways when type X vehicle is following type X vehicle:

$$\bar{h}_{A(x-x)} = U - \frac{C}{\text{Number of headways vehicle type X following vehicle type X}} \tag{2.3}$$

where U was uncorrected mean headway or mean headway and C was correction factor. Accordingly, the calculation of PCU equivalents e_x will be proposed as shown below:

$$ex = \frac{\bar{h}_{A(x-x)}}{\bar{h}_{A(c-c)}} \tag{2.4}$$

Table 2.5 shows the sample data and PCE calculation for auto-rickshaws as described below.

Table 2.5 PCE calculation for auto-rickshaws. Source: Saha and Hossain (2009)

Traffic Factors	$\bar{h}_{A(c-c)}$	$\bar{h}_{A(c-x)}$	$\bar{h}_{A(x-c)}$	$\bar{h}_{A(x-x)}$
No. of headways	3,545	1,417	1,343	623
Mean headways	1.8955	1.9193	1.9341	1.411
Adjusted mean Headways	1.942	2.035	2.056	1.674
PCE (Auto-rickshaw)	0.86			

GEETAM TIWARI, JOSEPH FAZIO and SUSHANT GAURAV (India) Model: The PCU for homogeneous traffic was based on the modified traffic density method (Tiwari et al., 2000). The density method based on underlying homogeneous traffic concepts such as strict lane discipline, car following and a vehicle fleet that did not vary greatly in width. An idealized traffic mixture of only passenger cars was equivocated with another 100 percent homogeneous traffic stream. The other homogeneous traffic stream consisted only of another traffic entity type such as heavy vehicles or recreational vehicles. The space meant speed of the passenger-car traffic stream was 60 km/h in **Figure 2.5**. The speed implied that passenger cars maintained a specific, average gap. As mean passenger-car speed changes, the average spacing changed such as, traffic concentration or density. Moreover, average spacing was also the inverse of density as shown in the following equation:

$$\bar{h}_{space} = \frac{1}{k} \tag{2.5}$$

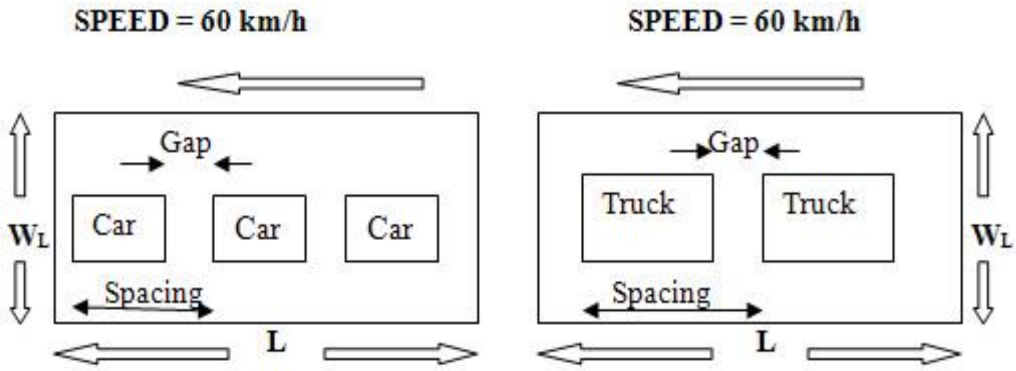
where k was density (entities/km), and $\bar{h}_{space}$ was average front-bumper to front-bumper spacing (km). Base conditions for Indian multilane rural and suburban highways have the following characteristics:

- Level terrain, with grades no greater than 2 percent of gradation to allow for bridges in the up or down directions
- 3.5 metre lane widths
- 0.5 metre from carriageway to sidewalk
- 3 metres of raised median
- No direct access point along the roadway

As the result, the passenger car and truck streams had equal space mean speeds when using the density method. One was able to equivocate the density of trucks to the density of passenger cars under homogeneous conditions to find the PCUs for trucks using the formula:

$$PCU_{Truck} = \frac{k_{car} / W_L}{k_{Truck} / W_L} \tag{2.6}$$

where k_{car} was the density of cars in pure homogeneous traffic (cars/km), W_L was the lane width in metres of the lane in homogeneous traffic, k_{Truck} was the density of trucks in pure homogeneous traffic (trucks/km) and PCU_{Truck} was the passenger car unit for trucks given homogeneous traffic behavior. In the density-based PCU method for homogeneous traffic where car following and lane-discipline behavior prevailed, all traffic entities used an equal W_L. **Table 2.6** shows the results of PCU during Peak and Off-peak hours by the Density Method.



(a) 100% passenger car in the traffic stream (b) 100% heavy vehicles in traffic stream

Figure 2.5 Homogeneous Traffic Density for PCU Estimation**.** Source: Tiwari et al. (2000)

Table 2.6 PCU – Peak and Off-peak hours based on the Density Method. Source: Tiwari et al. (2000)

Vehicle	PCU Peak Density	PCU Off Peak Density
Car	1.00	1.00
MC	0.42	0.47
LT	2.02	2.17
Bus	3.03	3.17
Truck	3.36	3.57

2.2.3 Optimum Cycle Times and Phasing for Vehicles Actuated (VA) Control

aaSIDRA -Full version 1.0.6.145 (2000) and TRAFFICWARE and CORSIM (2003),Traffic Engineering and Simulation Software, were used to compute the optimum cycle times and phasing at intersections. Traffic parameters during peak hours including queue length on the main road were measured and compared with the results from the software. Yusria Darma, Mohamed Rehan Karim, Jamilah Momad and Sulaiman Abdullah (2005)'s concept will be presented in the following part.
aaSIDRA (2000) - compute the optimum cycle times and phasing at intersections: aaSIDRA was a software package that was developed in Australia to analyze roundabouts. The inputted to aaSIDRA included the hourly volumes, as well as the intersection geometry. Although the intersection geometry was one of the inputs to aaSIDRA, it was not explicitly considered in this analysis. In addition, aaSIDRA analyzed other types of intersections, including both signalized and unsignalized intersections. The delay time per vehicle at intersection was particular to evaluate traffic situation at intersections. Level-of-service definitions based on delay (Highway Capacity Manual - HCM Method) and Control delay (d) per vehicle in seconds were presented at **Table 2.7**.

Table 2.7 Level of Service of Delay at intersection. Source: aaSIDRA (2000), Reference Guide Section 2.4

Level of Service	Signals and Roundabouts	Stop and Give-Way (Yield) Signs
A	d <=10	d <= 10
B	10< d <= 20	10 < d <= 15
C	20 < d <= 35	15 < d <= 25
D	35 < d <= 55	25 < d <= 35
E	55 < d <= 80	35 < d <= 50
F	80 < d	50< d

Delay to a vehicle was the difference between interrupted and uninterrupted travel times through the intersection. aaSIDRA delay estimates were based on the path-trace (instrumented car) method of measuring delays. The average delay predicted by aaSIDRA was for all vehicles, queued and unqueued. Based on the definition, the total (aggregate) delay was the product of average delay and the total demand flow rate. The total delay for a movement (or lane group) was the sum of total delays for all lanes that belong to the movement (or lane group). Moreover, aaSIDRA Guide Book stated that "the delay to a vehicle which decelerated from the approach cruise speed to a full stop (due to a reason such as a red signal, a queue ahead, or lack of an acceptable gap), waited and then accelerated to the exit cruise speed was considered to include the delay due to a deceleration from the approach cruise speed down to an approach negotiation speed and then to zero speed, idling time, acceleration to an exit negotiation speed along the negotiation distance, travelling the rest of the negotiation distance (if any) at the constant exit negotiation speed, and then acceleration to the exit cruise speed".

Darma et al. (2005) stated that several vehicles reaching the intersection came to a complete stop. The vehicles were necessary to stop either as a consequence of their arrival during the red interval or during the green interval when the queue of vehicles that had formed during the previous red interval had not yet fully dissipated. While it was further observed that the rest vehicles only experienced deceleration and acceleration delay, as these vehicles reached the intersection when all previously queued vehicles had already started to move and therefore only needed to slow down to maintain a safe distance with the vehicles ahead of them as seen in **Figure 2.6**. Besides the control delay, there was another type of delay which vehicles experienced at signalized intersection. This type of delay was identified as geometric delay. Geometric delay is the time lost due to the intersection geometry being large for turning movements. Total delay of a vehicle was the sum of control delay and geometric delay. On the other hand, drivers' perception and reaction time to the changes of the signal displayed at the beginning of the green interval and during yellow interval to mechanical constraints and to individual driver behavior also contributed to the traffic delay at signalized intersection.

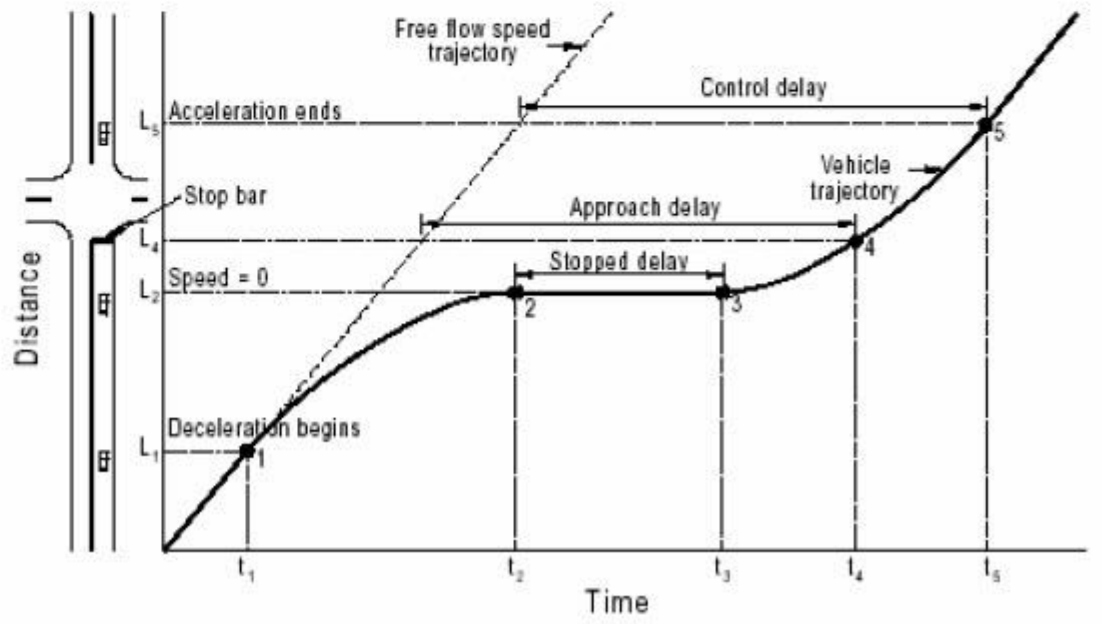


Figure 2.6 Delay Terms at a Intersection. Source: Darma et al. (2005)

Williston (2007) proposed that Trafficware Synchro was developed privately as an application of the HCM methodology and it was able to analyze many different facilities, including arterials and intersections. For an intersection, to input traffic volumes, geometrics, and control data including STOP/YIELD, or green time, cycle length, etc. were taken into consideration. The program explicitly outputs the Intersection Capacity Utilization (ICU) report and ICU LOS. These were based on the Percentile Delay Method, rather than the HCM methodology (Webster's Method). Nevertheless, the program offered an HCM report for both signalized and un-signalized intersections that was based on the HCM methodology. The report detailed the delays, LOS, v/c ratio, and average and 95th percentile queues. The results on-screen did not exactly reflect the HCM methodology.

2.2.4 Traffic Synchronization (Offset Times)

Williston (2007) recommended that SIDRA was a software package that was developed in Australia to analyze roundabouts. The inputs to SIDRA included the hourly volumes, as well as the intersection geometry. Although the intersection geometry was one of the inputs to SIDRA, it was not explicitly considered in the analysis because SIDRA was able to analyze other types of intersections, including both signalized and un-signalized intersections, particularly those with unusual geometry, such as five-legged intersections, the geometry was included in the inputs. However, in the case of roundabout analysis, the geometrics were not used in the analysis. The methodology included in the software was based on critical gaps, much like HCS+. A recent update of SIDRA introduced the use of an adjustment factor to account for the difference between U.S. driving conditions and those in the

United Kingdom (U.K.) and Australia, where drivers were more familiar with roundabouts. Recent studies had concluded that SIDRA might overestimate the capacity of single-lane roundabouts and might underestimate capacity for two-lane roundabouts. The MOEs from SIDRA include average delay in seconds, LOS, v/c ratios, and queue lengths.

The Offset or Green Wave Concept: the Offset time-phase or Green Wave phase was used of the method of ARRB –Australian Road Research Board (Akcelik, 1989). The offset between the starting times of the upstream and downstream green periods provided a reasonable progression for a platoon of vehicles as be calculated from:

$$O = \frac{t_c + (g_u - g_d)}{2} \qquad (2.7)$$

where t_c was the average cruising (uninterrupted travel) time and g_u, g_d was the upstream and downstream green times (all parameters were in seconds).

The effect of the formula was to synchronize the mid-points of successive green periods using the average cruising time for the platoon under consideration. The offset was equal to the average cruising time, O was t_c, so as to provide for uninterrupted travel of the front of a platoon (note that t_c used for an off-peak plan might be smaller than the value used for a peak period plan). In cases of the downstream, the queue was likely to interfere and the offsets were calculated from:

$$O = t_c - (\frac{N_d}{s}) \qquad (2.8)$$

where t_c was the average cruising time in seconds, N_d was the average number of vehicles in the downstream queue (before the arrival of the platoon under consideration), s was the saturation flow (veh./s) at the downstream signal and $\frac{N_d}{s}$ was the time for the downstream queue to clear the stop line.

The desirable offsets were expressed in terms of corresponding phase change times in the signal coordination plan as an input to the master controller. This was due to the fact that the offset calculations were based on the starting times of effective green periods. The following offset-phase change time relationship can be used for the purpose:

$$O_{ud} = (F_d + a_d) - (F_u + a_u) \qquad (2.9)$$

where O_{ud} was the offset for travel from u to d, F was the phase change time, a was the start lag (intergreen time, l, plus starting), (F + a) was the starting time of the effective green period and u and d denote upstream and downstream signals.

For manual signal plan preparation purposes, the same start lag was assumed for upstream and downstream signals, and hence, the following equation was used:

$$O_{ud} = (F_d + I_d) - (F_u + I_u) \quad (2.10)$$

Therefore, the phase change time at the downstream signal, F_d to achieve a desirable offset O_{ud} was:

$$F_d = F_u + I_u + O_{ud} - I_d \quad (2.11)$$

where F_u was the known upstream phase change time and I_u, I_d were the upstream and downstream inter-green times.

The difference between F_d from the mentioned equation and the phase change time calculated assuming operations were added to all phase change times at the downstream intersections so that the green times remained unchanged.

2.2.5 Rechecking of Traffic Signal Cycle Times and Phasing

Williston (2007) recommended that CORSIM was the corresponding micro-simulation program to HCS+ and was developed by the FHWA. The program worked reasonably well for signalized and un-signalized intersections, and various freeway segments, including basic segments, ramps, and weaves. Since the data from HSC+ was able to be transferred directly into CORSIM, the use of CORSIM for the simulation of freeways and freeway segments was desirable. Nevertheless, the simulation of an arterial corridor with signalized intersections required additional inputs into CORSIM to complete the simulation, i.e., intersection offsets, had to be input for the simulation to accurately reflect corridor conditions. For an arterial corridor with roundabouts at intersections, CORSIM did not provide roundabout specific features for input into the simulation model. In addition, there were known flaws with its modeling of roundabouts, particularly two-lane roundabouts. CORSIM exported reports on a variety of measures, including density, travel time, speed, and number of lane changes.

SimTraffic was also privately developed and was the simulation partner to Synchro. Since SimTraffic and Synchro used the same interface, there was no need to input additional data when transferring from Synchro to SimTraffic. As with CORSIM, a high level of labor intensive calibration was required to have confidence in the simulation results. The primary advantage of the Synchro /SimTraffic package was that analysis and simulation can be done from the same interface. The results were not going to exactly match the HCM methodology because Synchro was based upon the Percentile Delay Method rather than Webster's Method. However, for signalized intersections, the SimTraffic simulation gave a reasonable approximation of the expected conditions when properly calibrated. SimTraffic adequately simulates results for single-lane roundabouts; however, the results for two-lane roundabouts were flawed because the user controlled lane use within the roundabout.
Trafficware and Synchro simulation (2005) - for fine tuning phasing and cycle times, there were several software packages available to perform micro simulation for the various types of facilities. In

the research, the Trafficware and CORSIM Software were taken into consideration. Trafficware was privately developed and was the simulation partner to Synchro. Since Trafficware and Synchro used the same interface, there was no need to input additional data when transferring from Synchro to Trafficware. As with CORSIM, a high level of labor intensive calibration was required to have confidence in the simulation results. The primary advantage of the software package was that analysis and simulation could be done from the same interface. There was no need to input additional data, as the signal data, traffic volumes, link data, and other characteristics of the network were all contained in one file. The results did not exactly match the HCM methodology because Synchro was based upon the Percentile Delay Method rather than Webster's Method. However, for signalized intersections, the simulation software gave a reasonable approximation of the expected conditions when properly calibrated.

After completing the calculation of actual red time, the QCT (queue clearance times –rechecking actual effective green times as shown in **Figure 2.7**) were considered. QCT (Trafficware Synchro version6, 2003) was calculated as:

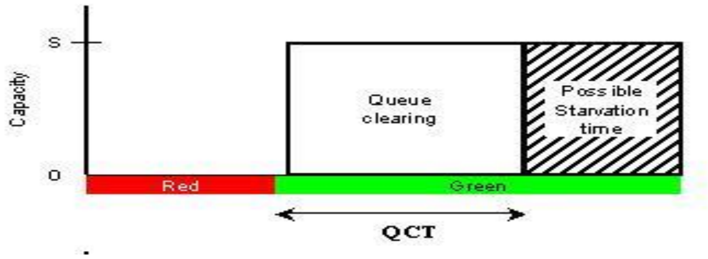


Figure 2.7 QCT Diagram within the Effective Green Times. Source: Trafficware Synchro version6 (2003)

$$QCT = SLT + \left[\frac{(PCU - eff.gr.t / lane)}{(Sat\ Flow / lane - PCU - eff.gr.t/lane)}\right] * (CLT + ART + SLT) \qquad (2.12)$$

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

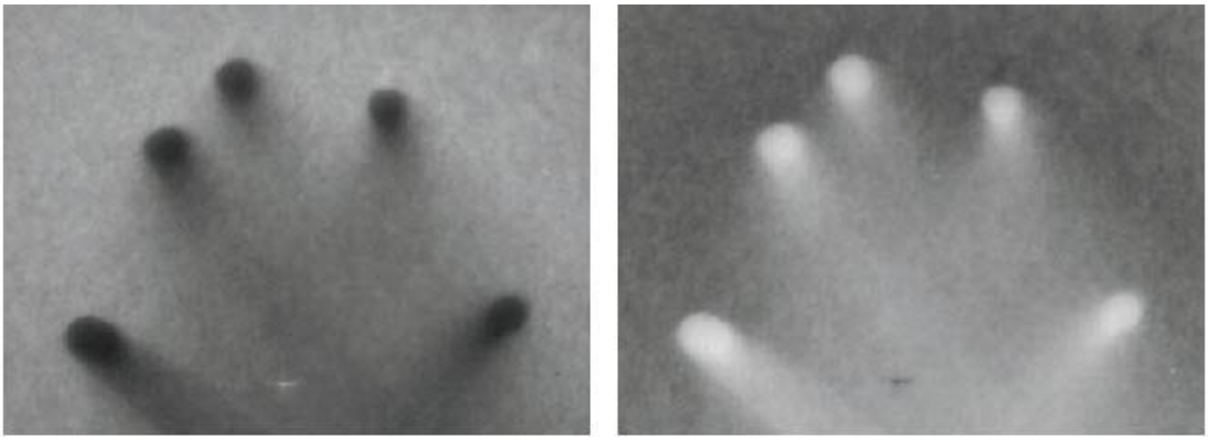
2.3 LANE CHANGING AND SPEEDING MODELS

The application of tracking objects was used by the Blob Tracking Techniques. The concepts of locations objects in 2 dimensions (x and y) data, the parameter of lane width, speed limit, gap of vehicle, and the Virtual Loop or tracking block will be illustrated. In addition, the calculation of speed in the VDO frame must be changed into the times and the length in pixel from CCTV will be also changed into the actual length as presented in the following parts:

2.3.1 Blob Tracking Techniques

Allexandre and Francowas (2004) studied that moving or non-background object segmentation was separated and the output of the stage was, for each frame, a set of labeled regions, or blobs. Different levels of tracking should be distinguished, depending on the semantic level of the tracked entities, and the amount of domain-specific knowledge involved. Possible classification of video data by semantic level, and the generic tasks were associated with their computation or inference. Tracking was presented in the research at the lowest possible semantic level in the sense of establishing temporal relationships between segmented generic features (blobs), without the use of domain-dependent information. The proposed tracking algorithm came at the second step up the semantic ladder, right after the initial segmentation. Blob appearance/disappearance and split/merge caused by noise, reflections, and shadows, were analyzed to infer trajectories and layers. These pictures were addressed in processes of higher semantic levels, and were out of the scope of the reported work.

Wang et al. (2007) proposed that the value range of pixels in the image was between 0 and 255. Based on the results of pre-process of image, the gray values of pixels in contact area were less than 10. In **Picture 2.2**, the images captured from DI multi-touch device: the left image was the original one captured by camera and the right one was inverted from the left. When fingers touched the panel of the multi-touch device, the contact area and the contactless area might be presented by different gray levels or colors in the images.



Picture 2.2 Images captured from DI multi-touch device. Source: Wang et al. (2007)

Lee and Nevatia (2008) advised that the tracking method processed the frames sequentially. The method analyzed the extracted foreground blobs from background subtraction process as described in the following items:

1) To apply tracking object's dynamic model to predict its new position
2) To generate an association matrix based on the overlap between the predicted Object Rectangle and the detected Blob Rectangle
3) In the association matrix, there were the track-blob matches (one-to-one and the updated Position of the Track), the current tracking objects (comparable to a regular vehicle, a new Created Tracking Object), a certain number of frames (the track of the object ends), Multiple Blobs and the split blobs into one to match with the object being tracked, Multiple Objects merge into One Blob and A mean shift color tracking method to locate the vehicle in the merged blob.

Figure 2.8 Results of vehicle tracking and detection (Yellow box: DCO (Don't Care Object), Green box: Detected ground truth, White box: Detected system output, Blue box: Missed ground truth, Black box: Detected but overlapped with DCO, Magenta box: Occluded ground truth (DCO), Cyan box: Stationary ground truth (DCO)). Source: Lee and Nevatia (2008)

2.3.2 Geometrical Design for Lane Changing Manoeuvre

Chen et al. (2005) commented that trajectories, which were usually two or three dimensional data sequences, often contained trajectories with different lengths. Most of the earlier proposals on similarity-based time series data retrieval were indicated on one-dimensional time series data. Moving objects were captured by recording the positions of the objects from time to time (or tracing moving objects from frame-to-frame in videos). Therefore, disturbance signals or errors in detection techniques might appear. Longest Common Subsequences (LCSS) had been applied to address this, however it did not consider various *gap* between similar subsequences, which led to inaccuracy. The gap was referred to a sub-trajectory in between two identified similar components of two trajectories. Different sampling rates of tracking and recording devices combined with different speeds of the moving objects might introduce *local shifts* into trajectories (i.e., the trajectories follow similar paths, but certain sub-paths were shifted in time). Even though the similarity measured, such as Dynamic Time Warping (DTW), and Edit distance with Real Penalty (ERP), was able to be used to measure the similarity between trajectories with local shifts, they were sensitive to nose-approaches.

Chen et al. (2005) recommended that the Euclidean distance was used to measure the distances between time series of the same length. However, it was common for the shapes of time series to be shifted in time domain. Therefore, warping distances such as Dynamic Time Warping (DTW) and Edit Distance on Real sequence (EDR) had been proposed for measuring distances of time series of arbitrary lengths. The optimal alignments of elements between two time sequences were obtained by repeating some elements so that the lengths of two sequences could be the same. Such a warping mechanism can well match similar time series with different time scaling. A comparison of warping distances was given. A warping distance was computed by dynamic programming over distance matrix, which had a time complexity of O (mn) (m and n being the lengths of two time series). To illustrate how warping distance was computed and all pair-wise distances of entries in 1D time series P and Q were taken into consideration.

2.3.3 Geometrical Design for Speeding Manoeuvre

Yu et al. (2007) pointed that least square method (LSM) to obtain the optimum coefficients were taken into account. To reduce the impacts of unreliable motion vectors, more sophisticated methods were introduced. The object motion estimation was composed of two components: motion segmentation and object tracking. Motion parameters were derived from the motion vectors associated with the object. Moreover, algorithms were similar to those used in optical flow field and they depended on the success of moving object segmentation. Two or more objects (smaller than a macro block) were contributed to distinct motions within a macro block. Vehicles in Sky cam video were generally no larger than a macro block and they were so small that it was difficult to find features to track them in pixel level, not to mention tracking in macro block level. To solve these problems, the researchers proposed an algorithm to estimate MEAN vehicle speed with MPEG motion vectors and investigated the speed of a group of vehicles rather than a single vehicle. The refined motion vectors were analyzed with application-dependent motion models to obtain the parameters of true motion. Thus, some applications might combine motion features with other features (edges, colors, etc.) or domain knowledge for high-level video analysis, e.g., video indexing, shot classification, etc. In addition, among these modules, the first two were dedicated to bridge the gap between the true motion and the raw motion vectors.

Srivastava and Delp (2010) indicated that video-based traffic monitoring systems demonstrated an ability to estimate the speed of vehicles in the camera’s field of view. A comprehensive traffic analysis system estimated the average vehicle speeds. The detailed methods for obtaining vehicle speeds in traffic videos were concerned. The system analyzed a vehicle’s approach by observing the variations in the vehicle’s velocity. This required tracking the vehicle using an object tracking method. A particle filtering approach for vehicle tracking with color and edge orientation histograms was taken into consideration. Furthermore, the tracker generated the vehicle's temporal position in image co-ordinates. By mapping these to ground co-ordinates, the desired representation of the trajectory was obtained. The calibration of the camera was measured by driving a vehicle at a constant known speed. The image and ground positions were used to generate a 2D look-up table (LUT). The LUT was used to obtain the ground position for unknown trajectories.

2.3.4 Parameter Calibration for Traffic Flow and Traffic Simulation

Hourdakis et al. (2002) proposed that regardless of the exact calibration procedure employed its success and efficiency depended on the measurements used during the validation as well as the goodness-of-fit measures employed. The calibration methodology presented in the research was primarily developed for freeway simulation. The most common measurements of the methodology was illustrated by using 5-minute measurements collected from detector stations, however it was easily applied to any set of measurements or time slices. In case of the calibration, it was enabled by using mainline station simulated and actual measurements and attempted to obtain the best match between the two by adjusting the simulator parameters through trial-and-error in the manual process or through optimization. The simulator parameters were calibrated for the objective fall into two main categories: global (those that affect the performance of the entire model) and local (those that affect only specific sections of the roadway). For examples, the global parameters were the vehicle characteristics (Length, Width, Desired speed, Max Acceleration/Deceleration, and minimum headway). Speed limits of sections of the freeway model were local parameters. During the calibration process, the global parameters were calibrated first followed by local parameter calibration.

The calibration process was performed in two main stages based on volume and speed, followed by an optional stage in which the control variable depended on the specific purpose for which the simulation was performed. For example, if the objective of the simulation was to test the effectiveness of an adaptive ramp-metering algorithm, ramp queues could be used as the appropriate validation variable in the third stage. Similarly, if the objective was to simulate accidents, the congestion backup was able to be used as an appropriate variable in a similar way as presented here. Volume-based calibration was performed first as it was also less complicated. Speed was a more sensitive measure to the fluctuations of traffic and progresses the calibration further. Furthermore, the optional 3rd stage was used to fine-tune the simulation model for the specific purpose of the simulation. The step-by-step procedure to be followed in each of the 3 stages of the calibration process was taken into consideration.

As summarized in **Table 2.8**, the U.S. Federal Highway Administration - FHWA (2004) reported that the error-checking task was necessary to identify and correct model coding errors so that they did not interfere with the model calibration task. Coding errors were able to distort the model calibration process and cause the analyst to adopt incorrect values for the calibration parameters. Error checking involved various tests of the coded network and the demand data to identify input coding errors. Calibration data consisted of measures of capacity, traffic counts, and measures of system performance, such as travel times, speeds, delays, and queues. Capacities were gathered independently of the traffic counts (except during adverse weather or lighting conditions); however, travel times, speeds, delays, and queue lengths were gathered simultaneously with the traffic counts to be useful in calibrating the model. Calibration involved the review and adjustment of potentially hundreds of model parameters, each of which impacted the simulation results in a manner that was often highly correlated with that of the others. Therefore, it was essential to break the calibration process into a series of logical, sequential steps - a strategy for calibration. Calibration targets were developed based on the minimum performance requirements for the micro simulation model, taking into consideration the available resources. The targets varied according to the purpose for which the micro simulation model was being developed and the resources available to the analyst.

Table 2.8 Wisconsin DOT freeway model calibration criteria. Source: The U.S. Federal Highway Administration - FHWA (2004)

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model Versus Observed	
Individual Link Flows	
Within 15%, for 700 veh/h < Flow < 2700 veh/h	> 85% of cases
Within 100 veh/h, for Flow < 700 veh/h	> 85% of cases
Within 400 veh/h, for Flow > 2700 veh/h	> 85% of cases
Sum of All Link Flows	Within 5% of sum of all link counts
GEH Statistic < 5 for Individual Link Flows*	> 85% of cases
GEH Statistic for Sum of All Link Flows GEH	< 4 for sum of all link counts
Travel Times, Model Versus Observed	
Journey Times, Network	
Within 15% (or 1 min, if higher)	> 85% of cases
Visual Audits	
Individual Link Speeds	
Visually Acceptable Speed-Flow Relationship	To analyst's satisfaction
Bottlenecks	
Visually Acceptable Queuing	To analyst's satisfaction

Park and Qi (2005) analyzed that the users in the initial phase were not able to identify correctly all the critical parameters or the reasonable range for each parameter. Two criteria could potentially help users select the parameter candidates to be calibrated:

1) Conduct a trial-and-error test for each parameter. If the parameter did not affect the simulation result at all, it was able to be excluded from the parameter candidate list.
2) Judge from a traffic engineer's point of view. For instance, the study network had only one lane for each approach and the origin/destination was simple without any diversion possibility. Parameters related to lane change or route choice behaviors should not have an impact on the simulation result. Therefore, the minimum headway (front and rear) and the waiting time before diffusion were eliminated from the parameter list.

Users were able to determine the acceptable range for each parameter selected on the basis of a review of the literature, including the manuals for simulation models and other existing research findings. The following was the list of parameters and acceptable ranges determined initially. A detailed description of each parameter was found in the VISSIM manual as described below.

1) Simulation resolution: 1 to 9 time steps per simulation second
2) Number of observed preceding vehicles: 1 to 4

3) Average standstill distance: 1 to 5 m
4) Saturation flow rate: 1,756, 1,800, 1,846, 1,895, and 1,946 vehicles per hour
   – Additive part of desired safety distance: 2.0 to 2.5
   – Multiple part of desired safety distance: 3.0 to 3.7
5) Priority rules for minimum headway: 5 to 20 m
6) Priority rules for minimum gap time: 3 to 6 s
7) Desired speed distribution: 40 to 50, 30 to 40, and 20 to 30 mph

The parameter ranges were modified on the basis of the field speed data and the estimated saturation flow rates. The modified desired speed ranges were 30 to 40, 32.5 to 37.5, and 27.5 to 42.5 mph; and the new ranges of the additive part of desired safety distance and the multiple part of desired safety distance were 1.0 to 5.0 and 1.0 to 6.0, respectively. The updated parameter set and its ranges were shown as follows:

1) Simulation resolution: 1 to 9 time steps per simulation second
2) Number of observed preceding vehicles: 1 to 4
3) Maximum look-ahead distance: 200 to 300 m
4) Average standstill distance: 1 to 5 m
5) Saturation flow rate
   – Additive part of desired safety distance: 1.0 to 5.0
   – Multiple part of desired safety distance: 1.0 to 6.0
6) Priority rules for minimum headway: 5 to 20 m
7) Priority rules for minimum gap time: 3 to 6 s
8) Desired speed distribution: 30 to 40, 32.5 to 37.5, and 27.5 to 42.5 mph

With the new parameters, another 200 cases were generated by the A Latin hypercube design (LHD) method. The result presented that the new simulated distribution covered the field data and indicated that the new parameter ranges were able to capture the field condition.

Furukawa and Ponce (2008) stated that the advent of high-resolution digital cameras and sophisticated multi-view stereo algorithms offered the promises of unprecedented geometric fidelity in image-based modeling tasks; however, it also put unprecedented demands on camera calibration to fulfill these promises. A novel approaching to camera was calibrated by the top-down information from rough camera parameter that estimated. The output of a publicly available multi-view stereo system on scaled-down input images were used to effectively guide the search for additional image correspondences and significantly improved camera calibration parameters using a standard bundle adjustment algorithm. The proposed method was tested on several real datasets - including objects without salient features for which image correspondences were found in a purely bottom-up fashion, and image-based modeling tasks - including the construction of visual hulls where thin structures were lost without our calibration procedure.

2.4 ENVIRONMENTAL AND FUEL CONSUMPTION TECHNIQUES

Motorist frustration caused by excessive delays or stops was reduced by adjusting timing to reduce stops and delays and provide coordinated flow through groups of signals. Emissions and fuel consumption were reduced by optimizing signal timing and coordinating traffic flow. Improving signal timing also had other indirect benefits. Reduced fuel consumption decreased emissions and, thus, improved air quality (Sunkari, 2004). Altering a driver's behavior potentially contributed to the reductions of vehicle energy/emissions. An advanced driving alert system provided traffic signal status information to help drivers avoid hard braking at intersections, defined a method for evaluating vehicle energy consumption and emissions at intersections, and investigated the potential benefits of such system (Li et al., 2009).

Furthermore, the study of traffic emission model and fuel consumption were also referenced by several researches, such as Asri and Hidayat (2005**),** Handajani (2011), Tamsanya and Chungpaibulpata (2009). The vehicle delay, fuel loss and noise level were increased particularly at the signalized intersection. The case study intersections representative signalized intersections of varying traffic volume was selected in this study to ascertain delay, fuel loss and noise level during idling of vehicles. The study indicated that the noise level exceeded permissible levels and vehicular delays were high at more than 60 sec/vehicle during peak hour at all important signalized intersections (Pal and Sarkar, 2012).

There are several concepts of the Emission **-**Traffic Noise and Air Pollution. In addition, the Traffic Fuel Consumption will be presented in the following parts:

2.4.1 Traffic Noise

The predictions of noise levels in the case study intersections were calculated by the methods of UK DOT (1988). The noise assessment criterion was from the Department of Pollution Control, Thailand (1996). Thus, L_{10} was equal to 73 dB(A). This was due to the fact that L_{10} was equal to the addition of both Leq dB(A) and 3 dB(A), RTA(1991). A first major installment in development of a fuel consumption based on intersection traffic control optimization technique was taken into consideration. The procedure was used to estimate basic signal timing parameters which minimized vehicular fuel consumption within an intersection influence area **(**Liao and Machemehl, 1995).

Coensel and Botteldooren (2011) proposed that the output of a microscopic traffic simulation run consisted of the instantaneous position, speed and acceleration of each vehicle at each time step.

Consequently, the instantaneous emission of each vehicle was calculated. For noise emissions, the Noise/Imagine emission model was used and was calibrated to generate the noise emission of the “average” European vehicle: while there might be differences between different types of vehicles in terms of noise emission, the model was going to predict measurement results aggregated over a sufficiently large number of vehicles sampled from the European fleet (regional corrections can be applied). This quantity related directly to the sound power level used for noise mapping purposes. In particular, the hourly averaged A-weighted sound power level emitted by the simulated road segment. Next to this, the Levels were calculated at a height of 1.5m and at a distance of 7.5m from the road.

The effect of a green wave on the sound level might vary depending on the measurement location.
The difference in L_{Aeq} along the section of interest, between the green and red wave coordination schemes were taken into consideration. It was found that the implementation of a green wave would result in a decrease in sound pressure level by up to 1.5 dBA near the signalized intersections, due to the reduction in number of accelerating vehicles, but would result in an increase by up to 2 dBA between intersections, due to higher average vehicle speeds. When compared with the desynchronized schemes, somewhat smaller effects were found: differences vary between a 1 dBA decrease and a 1.5 dBA increase (for green split). For higher intensities, the decrease in level near the signalized intersections was going to be somewhat less, while in between intersections, the increase in level would clearly be higher. The point of maximum increase also shifts with traffic intensity, because of the shift in queue length for the red wave scheme.

2.4.2 Vehicle Emission Models

Li et al. (2009) researched that when traffic was under-saturated, decelerate-idle-accelerate and decelerate-accelerate (no idle) sequences would be expected to occur in the vicinity of intersections when the traffic signal was red time. On the other hand, a quasi-steady cruise operation would be expected through “green light” intersections and in between intersections. When traffic was over-saturated, the influenced area could stretch to the entire link between intersections, where vehicles might experience stop-and-go conditions all the time.

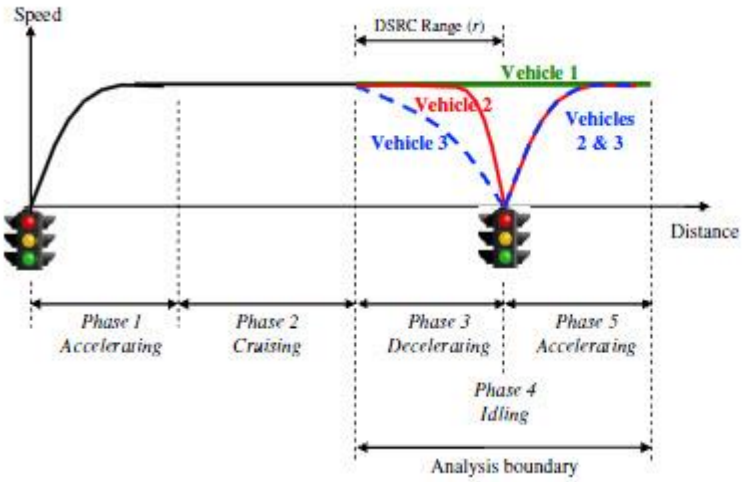


Figure 2.9 Driving behaviors prior to a signalized intersection.

Source: Li et al. (2009)

Figure 2.9 shows that the vehicle energy/emissions for the three scenarios would be different. Certainly, vehicle 1 would consume the least amount of energy and produce the least amount of emissions as it did not have to stop and idle at the intersection. In comparison with vehicles 3, vehicle 2 was likely to consume more fuel and produce more emissions.

Cartenì et al. (2010) strongly recommended that through the model system implemented the vehicle emissions had been estimated. The emissions had been divided into greenhouse gases and fine particles:

Greenhouse gases were gases in an atmosphere that participate in the greenhouse effect. The main greenhouse gases considered were:

- carbon dioxide (CO_2);
- carbon monoxide (CO);
- nitrogen dioxide (NO_2);
- methane volatile organic compounds (CH_4);
- other volatile organic compounds (VOC);
- equivalent carbon dioxide (eq.CO_2).

Fine particles were tiny subdivisions of solid or liquid matter suspended in a gas or liquid; it was possible to classify:

- PM_{10} were the particles of 10 micrometers or less;
- $PM_{2.5}$ represents particles less than 2.5 micrometers.

The car, as expected, proved to be the transport mode which produced the highest rate of pollutants. It showed a percentage incidence always greater than 40% for each greenhouse gas, with peak values of

60% for carbon monoxide and 74% for nitrogen dioxide. As regards fine particles, car flows emitted about 10 tons/year of $PM_{2.5}$ (about 20%) and about 12 tons/year of PM_{10} (about 23%). Motorcycles played a significant role as regards CO, CH_4/VOC and NM/VOC emissions. Indeed, motorcycle flows contribute less than 4% to $PM_{2.5}$ and PM_{10} emissions.

Transport Research Laboratory (1999) stated that the emission rates corresponding with operating conditions in certain bands were combined to provide a two dimensional matrix of emission factors, classified by the two operational variables. **Table2.9** showed one example of an emission matrix, specified in terms of speed and speed times acceleration.

Table 2.9 Instantaneous emission matrix - CO emissions (g/h), medium sized EURO I petrol

Speed x acceleration (m^2/s^3)	Speed (km/h)									
	0	5	15	25	35	45	55	65	75	85
-15	-	-	66	56	63	69	59	76	92	115
-10	-	-	57	61	63	84	94	141	129	134
-5	-	53	53	73	85	102	130	204	194	325
0	33	59	74	116	123	131	196	193	274	152
5	-	142	163	192	192	207	275	263	350	211
10	-	-	274	301	295	357	330	454	403	275
15	-	-	-	469	568	603	779	706	1041	308

Application of this type of model requires the specification of the speed profile of a journey,

Rakha H. and Ding Y. (2003) informed that the reductions in emission rates were able to occur if the vehicle stop involved a mild acceleration when the acceleration emission rate was less than the cruising emission rate. As a result, at high speeds the introduction of vehicle stops involving extremely mild acceleration levels were able to actually reduce vehicle emission rates.

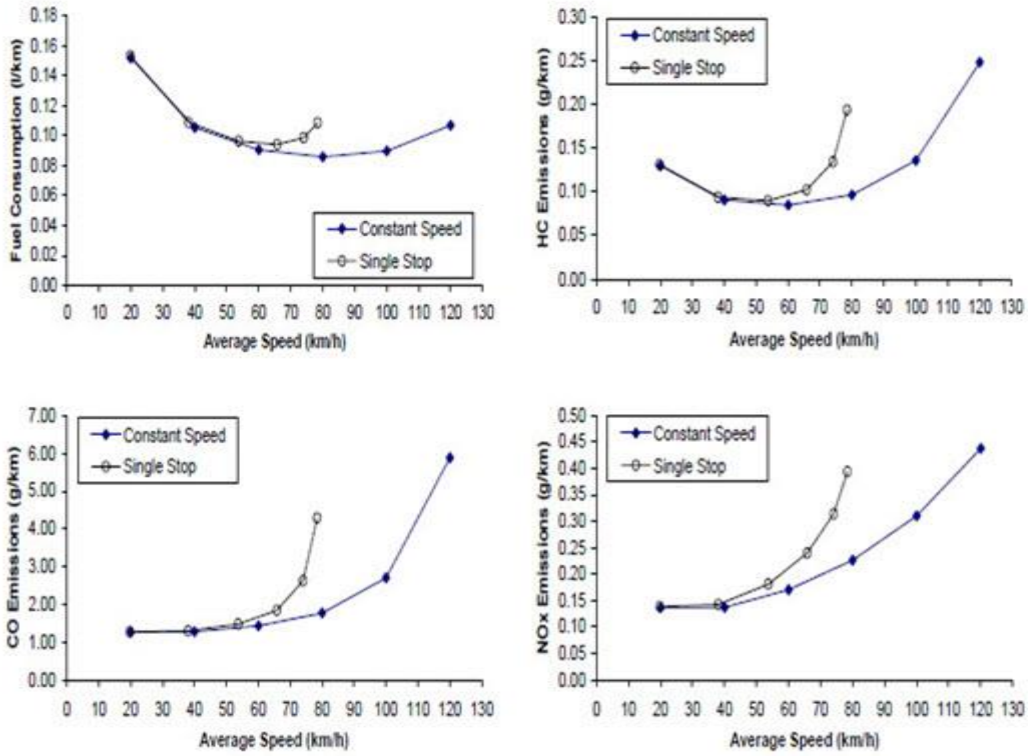


Figure 2.10 Impact of Single Vehicle Stop on Fuel Consumption and HC Emission Rate as a Function of Average Speed

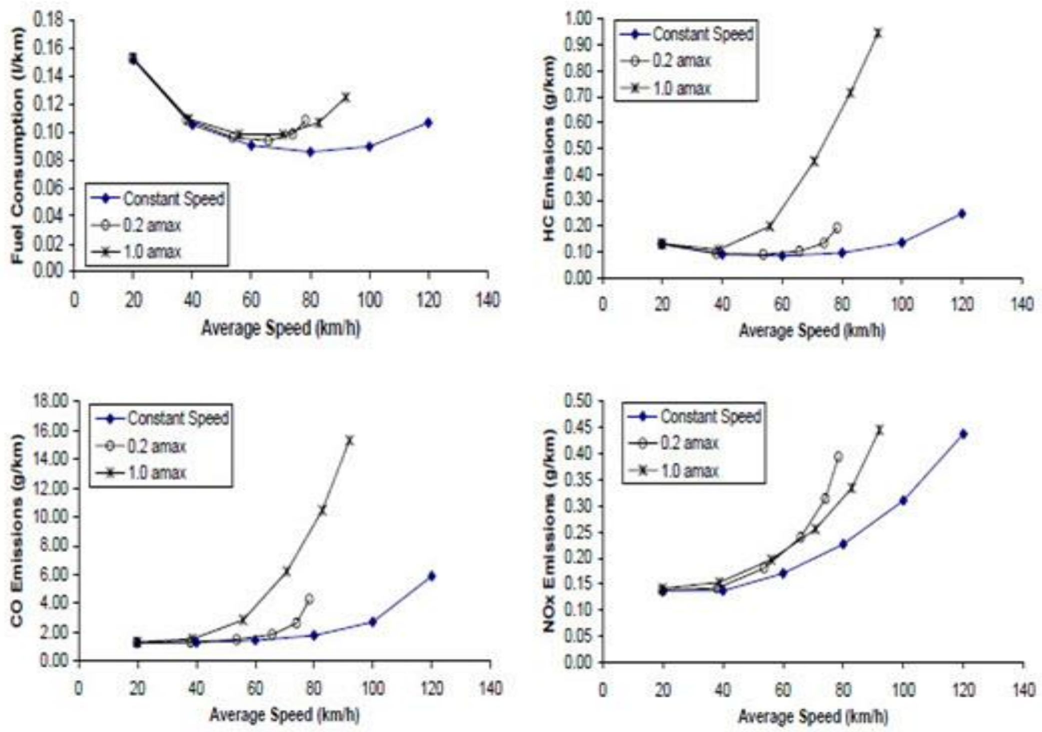


Figure 2.11 Impact of Level of Acceleration in HC Emission Rate as a Function of Average Speed (Distance = 4.5 km, Deceleration Rate for Single-Stop Cycles = -0.5 m/s2)

Bert De Coensel and Dick Botteldooren (2011) criticized that the implementation of a green wave resulted in a decrease in sound pressure level by up to 1.5 dBA near the signalized intersections, due to the reduction in number of accelerating vehicles, but resulted in an increase by up to 2 dBA between intersections, due to higher average vehicle speeds. From **Figure 2.10**, it also followed that a green wave had the least detoriating effect on noise levels when traffic intensities were low. For higher intensities, the decrease in level near the signalized intersections was somewhat less, while in between intersections, the increase in level was clearly higher.

In case of Air Pollution Emission, the following Figure showed the average amount of CO2, NOX and PM10 that vehicles emitted while travelling over the section of interest, as a function of traffic flow, for various signal coordination schemes and green split. It was chosen to present the results in g rather than in g/km, such that the figures represent the absolute effect per intersection. The case of noise emissions, all types of air pollutant emissions decreased when a green wave was installed, because acceleration had a large influence on air pollutant emission, a potential increase of emissions caused by the increase in average vehicle speed was overcompensated by the smoother traffic flow resulting from the coordinated traffic signals. This was caused by the influence of idling vehicles in the queue in front of a traffic light: while idling vehicles still emitted a considerable amount of noise, the fraction of total air pollutant emission caused by idling vehicles was relatively small.

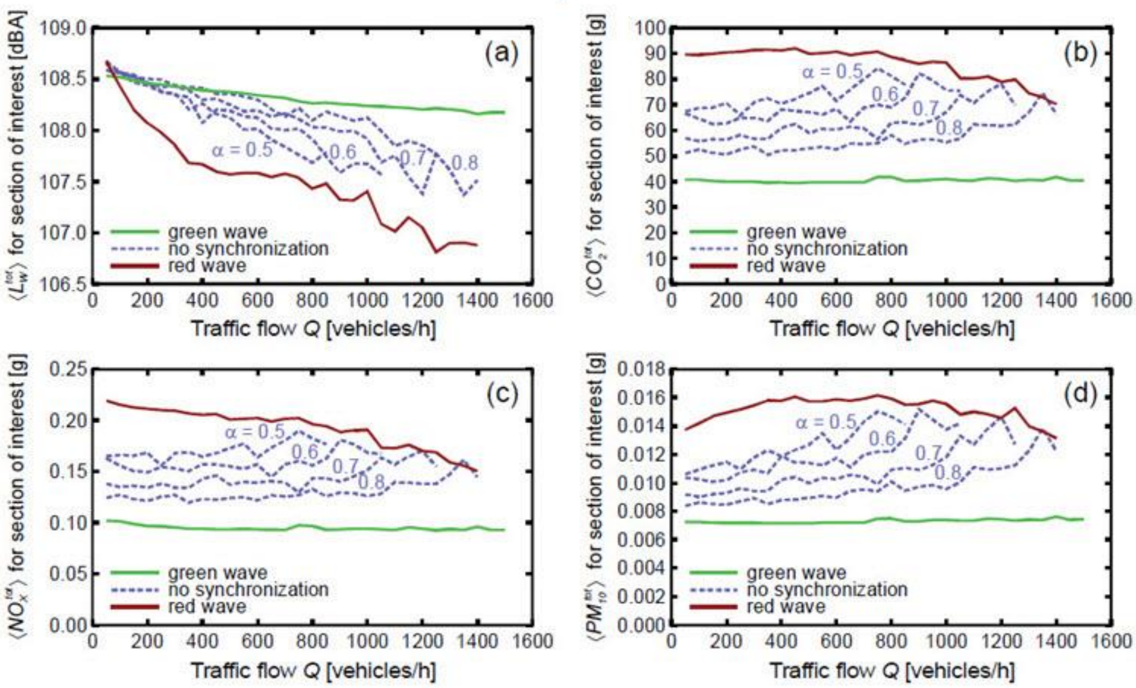


Figure 2.12 Average vehicle emission for the section of interest, as a function of traffic flow, for various signal coordination schemes and green split. Results were averaged over cycle time and green split (for the green/red wave).

The average of PM_{10} Concentration in Bangkok during 1992 to 2005 especially roadside was over the standard of PM_{10} as shown in the following Figure.

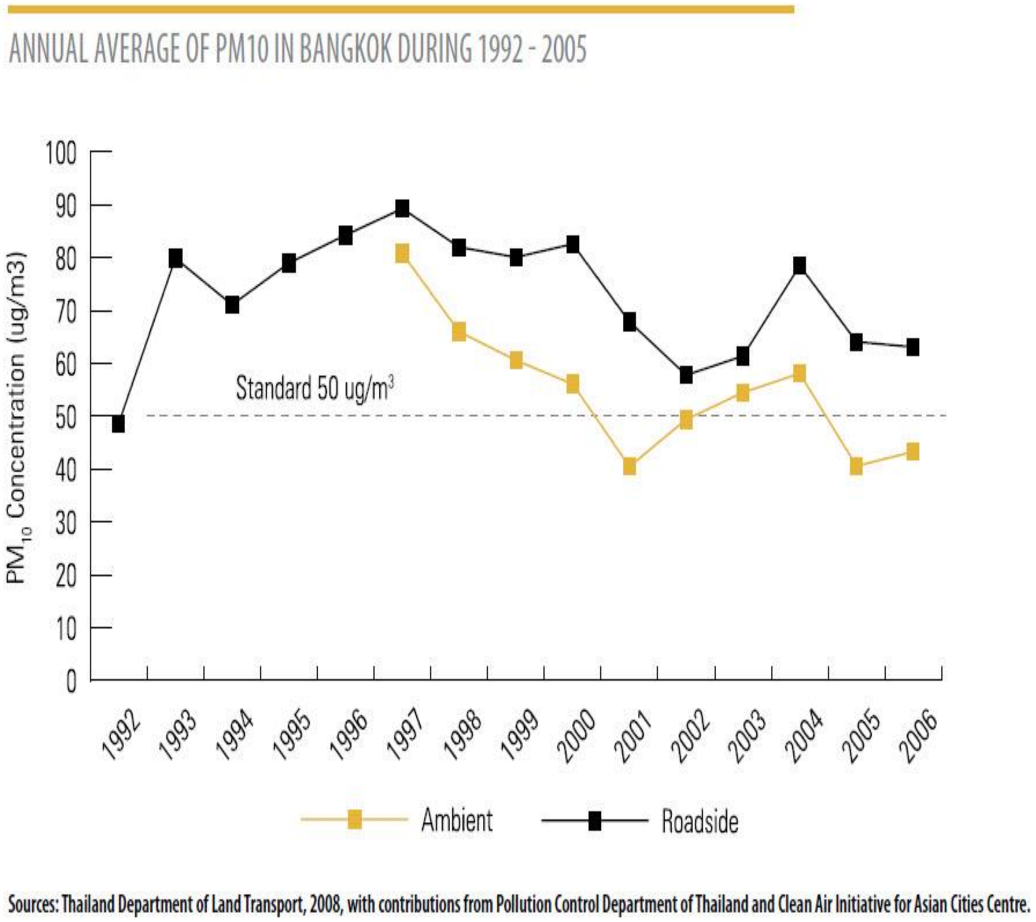


Figure 2.13 Annual Average of PM_{10} in Bangkok during 1992 – 2005

2.4.3 Fuel Consumption Models

Rakha H. and Ding Y. (2003) advised that in order to quantify the combined effect of vehicle deceleration and cruise speed on vehicle fuel consumption and emission rates, a total of 36 single-stop drive cycles involving 6 cruise speeds and 6 levels of deceleration were constructed. The analysis indicated that the vehicle fuel consumption rate per unit distance was insensitive to the level of deceleration.

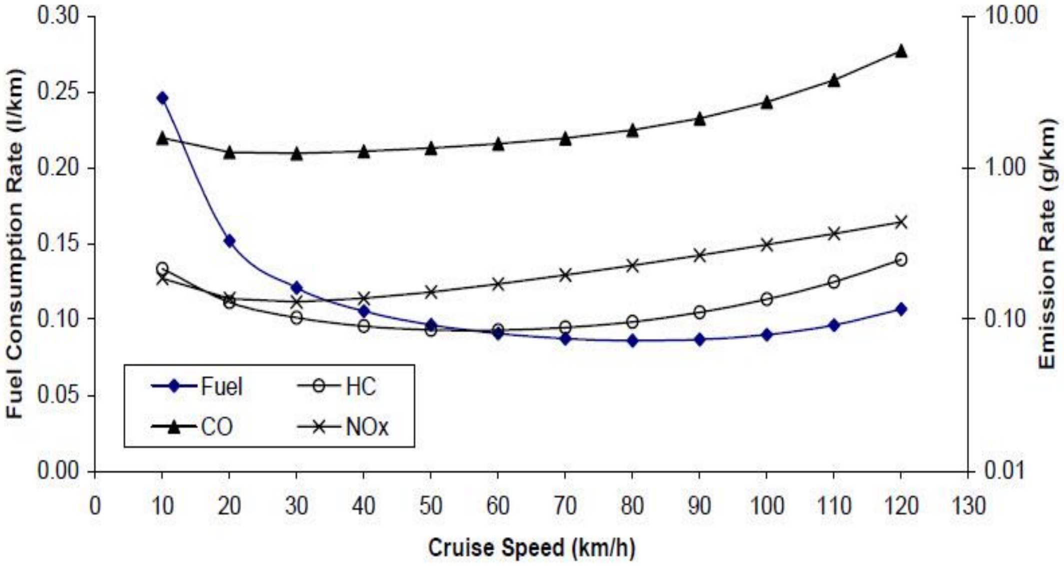


Figure 2.14 Variation in Vehicle Fuel Consumption and Emission Rates as a Function of Cruise Speed

Affum et al. (2003) commented that the average-speed model computed the total network energy use based on the average network speed. The accurate estimates of fuel consumption over road sections with average speeds were lesser than 50 km/h. The fuel consumed per unit distance (f_x in ml/km) was presented below:

$$f_x = \frac{f_i}{\nu_s} + cK \tag{2.13}$$

where f_i was the idle fuel consumption rate in ml/h; ν_s was average network speed of travel in km/h; c was a derived regression coefficient derived, using a default vehicle parameters and varies with driving conditions; and K was an adjustment factor to allow for varying vehicle parameters in the vehicle fleet.

The drag, inertia and effect of grade on fuel consumption were accounted for by the constant term (cK), both of which depended on the driving environment. The computed fuel levels for each fuel type were then multiplied by the appropriate greenhouse gas emission factor as shown in **Table 2.10** to estimate the total CO_2 gases emitted over the entire network.

Table 2.10 Fuel to CO_2 Conversion Factors. Source: NGGIC (1996)

Fuel Type	CO_2 Factor (kg/l)
Petrol	2.24
Diesel	2.66
LPG	1.51

Akcelik et al. (2012) proposed that a medium –size passenger car (Toyota Corolla Ascent, model year 2004, 1.8 litre 4 cylinder petrol engine, rated engine power of 100 kw, ADR79/00 certified, automatic transmission), to see **Picture 2.3**. This vehicle was comparable to the default passenger car used in SIDRA TRIP in terms of vehicle mass and main vehicle type.

Picture 2.3 Test Vehicle Used for Fuel Consumption Model Calibration Results.
Source: Akcelik et al. (2012)

Chapter

3

METHODOLOGY

3.1 TRAFFIC SIGNALIZATION TECHNIQUES

There are two parts of traffic signalization techniques. One is the Calculation Traffic Factors Section as presented in the section 3.1.1, 3.1.2 and 3.1.3; the other is the Installed Software in the Traffic Controller Section and the Rechecking Traffic Cycle Times and Phasing as described in the section 3.1.4.

3.1.1 System Components of Integrated ITS System

Before described PCU Concepts, there are 5 system components of integrated ITS system as presented in **Figure 3.1**. The first component is the Traffic Classified Count (TCC) by Virtual Loop Detector (VLD) and calculated PCU. These data will be evaluated of traffic factors such as, arrival rate (PCU/min), Delay/PCU, etc. The second component is the Adaptive Traffic Signalization System (ADTS). The ticker of VLD will be applied and adapted of Traffic Synchronization in this component. The third component is the Lane Changing and Speed Warning System (LCSW). There are two functions of a VLD. They will be Lane Changing and Speeding Features. The last components are the Environmental Impact and Fuel Consumption Predicting Models. These data will be evaluated in a Minute Based Assessment.

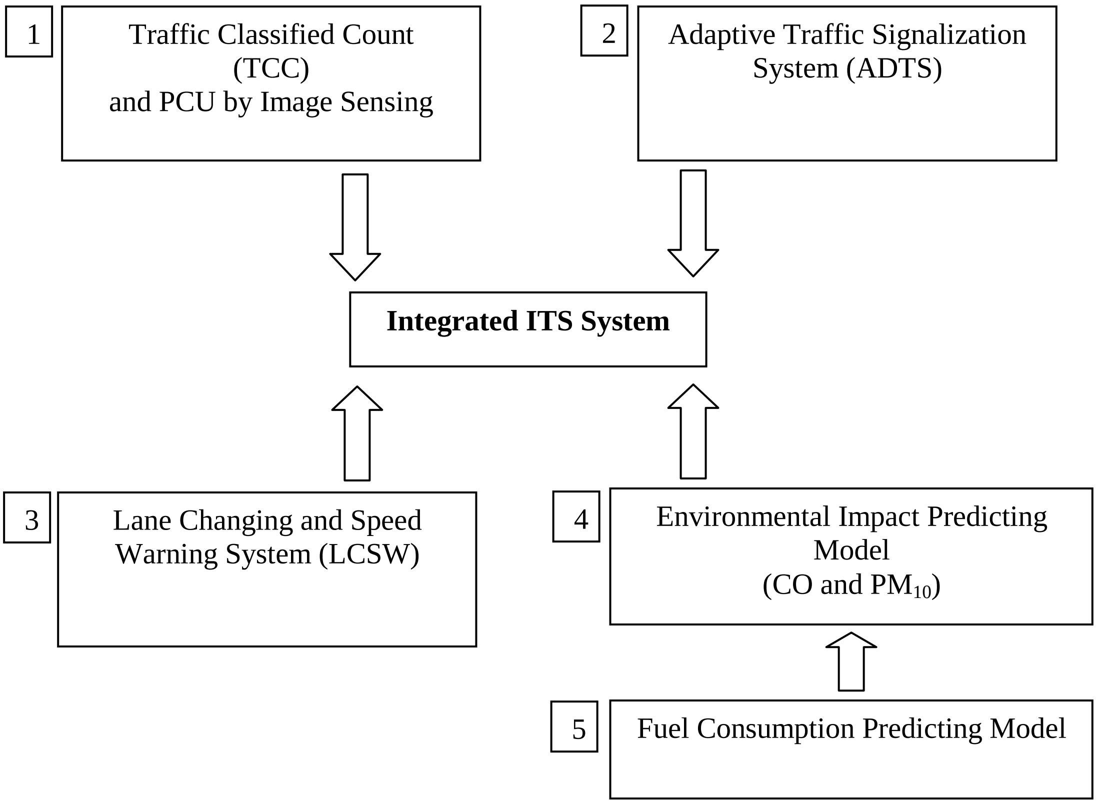


Figure 3.1 System Components of Integrated ITS System

3.1.2 PCU (Passenger Car Unit)

In case of heterogeneous traffic in Thailand, vehicles such as motorcycle, car, van, pickup, light truck, heavy truck, and bus will be driven as shown in **Figure 3.2**.

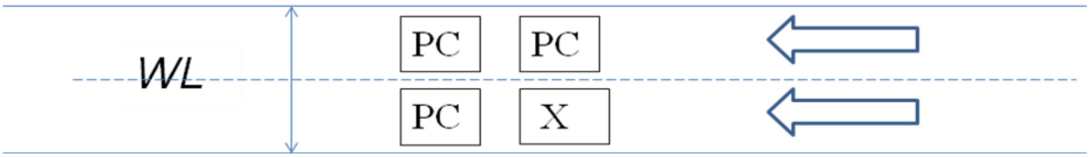


Figure 3.2 Heterogeneous traffic -flow in one direction.

It can be seen that a motorcycle is located at the middle of the gap between a car and bus. The motorcycle will also come to the front of a heavy truck and a light truck. Therefore, the PCU can be calculated by the traffic flow per direction for each type of vehicle as illustrated below:

$$PCU_x = \frac{\dfrac{\sum_Y q_{PC-Y}}{WL / adj.vehW}}{\dfrac{\sum_Y q_{X-Y}}{WL / adj.vehW}} \tag{3.1}$$

where PCU_X is Passenger Car Unit for x vehicle, q_{PC-Y} is Traffic Flow of Passenger Car (PC) following Type Y, q_{X-Y} is Traffic Flow of Type X following Type Y, WL / adj.vehW is Width per direction / Adjustment Vehicle-Width and Y is All Vehicle Types.

It can clearly be seen that most heterogeneous traffic does not use the delineated lanes marked on the pavement surface. These PCU will be calculated with traffic volumes to *input in SIDRA and Synchro* in order to find the optimum cycle times as described in the next part.

3.1.3 Optimum Cycle Times and Phasing for Vehicles Actuated (VA) Control

aaSIDRA and TRAFFICWARE and CORSIM ,Traffic Engineering and Simulation Software, aaSIDRA-Full version 1.0.6.145 (2000), Trafficware Synchro 6 (2003) are used to compute the optimum cycle times and phasing at intersections. Furthermore, traffic parameters during peak hours including queue length on the main road are measured and compared with the results from the developed software which started of C++ Software as described in Chapter 4 and 5.

3.1.4 Traffic Synchronization (Offset Times)

In case of the offset time between the T and 4 Leg intersections, the offset times are calculated based on the ARRB method (Akcelik, 1989). The maximum cycle times during peak hour for the 3-phase of T intersection and the 2-phase of 4 Leg intersection are 150 and 90 seconds respectively.

3.1.5 Rechecking Traffic Signal Cycle Times and Adaptive Traffic Signalization Model (ADTS)

There are two concepts of traffic signal synchronization. One is the rechecking of traffic signalization at each intersection in order to reduce the cycle times and the rechecking of the offset times or Green Wave. The other is the final rechecking of the QCT (queue clearance times). The QCT is applied for the rechecking of the actual effective green times.

In case of provided locations of vehicles-sensors at the case study intersections, the inbound direction on major road and turn right direction on minor road at T intersection are the major traffic volumes approaching to this intersection. Therefore, locations of virtual loop detectors or vehicles-sensors are setup at these directions. The vehicles-sensors at 4 Leg intersection are also located on the inbound direction of main road and on the inbound direction of minor road due to the major traffic volumes. In addition, there are 4 CCTVs as installed at these intersections and they can be moved to other directions owing to the uses of Pan-Tile-Zoom cameras.

Movements at the T intersection are in 6 directions with two left turn movements as free flow. For the 4 Leg intersection, movements are in 10 directions and two of them are free flow left turn. Parameter setting and sequence of 3 Phasing for the T intersection and 2 Phases at the 4 Leg intersection are illustrated in **Figure 3.3**. There are 4 Sensors of virtual loops which detect vehicles passing the Virtual Loops and send the signalized data to the traffic controllers. For Example during peak hours at T intersection, for vehicles passing through the Virtual Loop with headways within 5 seconds, the characteristic of traffic flow is steady state/steady flow. Therefore, the cycle time is extended up to the maximum green times of J1A, J1B and J1C (from calculation of SIDRA and Synchro) as shown in **Figure 3.4**. Furthermore, the additional phases (J2B-J1A and J1C-J2B) will be applied the concept of the offset times from section 3.1.3.

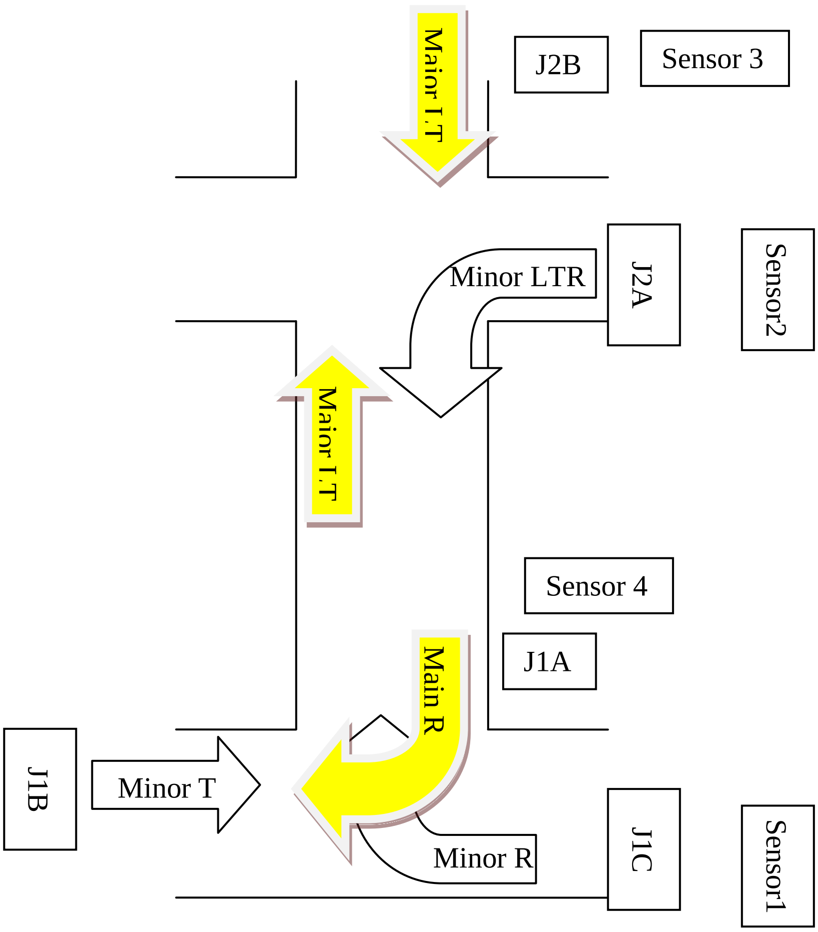


Figure 3.3 Sensors or Virtual Loops – locations.

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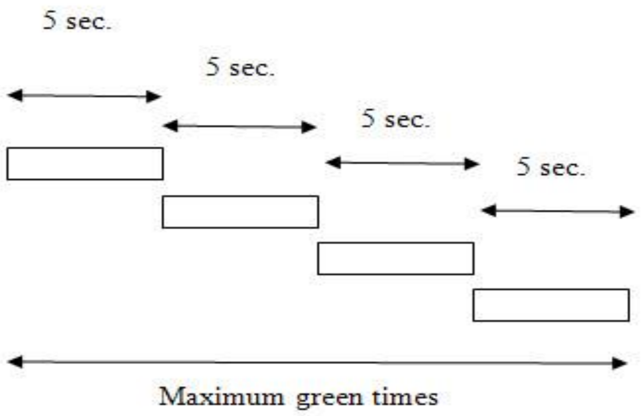


Figure 3.4 Adaptive Green Times up to Optimum Effective Green Times.

For the whole concepts of the new ITS Technology, the Model of these techniques will be concluded and illustrated in **Figure 3.5**.

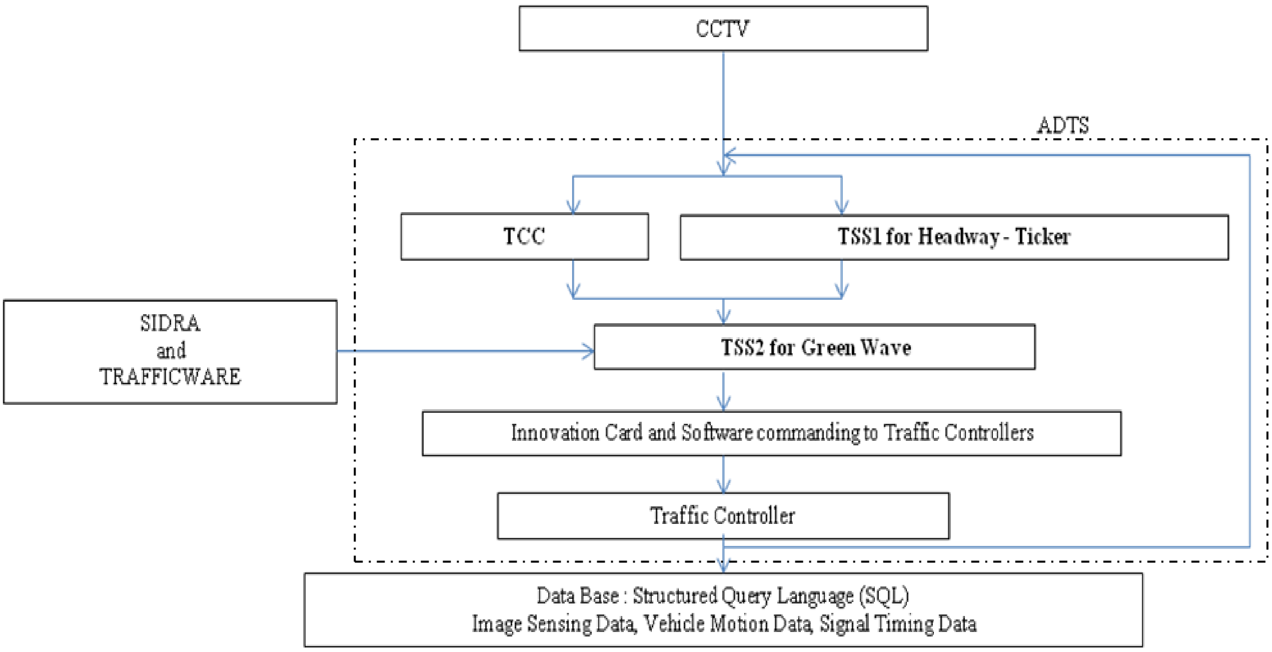
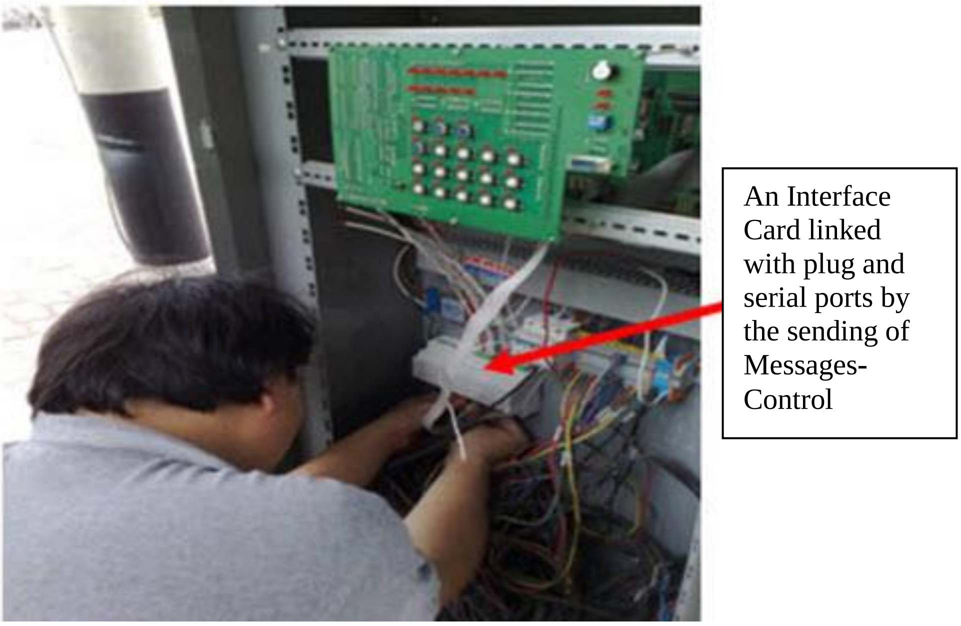


Figure 3.5 Adaptive Traffic Signalization System (ADTS)

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 new developed software are applied and evaluated for the traffic systems in the pilot intersections. Before implementation of traffic synchronization software, the traffic synchronization simulation will be taken into consideration. Moreover, the two interface cards are applied for the two traffic controllers so as to link the signals from Virtual Loop to traffic control as shown in the Picture 3.1.



Picture 3.1 A New Interface Card Connected with the Traffic Controller.

3.2 LANE CHANGING AND SPEEDING MODELS

3.2.1 Geometrical Design for Lane Changing Manoeuvre

Firstly, the Lane Changing Model as illustrated below uses the Geometrical Design Concepts together with the two circular empirical formulas. The positions of Lane Changing, which are 3 points, are located on **Figure 3.6**. The first curve of Lane Changing of circular curve is composed of coordinates among points (x_1,y_1), (x_2,y_2), and (x_3,y_3) respectively. The calculation of angle and length of Lane Changing used the concepts of geometrical design as shown.

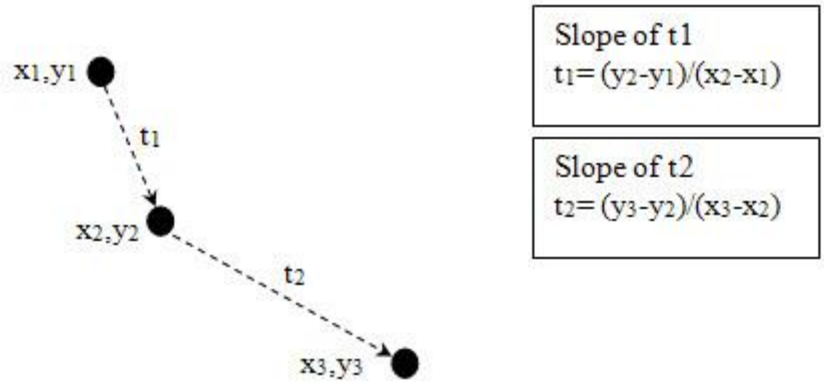


Figure 3.6 Three Points of Lane Changing Concept**.**

After calculation, the absolute values of (t2-t1), which are more than threshold values (checking status of moving vehicle), are taken into account. Coordinate (x,y) is evaluated from the pixels of frame by frame in the avi.file, however, the process of angle and length calibration is taken into consideration. In terms of speed, the calculation of speed depends on the time-frame. Moreover, the reference points of coordinates (x_1,y_1) and (x_2,y_2) are marked as the standard length (1 metre) in the software. The VDO frames are applied with the Blob functions and the first and last frames will be checked for the positions and length as shown in the following equations:

$$d = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \tag{3.2}$$

$$\text{velocity} = \frac{\frac{\text{pixDistance}}{\text{refDistance}}}{\frac{\text{frames}}{\text{fps}}} \tag{3.3}$$

In the case of the rechecked model, the authors' new concept is incorporated into the image sensing software as presented below:

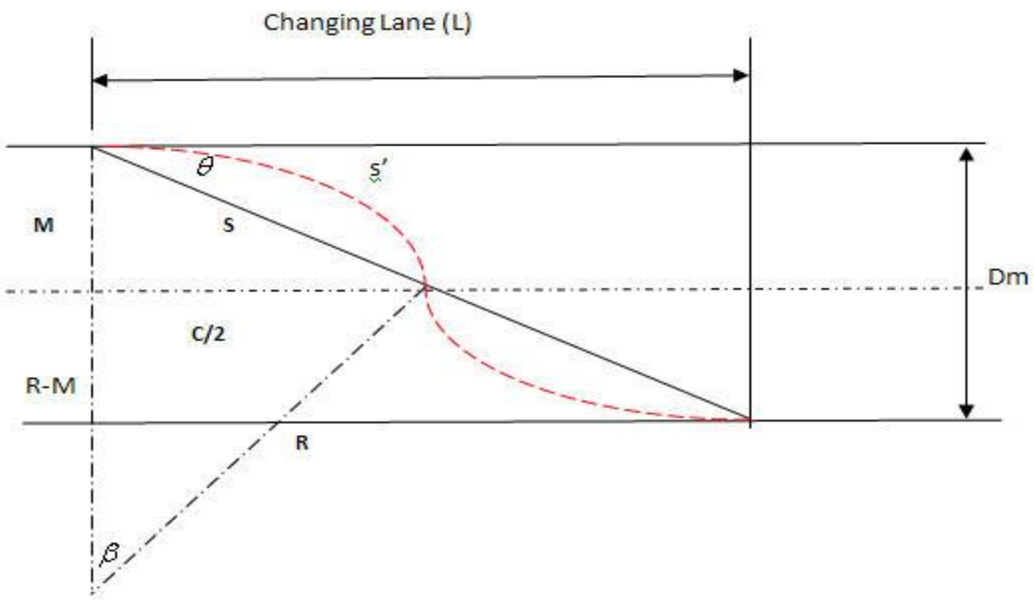


Figure 3.7 Geometrical Feature of Lane Changing Model.

$$\frac{C}{2} = \sqrt{R^2 - (R-M)^2} \text{ and } \frac{C}{2} = \sqrt{S^2 - M^2} \tag{3.4}$$

$$S = \sqrt{2 \times R \times M} = \sqrt{\frac{(V_f \times \frac{1000}{3600})^2}{9.81(0.025 + 0.300)} \times D_m} \tag{3.5}$$

where V_f is Final speed for lane changing, kph.

As for the Lane Changing length L, the length of cord of circular S and angle of Lane Changing θ are used in the following equations. In addition, the application of coding software was presented in the **Figure 3.7**.

$$L = 2 * S * \cos(\theta) \tag{3.6}$$

$$\theta - a\tan(\frac{Dm}{L}) * (\frac{7}{22} * 180) * \frac{1}{0.94} \tag{3.7}$$

Further, length of the circular is given as:

$$S' = \frac{\beta * R}{57.2958} \text{ and } S' = \frac{a\cos(\frac{R-M}{R}) * R}{57.2958} \tag{3.8}$$

Having obtained the length of the Lane Changing (L), the Stopping Sight Distance (SSD) based on the AASHTO's Standard (2001) is compared with it. If the L value is greater than SSD, drivers will drive their vehicles safely while Lane Changing. Furthermore, the gap spacing or headway is also considered, this is because L must be lower than the gap, otherwise the lane changing vehicle cannot move to another lane.

$$SSD = 0.278 * v_f * t + 0.039 * \frac{{v_f}^2}{a} \tag{3.9}$$

where v_f is final speed of Lane Changing of vehicle (m/s) and a is the acceleration (m/s^2) that is calculated as:

$$a = \frac{v_f - v_s}{t_f - t_s} \tag{3.10}$$

where v_s is the starting vehicle speed for Lane Changing (m/s) and t_s and t_f are the start and final times for Lane Changing (seconds) and *t* is the perception time which is assumed to be 2.5 seconds in this analysis. In case of Lane Changing of vehicle, the researcher used these equations to inform and check the acceptance gap and SSD for the drivers.

The speed in purple, the gap length in yellow, shortest length of Lane Changing in red, and the SSD stopping sight distance in red are taken into consideration. Additional, the more details of these will be described in Chapter 4 (Data Collection) and Chapter 7 (Lane Changing and Speeding).

3.2.2 Geometrical Design for Speeding Manoeuvre

The positions of speed, which are 3 points, are located on the **Figure 3.6 and 3.7**. The first speed of moving path of circular curve is composed of coordinates among points (x_1,y_1), (x_2,y_2), and (x_3,y_3) respectively. The calculation of speed used only two points, such as the first and last coordinate under the moving times. Once again, the referred equations are 3.2 and 3.3 and they will be used for the calculation of speed of vehicle. The actual distance unit is metre (m) and speed (velocity in this case) unit is metre/second (m/s) thus, the speed (m/s) must be multiplied by 3.6 so as to change into km/hr. In case of the calibration of speed, it is enabled by using the points as mentioned above simulated and actual measurements and attempting to obtain the best match between the two by adjusting the simulator parameters through trial-and-error in the manual process or through optimization. The calibration of the camera is also measured by driving a vehicle at a constant known speed. The image and ground positions are used and rechecked to generate the dimensions which will be compared between the ground locations and the CCTV Locations. More details of these concepts will be explained in Chapter 4 and Chapter 7.

3.2.3 Evaluated Data linking of the Warning Message to Variable Message Sign (VMS)

The recorded traffic volumes after the process of image sensing will be used to count the number of Lane Changing of vehicles and the software process will collect the data, such as number of Lane Changing and the over speed of vehicles. The recorded data will be transferred to the system by Structured Query Language (SQL) standard which is described in **Figure 3.8**.

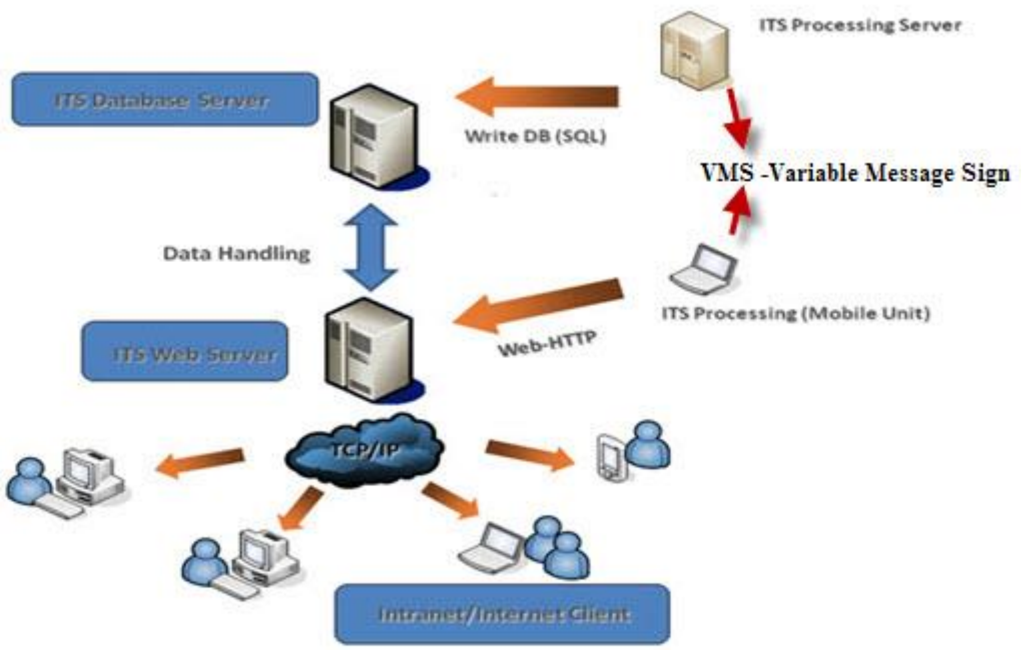


Figure3.8 The Schematic of ITS System.

The ITS Processing Server can be evaluated and can transfer the signal command to the traffic controller to link the signal to VMS as illustrated in **Figure 3.9**. Also, the developed system and software at the traffic controller will apply the evaluated command directly to the VMS. This method will reduce the travel time of traffic data. The details of the data collection will be explained in Chapter 5.

As for lane-changing maneuvers, the speed of a vehicle is checked by the time frame. The reference points of coordinates (x_i, y_i) are marked as standard length (1 meter). Headways and points of lane changing are determined by the time frame and coordinates. Coordinates (x_i, y_i) are evaluated from the pixels of the video frame-by-frame. The new system has the potential to substantially reduce queue lengths and accidents. The lane-changing accidents can be mitigated by signal from the image-sensing software, which transfers the signal to a variable message sign to warn drivers to reduce speed or to prohibit lane-changing maneuver.

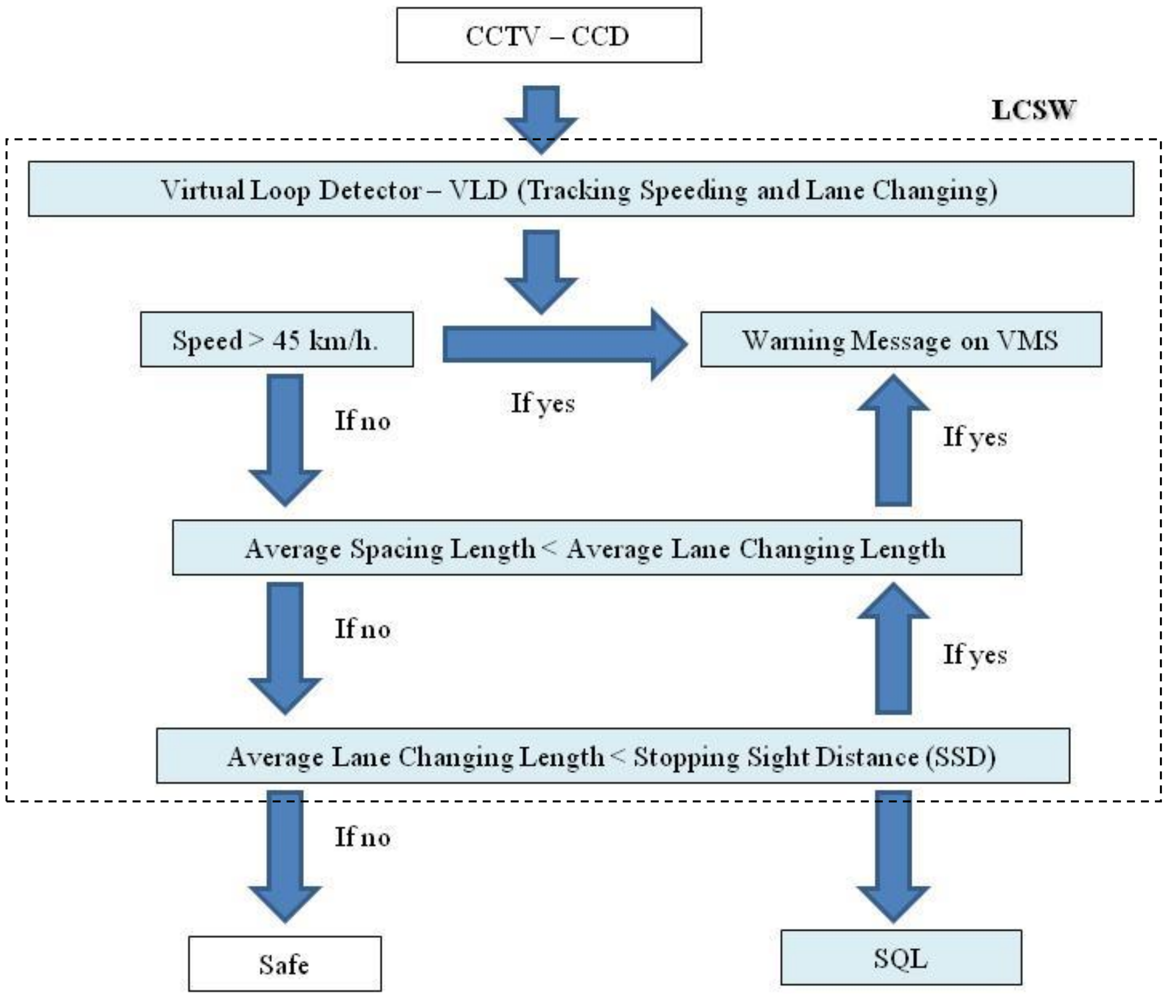


Figure 3.9 Criteria for Speed Control Model and Lane Changing Model.

3.3 IMAGE SENSING TECHNIQUES

3.3.1 Specification of CCTVs

The Specification of CCTVs: the requirements of CCTVs in this research are the uses of Pan-Tilt-Zoom (PTZ) of CCTVs so as to *save the budget of installation*. A CCTV can track vehicles on minor and major roads. Usually, there are at least four CCTVs to apply at the 4 Leg intersection, however *this research uses only two CCTVs for each intersection*. Other important requirements are 3 Megapixels CMOS of CCTV and Motion Detection, high resolution/frame rate, nearly zero Lux. and VDO Streaming MPEG-4 as described in some more details in the following parts:

1) Image Sensor Format 1/2.8" Sony 3Megapixels CMOS and Motion Detection (for Tracking Motion Function)
2) Video Resolution / Frame Rate 2048x1536@20fps, 1920x1080@30fps, 1280x1024@30fps, 1280x960@30fps, 1280x720@30fps, 720x480@30fps (for Continuous VIDEO Frame for Tracking and Classifying Vehicles)
3) Minimum Illumination 0.2 Lux Colour / 0.01 Lux Back & White @ F 1.2 (for Traffic Counting at Night Time)
4) Video Control Auto AE-Exposed, BLC, AGC, Brightness, Contrast, AWB, Sharpness, Saturation, Rotation, Mirror, WDR, Wide Dynamic 10 Levels, ON / OFF and Day/Night Mode Auto - IR Cut Filter (for Traffic Counting at Day and Night Time)

   White Balance Auto, Cloudy, Sunny, Fixed Indoor, Bulb, Fixed Fluorescent x1, Fixed Fluorescent x2, Window Toughened Glass, 100*82mm, Suitable for Normal Video and HD Cameras, Preset Up to 100 and More, Less Than 0.1° Precision (for Traffic Counting at Day and Night Time and Accuracy)
5) Streaming H.264, MPEG-4, MJPEG Dual / Triple Streaming (for Transfer Data to Control Room)
6) Security ID / Password Protection, IP Address filtering, User Access Log and Users 5-20 Multiple User Control; 3 control Level, Alarm Events File Upload via FTP and Email / Notification via Email, HTTP, TCP (for Security of System)
7) Protocols TCP/IP, UDP, HTTP, SMTP, DNS, ARP, DHCP, FTP, NTP, DDNS, UPnP, RTSP, RTP, Cable Hidden Cable Connections (for Telecommunication System)
8) Throughput CBR, CVBR up to 12Mbits (Using CBR will lower the encoding performance a little, but will ensure a constant bit rate flow and Using CVBR to ensure there are no bandwidth spikes that could break-up playback in low-bandwidth situations)

9) External digital Output Activation / Micro SD Recording (for Video Recording in Collected Data)
10) Lens Zoom Ratio Optical 20X, Focal Length / Angle Of View 4.7 - 94mm / 70.9 - 4.0 Function Auto Focus, Auto IRIS Zoom Lens, Pan & Tilt and Pan & Tilt Outdoor DC Variable Speed, Rotation Range / Speed Pan: 365° ±2°,Tilt: +20° ~ -90° / Pan: 48°/s , Tilt: 24°/s, Feedback Offer PTZ Angle Feedback Protocol Signal Via Bidirectional RS485 (for Increasing the Efficiency of a CCTV using for the Traffic Counting of 2 Directions)
11) Camera Housing All Weather Outdoor, Including Sunshield, Internal Fan and Heater, Internal High Precision Telemetry Receiver PCB, Weatherproof IP67, Temp Range -40°C ~ +60°C, Heater / Fan Thermal Controlled, On: 10±5°C, Off: 20±5°C / Thermal Controlled, On: 40±5°C, Off: 25±5°C (for the Protection and Extending of the Service Time and Maintenance)

The Comparison Results of Traffic Implementation in Thailand: these data are compared between the ITS of Royal Thai Police in Metropolitan Bangkok Area (Narupiti et al. (2012)) such as, the queue length, delay times, speed, etc. and the ITS New Concepts of this research as presented in **Table 3.1**.

Table 3.1 Comparison between the ITS of Royal Thai Police in Metropolitan Bangkok Area and the ITS New Concepts of this research.

The Previous Technology	The New Technology
1. Fixed Cameras for Traffic Counting only a Major or a Minor Road. 2. Only One Function so as to count of Traffic Volumes by Classified Count 3. Traffic Counting of an Intersection (Isolated Traffic Intersection) 4. The applied SDK – Software Development Kids for the phase co-ordination 5. Virtual Loop Detector is not provided for the Ticker of Approaching Vehicle	1. Pan Tilt Zoom CCTV for Traffic Counting and Ticker of Virtual Loop Detector for a Main Road and a Minor Road 2. Two Functions of Virtual Loop Detector: Traffic Classified Count and Ticker of Approaching Vehicle 3.Transferred and Evaluated of Traffic Counting from the CCTVs of Two Intersections so as to propose the Green Wave or Offset Times at Traffic Controllers 4. To develop the System for the Cluster Area Traffic Control in the nearly future 5. To set the Headway within 5 seconds otherwise become from Green Time to Red Time 6. To Count a Number of Lane Changing Vehicles 7. To warn the Lane Changing Vehicles on Variable Message Sign (VMS) 8. Checking the Over Speed on VMS 9. To evaluate and predict Environmental and Fuel Consumption Data

<u>The Comparison Results of Video Imaging Vehicle Detector (VIVD) (et al. (2000))</u>: they recommended that VIVD featured a greater degree of installation flexibility (Sumitomo Electric Industries, Ltd). The features of the VIVD are composed of the compact size, light weight, aesthetically acceptable appearance, and higher flexibility in installation owing to a built-in zoom lens. **Table 3.2** shows the comparison of Presence Detection Evaluation of CCTVs.

Table 3.2 Comparisons of Requirements.

Requirements	Qualifications	Details of VIVD Concepts	Details of New Concepts
Presence Detection	Detection Target	Motorcycle and Larger	Motorcycle and Larger
	Number of Lanes	2 Lanes max	2 Lanes max
	Number of Detection Areas	2 max	2 max
	Accuracy of Presence Detection	98% to 105%	95% to 100%
	Occupancy Accuracy	95% to 105%	93% to 100%
Velocity Measurement	Detection Target	Compact Cars and Larger	Motorcycle and Larger
	Number of Lanes	4 Lanes max	4 Lanes max
	Velocity Range	0 to 160 km/hr	0 to 120 km/hr
	Measuring Accuracy	90% or Higher	90% or Higher

3.3.2 Open Source of Coding in the Developed Software

In case of Open Source of Coding in the developed software, some parts of Open Source are used for the only blob functions of image sensing software in traffic classified counts. The details of blob functions will be described in Section 3.3.4. These concepts as mentioned before are developed by the Visual C^{++} Enterprise Edition 6.0 Computer Language and the Open Source referring to http://ubaa.net/shared/processing/opencv/-website. Lane Changing, Controlled Speed and Other Software are also developed by the Visual C^{++} Version 8.0 Computer Language.

3.3.3 Tracking and Detection of Virtual Loop Detector

There are two functions of VLD under the TCC and TSS1 Software. One is used for the traffic counting when the vehicle passes through a rectangular box. The other does as a trigger for sending the signal of passing vehicles on the loop to extend the green times. If Headway of vehicle is more than 5 seconds, the signal will send the changing stage-command to a traffic controller promptly. VLD of TSS2 Software will check the offset times or green wave when vehicles approaching to intersections by simulation from traffic classified counting and real-time monitoring. Finally, there are two phases algorithm; one is a normal phase so as to manage traffic situation at each intersection, other is an additional phase in order to focus on the offset times or Green Wave.

The Circular VLD of LCM and ES Software will be provided for the tracking of vehicle-path, such as starting speed (ν_s), final speed (ν_f), angle of lane changing (θ), Stopping Sight Distance (SSD), Average Lane Changing Length (ALCL) and Average Spacing Length (ASL).

As shown in **Figure 3.2**, phases J2A and B for the Four Leg intersection are also the same as the J1A, B, and C's concepts. However, the evaluation of the optimization of cycle times of main direction flows and offset times (J2B, J2A, and J1A) is done by the synchronization model and is described in the evaluation of traffic signalization. There are two algorithms as described in the following parts:

In case of Normal Phase Algorithm: it is presented in the pseudo code as shown in the Appendix. In case of Phase J1-A, if there is detected car at J1-A within 5 seconds (headways), the green time changes to the red time. The following Phase is J1-B and the effective green times are between 20 and 50 seconds and the third Phase is J1-C which varies 20 to 35 seconds. The optimization time of each phase is calculated from SIDRA and Synchro (aaSIDRA-Full version 1.0.6.145, 2000, Trafficware Synchro 6, 2003).

In case of Additional Phase Algorithm (Offset Times or Green Wave): the Offset Times-phase or Green Wave phase will be proposed for the vehicles passing from one intersection to the other intersection, such as the group of direction flow of J2B phase and J1A phase, the group of J1C phase and J2B, and the group of J2A and J1A. **Figure 3.3** shows the algorithm of Green Wave Phase and Offset Times. It will be described that the offset times as mentioned before and calculated based on the method of ARRB (Akcelik, 1989). In case of J2B and J2A to J1A direction, 34 seconds of offset time will be taken into consideration and it will be minus with the amber and all red times (7 seconds). Therefore, 27 seconds of offset time will be proposed for the Green Wave phase. In case of J1C to J2B 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). Furthermore, the increment times of J1A phase is during 0.5 to 0.8 times of green times of J2B phase based on traffic volumes and calibration of filed data.

3.3.4 Classified Count of Vehicles

There are three concepts of Classified Count of Vehicles Software; First concept is presented about the ***Motion Techniques*** which is the distinguishable process between static and dynamic objects. Second concept is illustrated about the ***Blob Tracking Technique*** which is the screening, evaluating and splitting of objects in background processes. Third concept is applied for the finding of the focused objects and for the inputting of image data at the different times are evaluated by the ***Optical Flow Technique***. The more details of these concepts will be described in the following parts:

<u>In case of Classified Vehicle Software:</u> it is based on the process of motion techniques. Therefore, the process can be distinguished between static and dynamic objects such as electrical poles and traffic signs, etc. After the vehicles pass the Virtual Loop, the process starts to adjust and filter the images as described before. The collected data are checked and rechecked with the prototypes of vehicles (size, width and length) as recorded in a server. However, the Length and Height of vehicles will cause an error in the classified results.

Process of the system starts from the collected VDO streaming at Analog Cameras and the Analog VDO will be compressed by MPEG4 encoder so as to send the images to Servers by routers. The developed software at server will calculate and evaluate two parts; one is the traffic counting of 5 types of vehicles (classified count) by using the Image Sensing Technique and the traffic management at intersection in order to calculate the traffic cycle times and phasing. In the next process, the resulting data will be sent from severs to traffic controller by network. There are 5 types of vehicles; motorcycle, passenger car, light truck and mini bus, heavy truck and bus, and trailer. Passing vehicles are detected and counted when they pass through a rectangular box or a Virtual Loop. Processes of the system are presented below;

- 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 (to see **Figure 3.10**)

Figure 3.10 FG and BG and vehicles on FG detection technique**.**

$$BI_{color-channel}(x,y) = (1-a) * BI_{color-channel}(X,Y) + a * CI_{color-channel}(X,Y) \qquad (3.11)$$

where Color-Channels are Red, Green, and Blue, BI is the Accumulative Background Pictures in each frame, CI is the Current Picture and Learning Rate is $0 \le a \le 1$ while (x,y) is the coordinate in 2 dimension.

In case of Concept of Blob Tracking: the screening of objects in background is evaluated and split. The objects which are separated are divided into a single object in order to track each object. Dimensions, Locations, and Number of Vehicles of the Virtual Loop area are applied by the Trajectory Generation Methods. The above processes are presented in **Figure 3.11**.

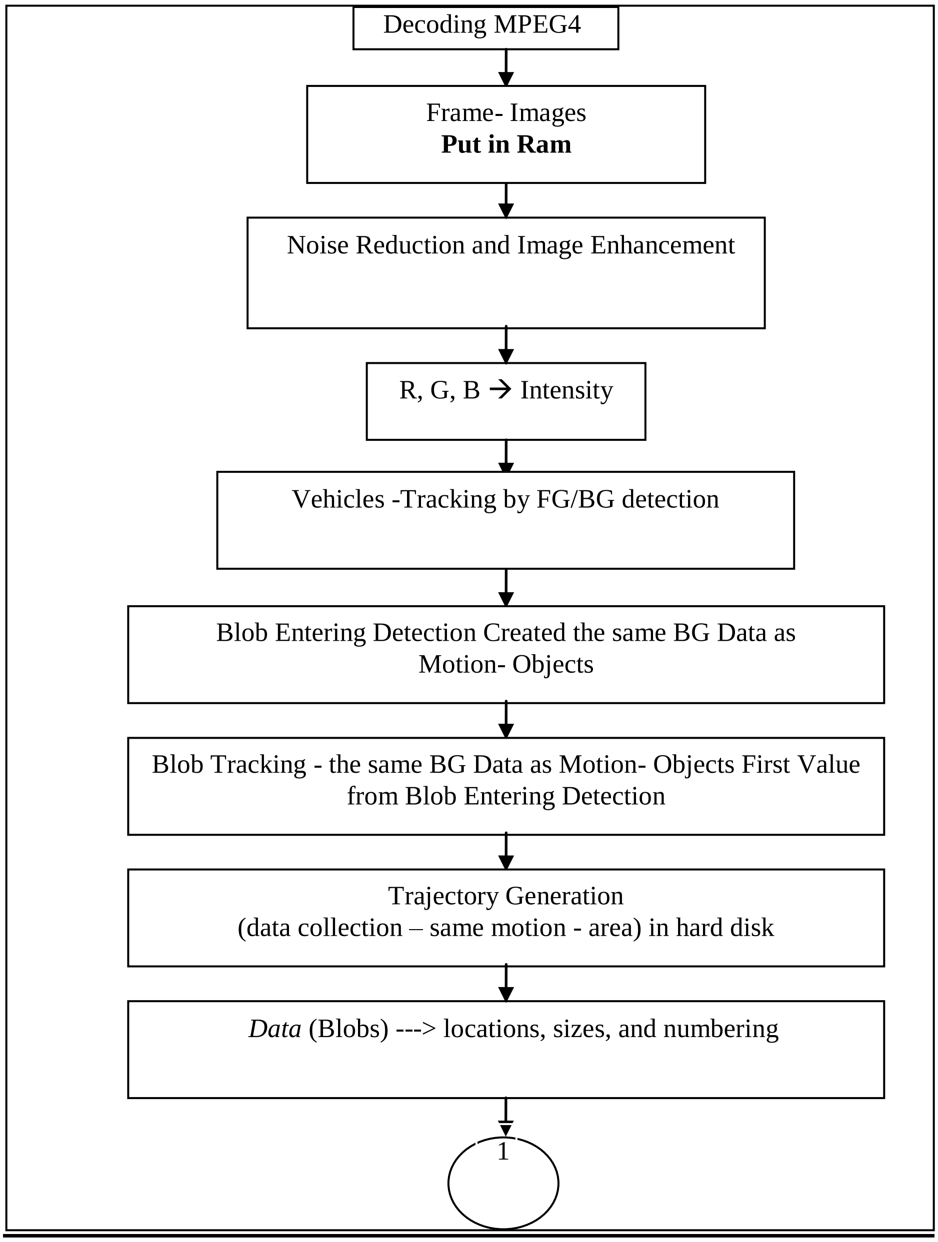


Figure 3.11 Image sensing structure software.

VDO frames are decoded from MPEG4 into Bitmap, and a noise reduction process is applied so as to adjust and filter the images to make them bright, clear, sharp, and coloured. These images are controlled by the window frame. Again, when the vehicles pass though the Virtual Loop, they can be detected. There are 5 modules of Blob Entering System as depicted in this diagram (**Figure 3.12**):

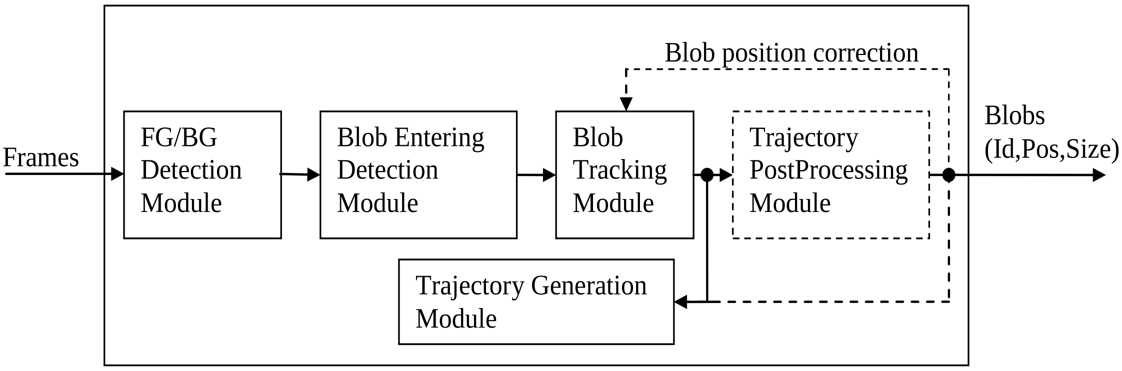


Figure 3.12 Blob Tracking System – 5 Modules.

Source: Yuanfang, 2009, http://www.scribd.com/doc/13657998/Blob-Tracking-Modules, (Accessed 20 April, 2010)

This flow chart is called 'Blob Tracking Auto' module and implemented as an individual module in BlobTrackingAuto.cpp and BlobTrackingAuto.h files. FG/BG Detection module performs foreground/background segmentation for each pixel. Blob Entering Detection module uses the result (FG/BG mask) of FG/BG Detection module to detect new blob object entered to a scene on each frame. Blob Tracking Module initialized by Blob Entering Detection results and tracks each new entered blob. Trajectory Generation module performs a saving function. It collects all blobs positions and save each whole blob trajectory to hard disk when finished. Trajectory post processing module performs a blob trajectory smoothing function. The application of Blob Entering Detection Techniques is shown in **Figure 3.13**.

Figure 3.13 Results of the Application of Blob Entering Detection Techniques.

Optical Flow Technology: it is applied for the finding of the focused objects. For example, input image data at the different times as shown at the left hand side are evaluated by the optical flow and after the process. It will be objects with velocity (Velocity Vectors) as shown at **Figures 3.14**.

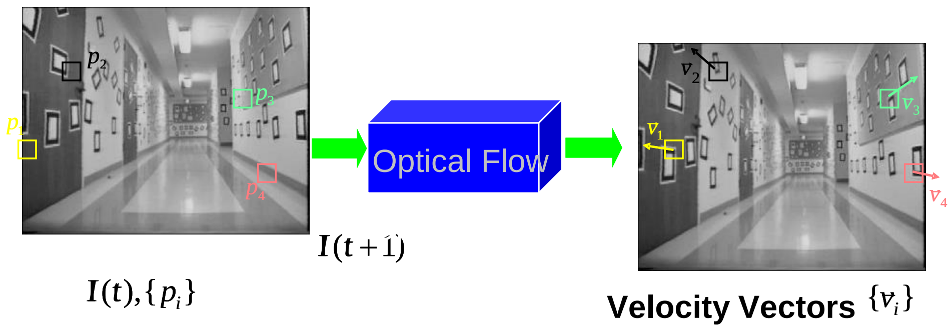


Figure 3.14 Using the Optical Flow Technology to find the Velocity Vectors.

From **Figure 3.14**, it can be seen that the Velocity Vectors are written into the equations as presented for 2 dimensions in **Figure 3.15** below:

$$2D: \frac{\partial I}{\partial x}\bigg|\left(\frac{\partial x}{\partial t}\right) + \frac{\partial I}{\partial y}\bigg|_t \left(\frac{\partial y}{\partial t}\right) + \frac{\partial I}{\partial t}\bigg|_{x(t)} = 0 \tag{3.12}$$

$$\frac{\partial I}{\partial x}\bigg|\mu + \frac{\partial I}{\partial y}\bigg|_t \nu + \frac{\partial I}{\partial t}\bigg|_{x(t)} = 0 \tag{3.13}$$

$$\frac{\text{Notation}}{I_x\mu + I_y\nu + I_t} = 0 \quad \text{At a single image pixel to get a line: } I_x\mu + I_y\nu = -I_t \tag{3.14}$$

$$\nabla I^T u = -I_t \tag{3.15}$$

$$u = \begin{bmatrix} \mu \\ \nu \end{bmatrix} \quad \nabla I = \begin{bmatrix} I_x \\ I_y \end{bmatrix} \tag{3.16}$$

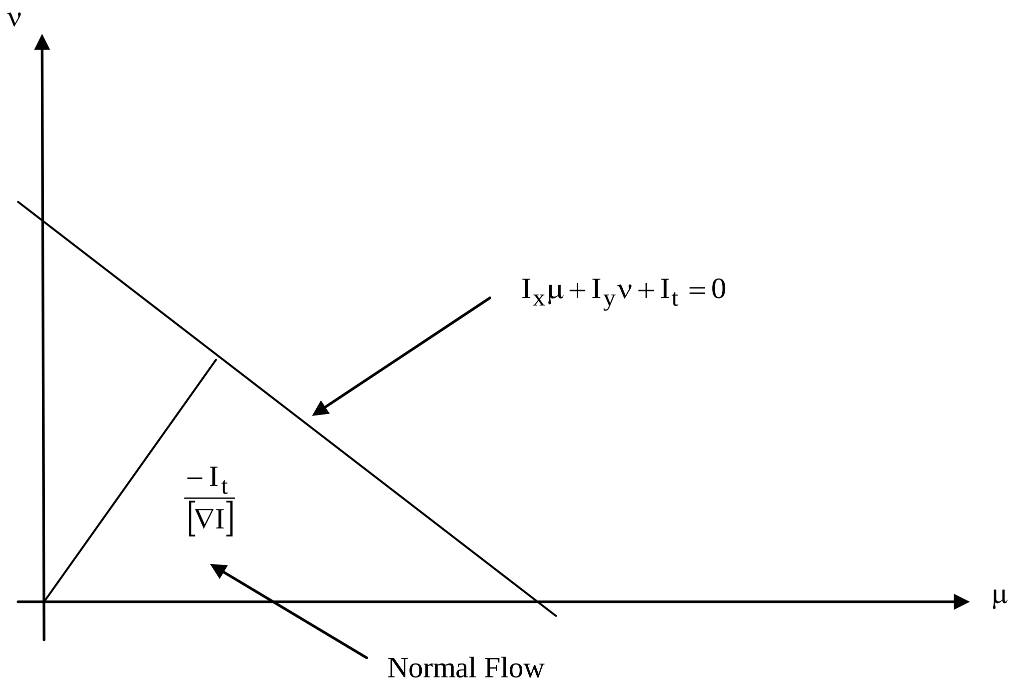


Figure 3.15 Velocity Vectors (2 dimensions) as written into the equation.

where I_x is the bright on Pixels (x –axis), I_y is the bright on Pixels (y –axis), I_t is the bright on Pixels varied on times, T is time changing at each image, μ is velocity of pixels as changing on image (x –axis) and ν is velocity of pixels as changing on image (y –axis).

At the moment, the Vision System has an effect on the traffic engineering by use of tracking and classification of vehicles. In case of tracking systems at the real-time, several methods will be taken into consideration such as, Detecting Symmetry Point, Approximating Optical Flow, and Matching Templates. Therefore, this research applies concepts of Optical Flow and Background Extraction with Differencing Image. The concepts are not suitable for high density traffic volumes and incidents in night time. The classification of vehicles is used and applied with the concepts of Maximum Likelihood Estimation; however the length and height of vehicle will cause the classified results to be unreliable. Thus, the researcher will use and apply the 3 steps as outlined below:

1) Tracking Vehicles at the zoning area will be minus between the background and the present picture while the vehicles are still passing the area. Moreover, the accuracy of each image will be dependent upon the climate, UV ray, and location of cameras.
2) Tracking area will use the first item as mentioned above and the present data so as to compare.
3) The overlapped objects will be the focus of the observed area. Thus, the split of overlapping objects will be taken into consideration.

3.3.5 Lane Changing and Speeding

This research presents the result of a pilot study using the locally developed ITS technology to reduce intersection crashes due to speeding and dangerous lane changing behaviour. The technology was developed and tested at two intersections in Bangkok, Thailand. Due to this tracking method, the environment of calculation uses the high technique. Therefore, the high technique tracks each Blob promptly in the real-time. In case of the Blob Tracking Techniques, the process of dynamic time warping and K-Nearest Neighbors method are taken into consideration.

<u>The starting of parameter values of this system</u>: they are the size and location of analyzed window, the shortest gap of vehicles, the threshold percentage of pixel to hold for counting of the same vehicle, etc as taken into consideration. The application of this technique will use the frame of smaller window of VDO. This leads to the analysis of proper figure in this frame by sending the figure in the process so as to separate the vehicle from the background. The next step is to identify each vehicle and to transfer the data to the Lane Changing vehicle system as presented in **Figure 3.16**.

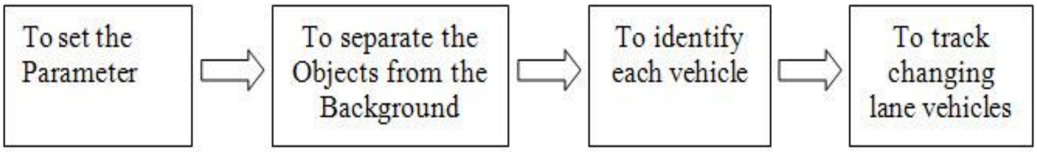


Figure 3.16 Process of the Tracking of Lane Changing Vehicles**.**

The process of this mentioned method is applied to the statistic model which is under the Library of Open CV. The Library that is the Open Source is used by researchers worldwide. As a result, the Foreground Image is segregated from the background as shown in **Figure 3.17**.

(a) Separated object frame from VDO (b) Separated object from the background

Figure 3.17 Tracking of Lane Changing Vehicles**.**

Figure 3.17(b) is sent to the tracking vehicle so as to count the number of Lane Changing vehicles. The Lane Changing vehicle is a function of the width and angle of the Lane Changing vehicle by the average width and angle of vehicle which is parameter (P). Therefore, it applies to the Number of Car Stat (P→Number of Car Stat) and it leads to the number of Lane Changing vehicle.

<u>The calculation of speed in the VDO frame:</u> it must be changed into the times and the length in pixel from CCTV and it is changed into the actual length. The input data will be presented below:

1) Frame per second (fps) of VDO for the consideration of actual time.
2) Length of Points (x_1,y_1) and (x_2,y_2) at the 1 metre length is placed in the VDO Frame as (refDistance).
3) The average speed is applied by using the next equations;
   - $Blob_{(last\ frame)} - Blob_{(first\ frame)}$
   - The Distance in pixel (pixDistance) is referred from the location of vehicle in the first frame and the last frame. The following equations will describe of the distances and speed.

- $d = \sqrt{(x_2 - x_1)^2 + (y_1 - y_2)^2}$ (3.17)

Where, d is the calculated distance.

- $\text{Speed} = \dfrac{\dfrac{\text{pixDistance}}{\text{refDistance}}}{\dfrac{\text{frames}}{\text{fps}}}$ (3.18)

The actual distance unit is metre and speed (velocity in this case) unit is m/s, the speed (m/s) must be multiplied by 3.6 so as to change into km/hr. Furthermore, the coding of tracking speed of vehicles software will be shown and described in Appendix.

3.3.6 Environmental Impact and Fuel Consumption

A before and after study of fuel consumption of a typical passenger car, the average speed, the level of air pollutions in terms of CO, PM_{10} and noise pollution in term of L_{10} using the authors' developed ITS technology and predictive models are presented in **Figure 3.18**. In case of Noise Pollution, the noise pollution between the predicted results from the model and the results from the method of UK Department of Transport - Welsh Office (1988), Cheewapattananuwong and Samuels (1996), Samuels and Cheewapattananuwong (1997) will be compared. In case of the air pollution and fuel consumption, the predicted equations will be applied for the collected data as compared and calibrated by the statistical methods. All of the results will be presented with the average speed of each green times, in addition, the results show that fuel consumption and pollution levels have improved since the installation of the ITS system as presented in the Chapter 4 and Chapter 8.

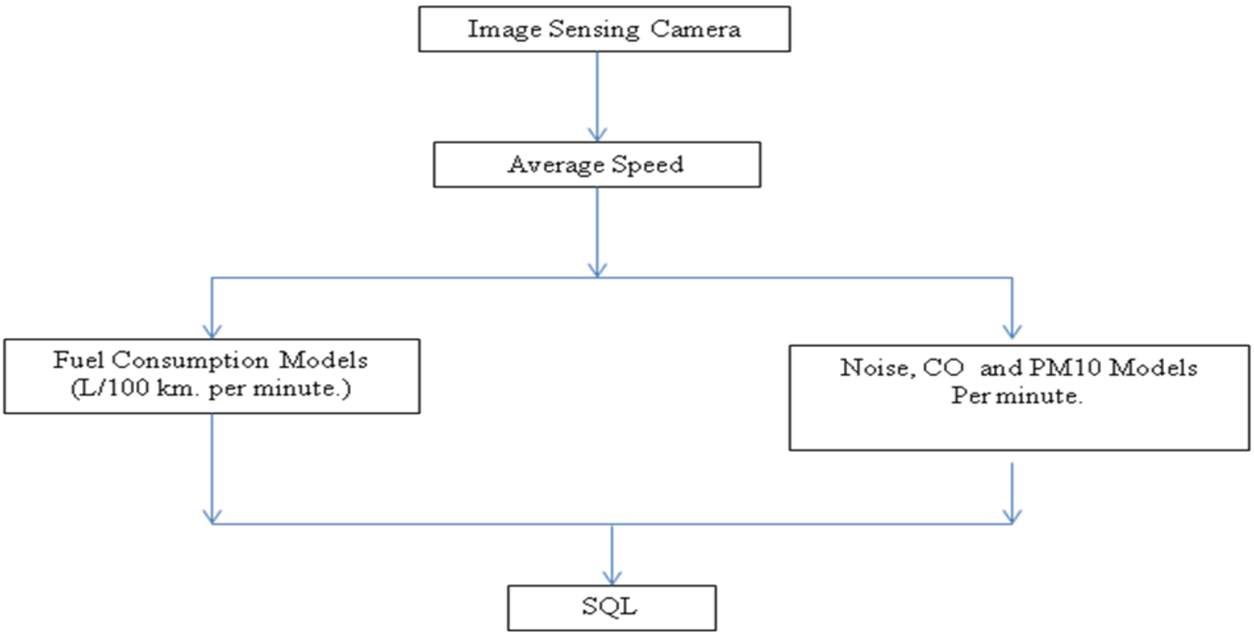


Figure 3.18 Environmental Impact and Fuel Consumption Predicting Model.

3.4 TELECOMMUNICATION TECHNIQUES

Due to the higher budget of the previous installation of ITS, such as Royal Thai Traffic Police, Bangkok Metropolitan Authority (BMA), Department of Highways (DOH) and Expressway Authority of Thailand (EXAT), the researcher realizes to reduce and save the budget and focuses on the bird e eye view design of the schematic of ITS as shown in **Figure 3.19**.

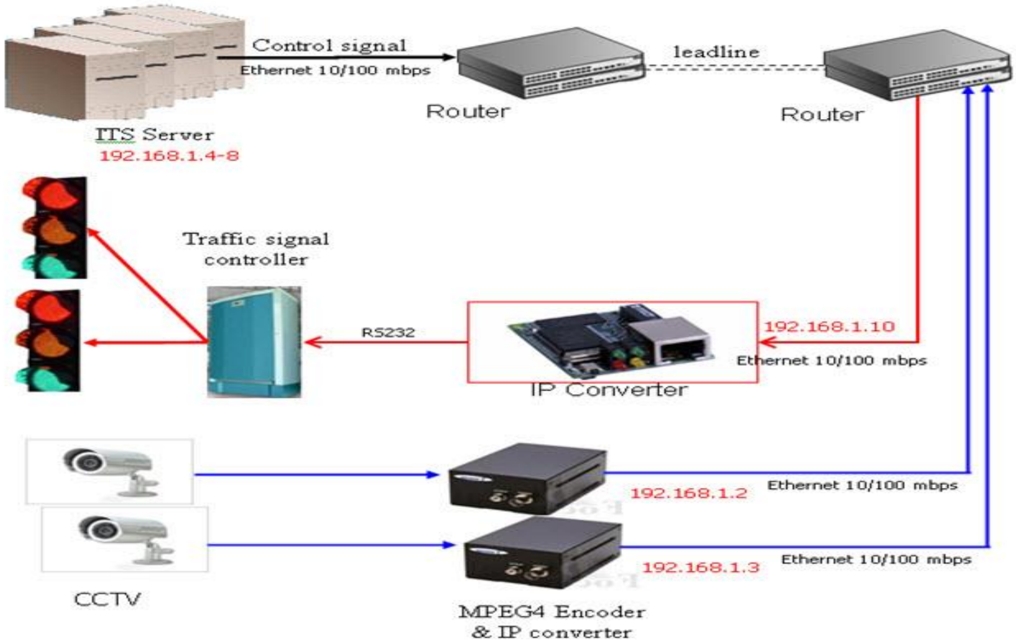


Figure 3.19 Schematic of CCTV and Equipments for Using Image Sensing Technique to Control the Traffic Controller.

Therefore, the concepts of the adaptive traffic signalization are focused on the analog cameras based on the motion tracking function as complied with the developed software, the finding MPEG4 encoder so as to send the images to Servers by routers, the convertor providing the continuous VDO streaming (> 15 frame per second) (Hirunvanichakorn, 2006) and keep the lowest bytes, the effective network such as, server, routers, traffic controller, etc.

3.4.1 RGB – Red Green and Blue

<u>The size of image:</u> it is 640*480 Pixel or 8 Bits (Resolution is 256 colours). The data and image is also equal to 640*480*3 colours*8 Bits or 7,372,800 Bits or 921,600 Bytes. If the frame rate is 25 frames/second, the minimum transfer data will be 7,372,800*25 or 184 Mbits. Therefore, the data cannot be transferred by the original computer (Ethernet 10/100 Mb) and the data must be compressed by MPEG4 Digital Technology which is 100 times compression (Pangchan and Wutipornpong, 2003).

As the result, trend of band width decreased dramatically to 384 Kbits/second and the normal computer (TCP/IP) can be taken in account.

3.4.2 Noise Reduction and Image Enhancement

Noise reduction and image enhancement techniques are applied to adjust and filter the images to make them bright, clear, sharp, and coloured. These images are controlled by the window frame. Red, green and blue colors with changing intensity help to reduce the size of image, that is 640*480 pixel or 8 bits (resolution is 256 colours). Moreover, the data and image is also equal to 640*480*3 colors*8 bits or 7,372,800 bits or 921,600 bytes. If the frame rate is 25 frames/second, the minimum transfer data will be 7,372,800*25 or 184 Mbits. Therefore, the data cannot be transferred by the original computer (Ethernet 10/100 Mb) and must be compressed by MPEG4 digital technology which is 100 times compression (P. Hirunvanichakorn, 2006). As a result, the trend of band width decreased drastically to 384 Kbits/second and a normal computer (TCP/IP) can be used. Tracking vehicles on the foreground/background (FG/BG) detection by the deleted images between FG and BG is created by the same BG Data as Motion Objects Flow by Blob entering detection techniques in order to increase the accuracy level. In regards to the number of vehicles passing through the Virtual Loop, the dimensions of each type of vehicle is generated by recognition developed software and stored in server's memory. For example, when a motorcycle passes the Virtual Loop, its dimensions are evaluated by the software. The whole open sources coding was used in the development of the new image sensing software.

3.4.3 Electrical and Coding Equipments

The researcher used to apply the concepts of electrical and coding equipment in 2007 so as to test the capable electrical signals to traffic controller more than 500 metres, thus the electrical commanding to the equipments was not efficient, such as the fluctuated signals or noise signalization and data lost in sometimes. In this study, the researcher provided the maximum of cable link within 500 metres. The coding equipment will efficiently protect the noise signalization which is dependent upon the length of cable. Therefore, the length for phase coordination is not more than 500 metres due to the size and price of cable.

In case of the electrical signal, it is changed to be the Injection Laser Diode and it will be re-changed to be the electrical signal again. In case of telecommunication, the High Speed Internet Connection (512 Kbits/Sec.) will be taken into consideration. This is owing to the fact that the minimum frame rate for 2 cameras is 25frames/second (fps) or the minimum requirement of capacity of lease line is more than 384 Kbits/second. The responding time after the evaluated process must be lower than 60 milliseconds so as to send the commanding line to the traffic controller as soon as possible. Most importantly, the traffic situation will be solved promptly to remedy the potential crisis.

3.4.4 Interface Card for Plug – In with All Traffic Controllers in Thailand

The coding of tracking vehicles, such as the classified vehicles in Virtual Loop detectors, the linking of signal from Virtual Loop to traffic control, the simulation of traffic synchronization before the setup software with the traffic controllers at the intersections, traffic board controller. Finally, the flow diagram will be shown in **Figure 3.20**.

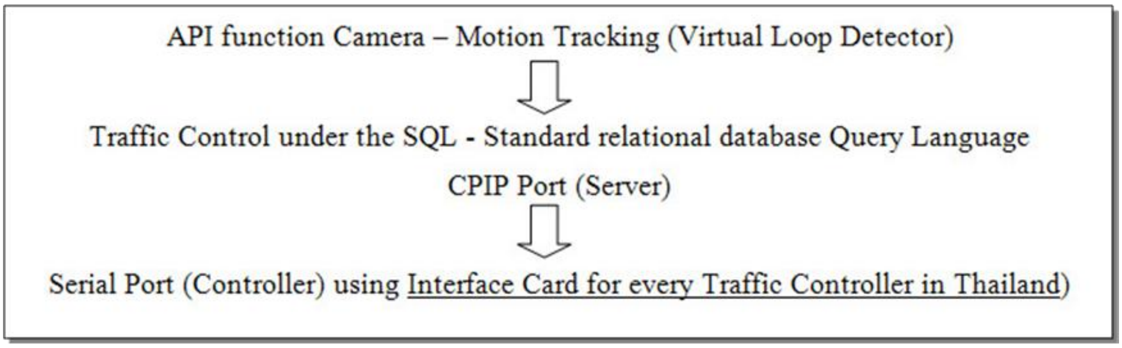


Figure 3.20 Evaluated Traffic Data Commanding to Traffic Controller and Traffic Control Centre by CPIP and Serial Port.

3.4.5 System Integration (SI)

In case of the network system, it is very important for VDO streaming flow and data flow due to the fact that they have an effect on the traffic volume evaluation at the control room. The System Integration (SI) of Network, Appropriated Equipments and Software are illustrated in **Figure 3.16**. The SI of ITS Network is complied with the developed software (Synchronization, Adaptive Traffic Signalization, Controlling Speed and Lane Changing) and the equipments as mentioned above therefore, the ITS system will be operating most effectively.

3.4.6 Functions of CCTVs complied with Software

In case of Traffic Synchronization and the adaptive traffic signalization, the Virtual Loop is the area for traffic counting where vehicles flow through. Traffic counting and classification start with the dimensions of vehicles. Furthermore, the developed software for image sensing can calculate and evaluate the frames of images. The classified traffic count uses trial and error method to obtain accurate dimensions of each vehicle. In this research, CCTV cameras were used for several functions;

the cameras count traffic volumes on major road during Off Peak and Peak hours and also count the volumes on minor roads. Therefore, a Virtual Loop in a camera has two functions; as a Loop Detector (traffic sensor by trigger) and as a classified traffic counter. In the case of the trigger Virtual Loop, traffic data and signal is transferred to controllers for computation of the Headways. If there is no vehicle passing through the Virtual Loop within 5 seconds, the signal will command the traffic controllers to change the green time-phase to amber and red times, respectively. Details of the adaptive traffic signalization are presented in Chapters 4, 5 and 6.

In case of Speeding and Vehicle Lane Changing Model, the researcher arranges the equipments, network system, and developed software as detailed below:

1) Software and Equipments for Vehicle Detection so as to check and recheck safety gap and speed.
2) Software Equipments for Controlling Speed and Vehicle Lane Changing by the safety length.

The details of these concepts will be described in the Chapter 4 and 7.

In case of the Evaluated Traffic Data commanding to Traffic Controller and Traffic Control Centre, the traffic data collection of tracking vehicles must be concerned with the criteria of installation of cameras as described below:

1) The camera must be installed before the stop line due to the fact that the motion detection software will be in error if the red times are more than the cycle times.
2) The angle of cameras must be placed in the line of lanes (to avoid the oblique line).
3) The height of cameras must be at 12 metres or more to allow clear sight of the obscured following vehicles.
4) The cameras are chosen based on specification, especially high contrast between textures of road and vehicles.
5) Fine Tuning Parameters in the software adjusts the best parameters in the files.

Cycle times at T and 4 Leg intersections decrease dramatically due to the triggers. The triggers of Virtual Loop detect the vehicles passing them within 5 seconds (from the calibration Headway), otherwise the loops will sync to controller so as to change the state from green times to red times promptly. The green times could be extended when vehicles pass a Virtual Loop up to the maximum of green times.

3.4.7 Data Collection and Evaluated Traffic Data Commanding to Traffic Controller and Traffic Control Centre

The structure of SQL Language: there are 2 types of pronunciation in SQL; SQL and SEQUEL (Structured Query Language) which are the data system language. This can build and operate by the relational database based on English Version. The SQL were developed from the idea of relational calculus and relational algebra that were constructed of the code by IBM – Almaden Research Center and the first and second names of SQL were SEQUEL and SQL respectively. SQL, which is the commonly used software, is of a different scope of commanding than ORACLE ACCESS SQL Base of Sybase INGRES or SQL Server (Microsoft). American National Standards Institute (ANSI) has arranged most commanding systems to run the software provided in three parts as described in Chapter 5.

Embedded SQL: the normal command language is written by the Pascal, Cobol or C++. Moreover, the SQL has not a command language for control statement such as, if..then…else for…do or loop or while. This leads to a limit of the set of command. Therefore, the application of SQL embedded in the other languages is used for increasing efficiency:

```
while not end-of-file(input) do
begin
readin(id-num, roadname,loc,comm);
EXEC SQL INSERT INTO CAPACITYTAB
VALUES(:id-num,:roadname,:loc,:comm);
end;
  Incase of INSERT INTO CAPACITYTAB
 VALUES (:id-num,:roadname,: loc, :comm);
```

The application of Pascal Language: it is able to increase the number of loops and recording so as to keep the values in the variables (id-num, salesperson, loc, comm.) of CAPACITYTAB. The repeated loops are used for the reading of the whole data in the files. The interactive SQL are the same as operating as the embedded SQL. However, the embedded SQL can link to the other languages.

3.5 ENVIRONMENTAL AND FUEL CONSUMPTION TECHNIQUES

3.5.1 Traffic Noise

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). Therefore, 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 data are the same owing to the fit comparative values of the relative coefficients factors. **Figure 3.21** shows the set-up of data collection.

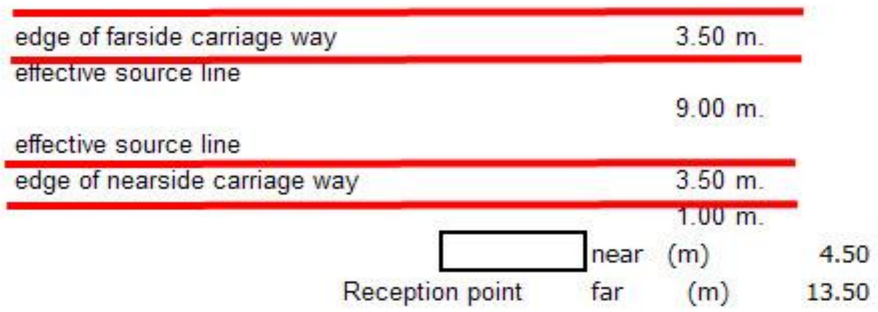


Figure 3.21 Collected Data - Location of Noise and Air Pollution.

Finally, the traffic noise pollution from this method will be compared and calibrated with the collected data from the field or the case study intersections. Furthermore, the R^2 (Goodness of Fit Correlation) and Correlation Coefficient will be taken into account. Therefore, the new emission model at the case study area will be predicted and presented in the Chapter 4 and Chapter 8.

3.5.2 Vehicle Emission Models

The EU developed Air Pollution Emission standards in 1995. Therefore, the values of EU standard emissions of Passenger Car for CO and PM_{10} have decreased significantly from 1995 to 2011 as shown in **Table 3.3**.

Table 3.3 Values of EU Standard Emissions of Passenger Car for CO and PM_{10} During 1995 to 2011. Source: Pollution Control Department Thailand (2012)

	Comparison of EURO Stadard during 1995 - 2010 Year	CO PPM	D%	D1995-2011%	PM10 mg/m^3/24hr	D%	D1995-2011%
	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	

For the present study, the existing CO and PM_{10} data in 2012 were measured at the study intersections during 14 to 16 November, 2012 as shown in Chapter 4 (Data Collection). The traffic air pollution data at the case study intersections were collected and this leads to the lower level of traffic air pollution when compared with the standard level of each type of air pollution. Consequently, the data will be calibrated to find the emission model of traffic air pollution. Moreover, the R^2 (Goodness of Fit Correlation) and Coefficient Maximum Error will be taken into consideration.

In Canada, the Working Group on Environmental Noise of the Federal/Provincial Advisory Committee on Environmental and Occupational Health acknowledged that: Noise was more than just a nuisance because it constituted a real and present danger to people's health. Noise was able to produce serious physical and psychological stress. The body at times responded with extreme tension, such as a strange sound in the night (Basrur, 2000). Moreover, noise was able to produce physiological changes. For example, patients exposed to noise pollution had decreased oxygen saturation (increasing need for oxygen support therapy), elevated blood pressure, increased heart and respiration rate, and worsened sleep. There was also strong evidence that noise increases stress in adult patients, heightening blood pressure and heart rate. The obvious problem, sleep loss, leads to slower recovery times and greater likelihood of readmission to hospital (Short and Pearson, 2011). The details of the results from the collected data will be presented in the Chapter 4 and Chapter 8.

3.5.3 Fuel Consumption Models

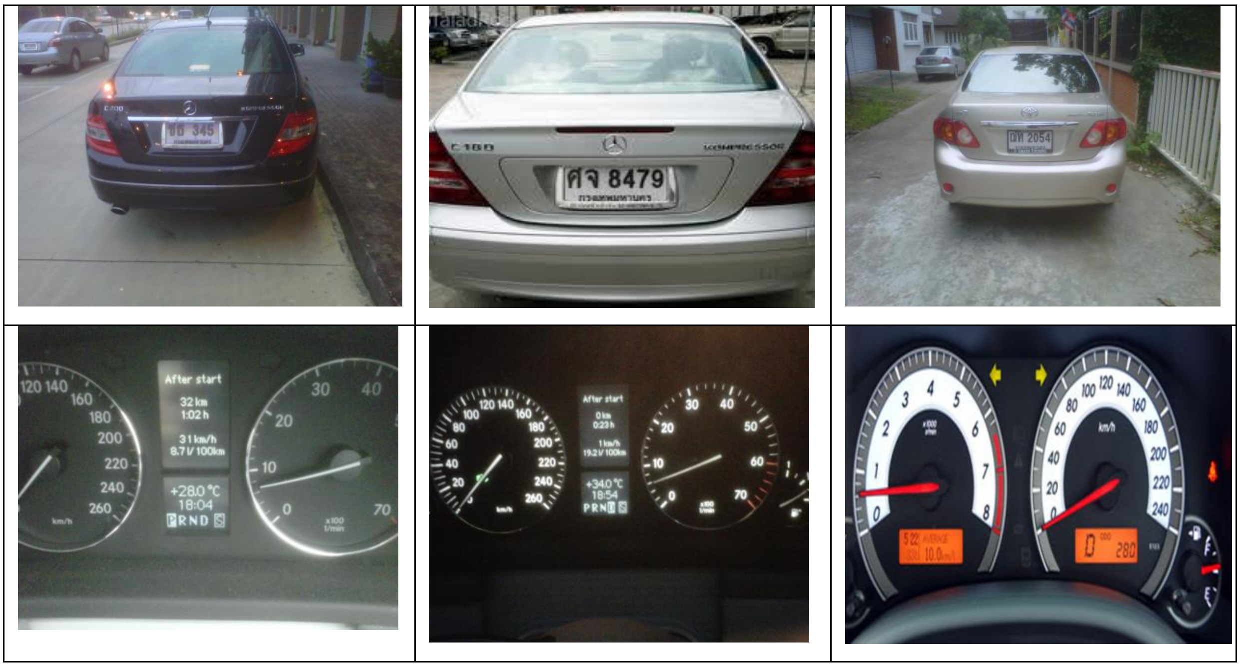
The concepts of fuel consumption are presented below:

The vehicles (4 wheels), such as 1.6 L Toyota Altis, 1.8 L and 2.0 L Mercedes Benz, and the traffic congestion situations during peak hours in the morning and evening are taken into consideration. In case of traffic situations, the data of average speed and fuel consumption during the Peak and Off-peak hours are collected by the recording data on the mile display in liter per 100 km as can be seen in Picture 3.2. The registration data of license plates of the vehicles, especially car and sedan (4 wheels) in 2010 show that the cars > 2000 cc are 50.423 percent and < 2000 cc are 49.577. Therefore, the researcher chose the fuel consumption model of 1.6 L Toyota and 2.0 L Mercedes Benz as the representatives of all passenger cars.

The statistic theories of the relationship between average speed and fuel consumption (L/100 km) are taken into account under the R^2 Goodness of Fit. The model of fuel consumption will be applied with the traffic arrival at the intersections and the average speed of vehicles.

The average fuel consumption cost of cars (> 2000 cc and < 2000 cc) are applied by the average of petrol prices list of all fuel types from July 2011 to June 2012 and the average prices of passenger car (4 wheels) was compared by the composition of all fuel types.

The results of these items (fuel consumption at the intersections) will be calculated the fuel consumption in L/100 km, L/km/PC and B/km respectively.



Picture 3.2 Display of Fuel Consumption of All Vehicles During Peak and Off-peak Hours.

Chapter

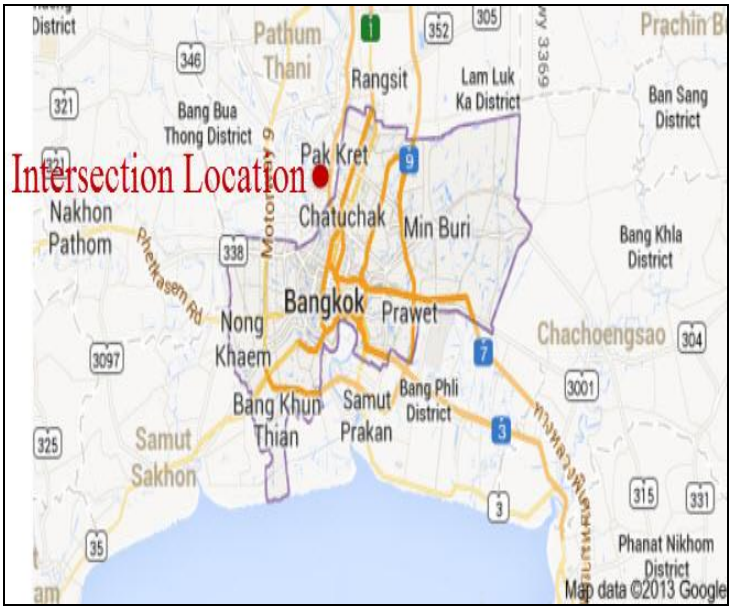
4

DATA COLLECTION

4.1 STUDY SITE

4.1.1 Road Conditions

This research describes one of the pioneering uses of ITS technology to mitigate congestion and reduce accidents at intersections. The intersections under study are located in suburban Bangkok, Thailand as presented in the **Figure 4.1** (https://aps.google.co.th/, 2013), where an extraordinary number of major accidents have occurred as a result of red light running, excessive speeding and reckless lane changing. In case of geometrical features of intersections (460 metres), such as T-intersections and four- leg intersections as described in Pictures 4.1 and 4.2, it gives rise to several conflict points at those types of intersections. Without proper control at such conflict points, accidents are likely to occur. Through the use of accident analysis modeling, and ITS technology, it is possible to improve traffic flow and reduce the number of crashes. In Thailand, the ATC –Area Traffic Control in CBD of Bangkok, which is the responsibility of Bangkok Metropolitan Authorities (BMA), has not been improved from the installed SCOOTS or SCATS (Jansuwan and Narupiti, 2005). This is owing to the fact that these systems have already been designed only from nodes to nodes within the grid area and they were applied with magnetic sensors or loop detectors, however the conditions of sois have not taken into consideration (Shepherd, 1992) and the vehicles from lanes led to blocked traffic flow from major roads. In addition, the application of (ITS) technology by CCTV of the Royal Thai Police for improvement of traffic flow including an image-sensing concept for adaptive synchronization was used to detect traffic volume, speed and queue length (Narapiti et al., 2012). This thesis proposes the image sensing concept which includes the traffic classified counting. Moreover, the traffic volumes will be used to calculate and evaluate signal phasing and cycle times for adaptive synchronization. In this operation, two closed-circuit television cameras and electronic equipment installed at each intersection were used to track vehicles passing through virtual loops, similar to the way in which induction loops in pavement detect vehicles. A variable message sign was used to flash a warning to errant drivers. After the implementation of this locally developed ITS technology, traffic flow improved significantly and the number of accidents caused by red light running and speeding has decreased dramatically.



T or 3 Leg Intersection

4 Leg Intersection

Figure 4.1 Location of Case Study – Intersections.

Picture 4.1 the Three–Legs or T Intersection used in the case study.

Picture 4.2 the Four–Legs Intersection used in the case study**.**

Traffic volumes at many intersections in suburban Bangkok, Thailand, are at saturation level; this saturation creates long delays, which lead to driver frustration (Department of Highways, 2012). The fixed time of many existing traffic controllers in suburban Bangkok has exacerbated the situation. The queuing drivers become even more frustrated when they see an approach with few vehicles getting more green time than necessary; the long cycle times further aggravate the situation, especially when drivers are in a rush. A common cycle time is often set for all periods. Phases and cycle times of these intersections are not designed for traffic synchronization. Many drivers try to speed through the intersection during the dilemma times to avoid long delays. In this study, vehicle actuated traffic controllers and the authors' new traffic management software are used. The software optimizes phase and cycle times and can adapt to real-time traffic volumes.

4.1.2 Traffic Situations

Traffic flows at many intersections in suburban Bangkok are at saturation level; this creates long delays which lead to drivers' frustration as mentioned above. The fixed time nature of many existing traffic controllers in suburban Bangkok has exacerbated the situation. The queuing drivers become even more frustrated when they see approach with few vehicles getting more green time than necessary; the long cycle times further aggravate the situation especially when the drivers are in a rush. A common cycle time is often set for all periods. Many drivers resort to speeding so as to pass the intersection during the dilemma times to avoid long delay as phasing and cycle times of these intersections are not designed for traffic synchronization. The existing cycle length of T intersection is 150 seconds, and the existing cycle length of Four Leg intersection is 90 seconds. The next Figures show the existing phasing and cycle times at intersections (Fixed Time Signalization).
The calculation of cycle times and phases at intersections are used for finding the optimum cycle times and phases as run on the SIDRA and Synchro software. The traffic factor during peak hour, such as queue, is measured on main roads (inbound direction). **Table 4.1** shows the maximum cycle times and the best phasing for those times.

Table 4.1 Output from the SIDRA and Synchro software.

SIDRA		Synchro	
Cycle Times max. (sec.)	150 , 90	Cycle Times max. (sec.)	150 , 90
Number of Phasing	3 , 2	Number of Phasing	3 , 2
Queue (m)	451.0 , 959.0	Queue (m)	423.9 , 987.3
Actual Queue (m)	420.0 , 890.0		

Note: (Three Leg Intersection- values, Four Leg Intersection- values)

Queue Length of vehicles during peak hour at the Three Leg Intersection is about 420 metres on major road to the Four Leg Intersection (460 metres) and the queue length of Four Leg intersections is nearly 890 metres (see **Picture 4.3**). Moreover, the offset times between 3 phases at the Three Leg intersections and 2 phases at the Four Leg intersections (local people prefer driving under these phases) are calculated using the method of ARRB (Akcelik,1989). The general directions of vehicles at Three Leg and Four Leg intersections are 6 and 10 movements respectively. In case of Four Leg intersection, there are only 10 directions without right turn movements due to the preference of local public. The phases at Three Leg and Four Leg are 3 phases and 2 phases and the cycle times at Three Leg and Four Leg intersections are 150 seconds and 90 seconds as presented in **Figure 4.2, 4.3, 4.4 and 4.5**.

Picture 4.3 Queue Length at T Intersection is about 460 metres under the Fixed Times System.

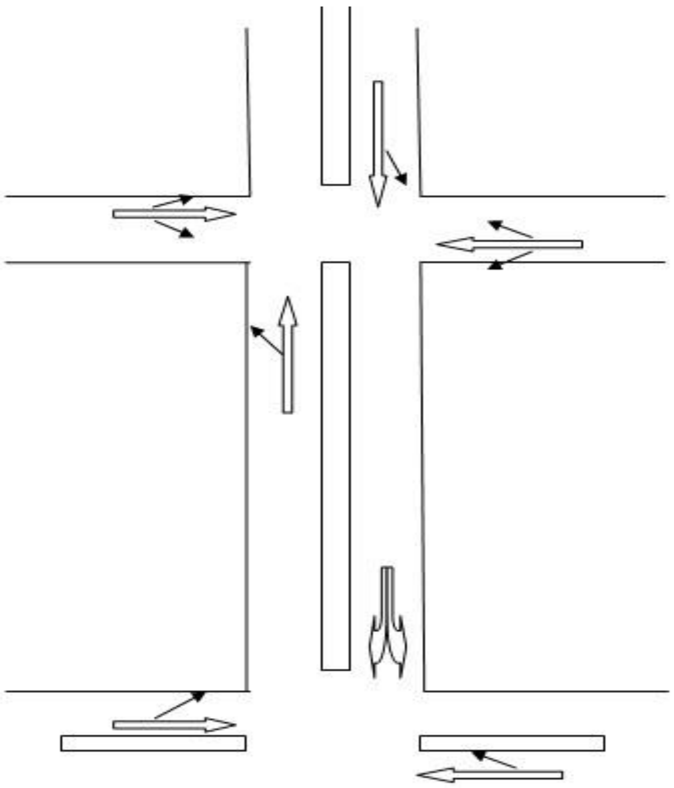


Figure 4.2 Directional Traffic Flow at the existing intersections**.**

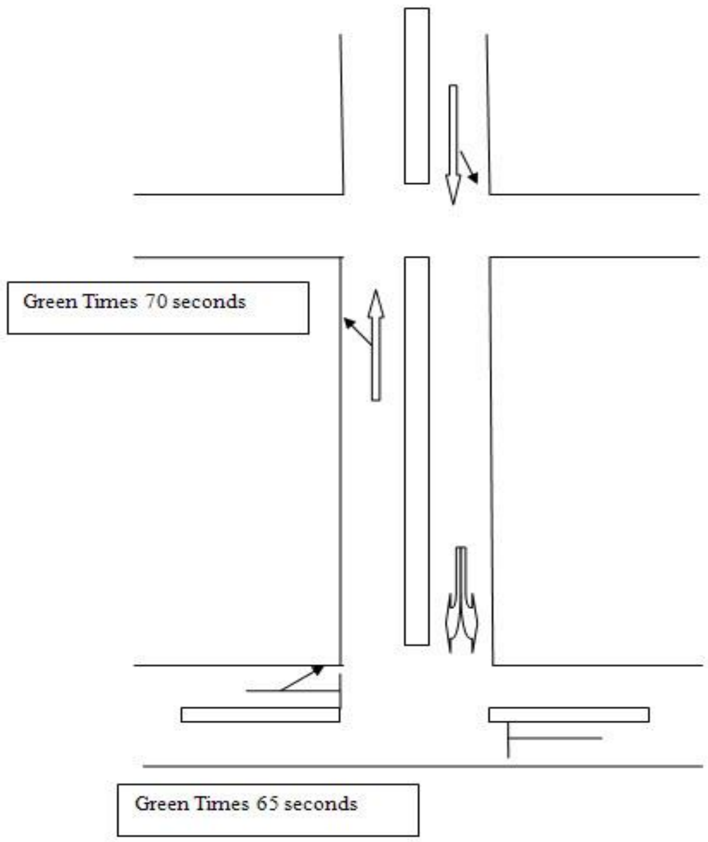


Figure 4.3 Traffic Phasing I at the existing.

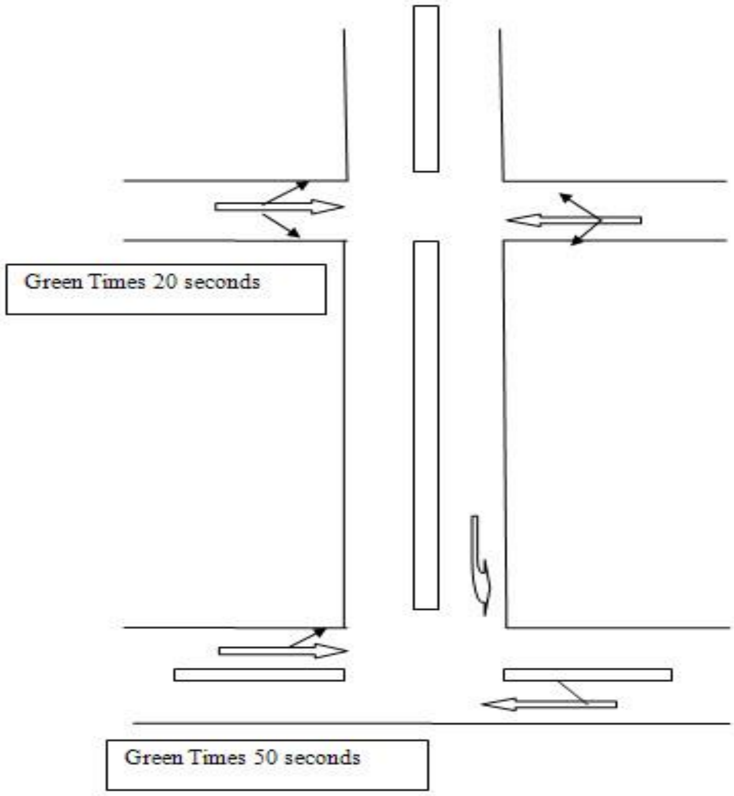


Figure 4.4 Traffic Phasing II at the existing intersections.

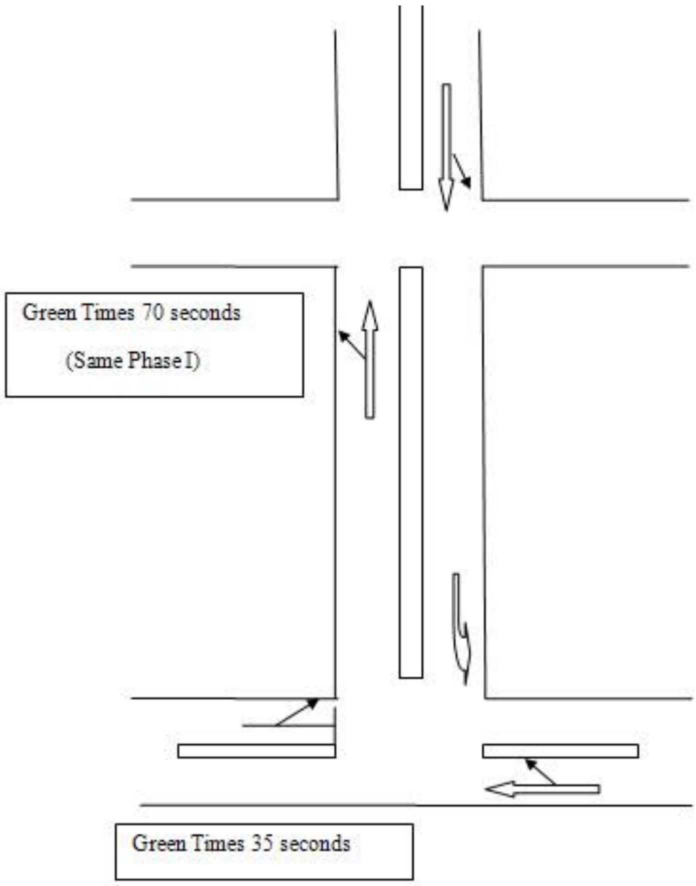


Figure 4.5 Traffic Phasing III at the existing intersections.

4.1.3 Traffic Accidents

Crash data from January 2005 to October 2011 were used to analyze the causes of crashes at both intersections. The major causes of accidents were drivers' disobedience of traffic laws and malfunction of the equipments. Therefore, the main crashes during 2006 to 2008 were caused by Red Light Running (RLR) as illustrated in **Figure 4.**6 and **4.7.**

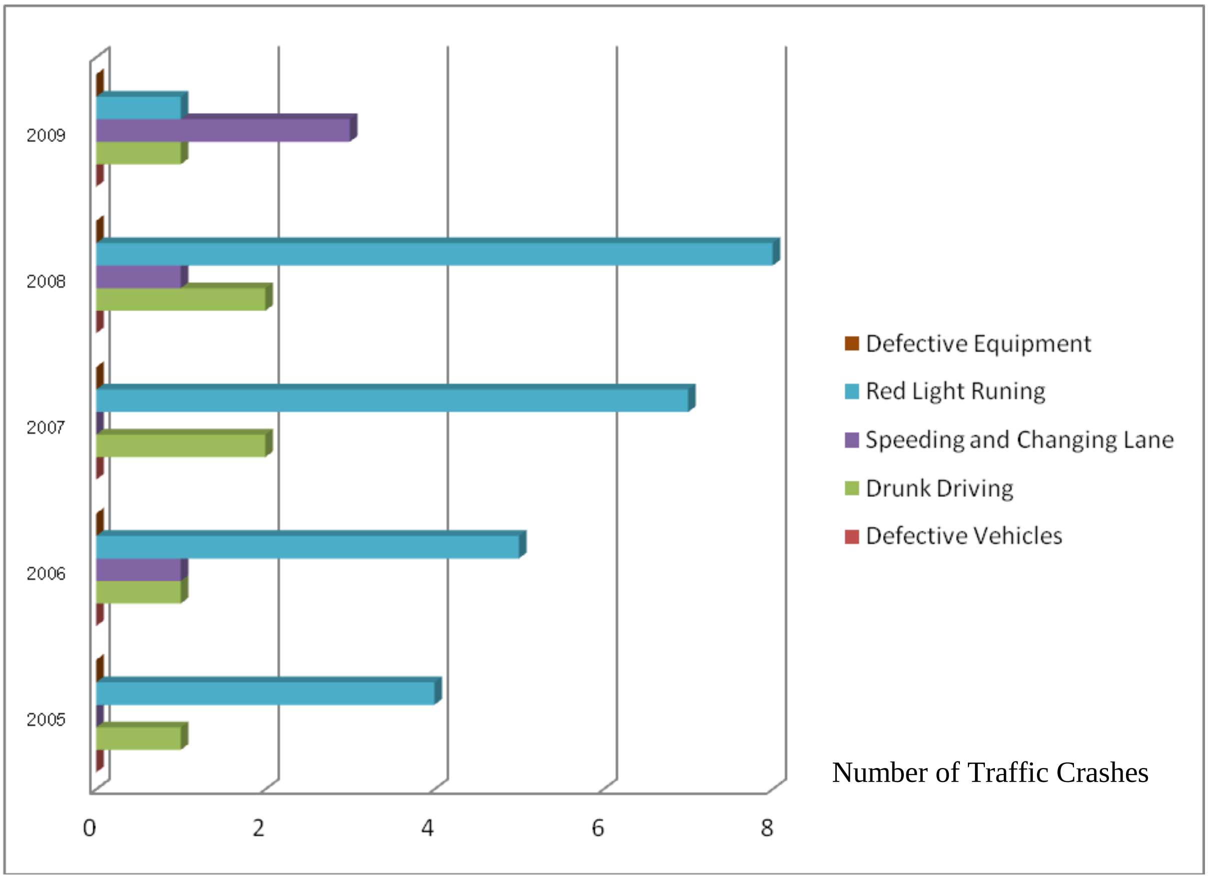


Figure 4.6 The number of accidents (injuries, and fatalities) by the causes of accidents at the intersections during 2005-2009.

Source: Maintenance Division (DRR), Provincial Disaster Department and Nontaburi Public Hospital (2011)

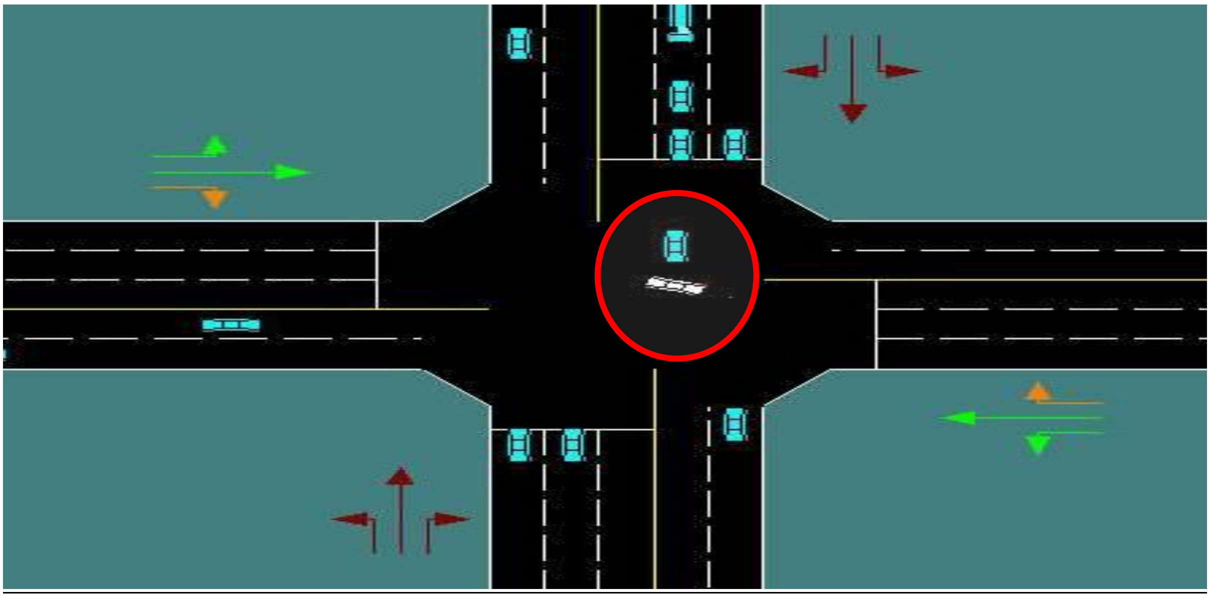


Figure 4.7 Red Light Running (RLR) in Model leads to the major cause of traffic accidents during 2005 to 2008.

Results of data analysis revealed that number of accidents at the two intersections during 2005 – 2008 with minimum and maximum of number of accidents occurring at the same site were 2 and 7 respectively. The results have been presented in **Table 4.2**. Number of Accidents and Injuries during 2005 to 2008 at T Intersection fluctuated between 3 and 6. By way of contrast, Number of Accidents and Injuries at 4 Legs Intersection increased substantially.

Table 4.2 Numbers of Accident, Injury, and Fatality at the Specific Intersections during 2005 – 2008. Source: Maintenance Division, DRR, Provincial Disaster Department and Nontaburi Public Hospital (2008)

Year	Types of Intersections			
	T Intersection		4 Legs Intersection	
	Number of Accidents	Number of Injuries	Number of Accidents	Number of Injuries
2005	3	4	2	1
2006	4	5	3	2
2007	6	6	3	3
2008	4	4	7	4

Refer to **Figure 4.6**: the major crashes in the year 2009 were a result of speeding and lane changing, with the number of reported crashes at 3 times per year. In addition, in 2009, speeding and lane changing also constituted the major cause of crashes at the intersections as can be seen at **Picture 4.4**. Department of Rural Roads (DRR) defined them as black spots (Department of Highways, 2000). Intelligent Transport Systems (ITS) technology, such as, image sensing method have been used and applied as a remedy for traffic accidents at these intersections. In case of before -situation, the two intersections, 460 meters apart, were controlled by the Fixed Time System (designed and factory built) (Al-Mudhaffar, 2006). The ITS technology, especially the application of traffic signalization with the use of virtual loop detectors and phasing co-ordination concepts, were proved effectively in dealing with RLR crashes (Cheewapattananuwong et al., 2011). Furthermore, the ITS technology developed by the researcher has again been effective in reducing these crashes. These crashes for the years 2010 and 2011 decreased substantially.

Picture 4.4 Dangerous Lane Changing and Speeding cause most accidents at intersections.

The increasing accidents during 2005 – 2008 were used to analyze the number and causes of intersection crashes as shown at **Figure 4.6**, **Figure 4.7** and **Table 4.2**. In addition, there are three major causes of traffic accidents which are Red Light Running (RLR), Speeding, and Drunk Driving. The Department of Rural Roads (DRR) has designated these two pilot intersections as Black Spots since there were more than 5 accidents occurring per year according to DOH's definition (Department of Highways, 2000). The existing traffic signalization using fixed time control leads to the saturation traffic flow and hence created long delays and drivers' frustration. It is found that major causes of accidents are drivers' disobedience of traffic laws, red light running (RLR), and speeding. Therefore, a pioneering intelligent transport system (ITS) technology with image sensing capability has been proposed to mitigate congestion and accidents at these two intersections. Moreover, the number of injuries at T and Four Leg intersections increased substantially; however, there were no fatalities at either intersection.

If the changing lane vehicle moved into the gap which is smaller than SSD as described in **Table 4.3**, the accidents at the risky area will occur. The developed software (after case) had shown the shortest length of changing lane and SSD so as to remedy the traffic accidents at this area. It causes the following vehicle to stop suddenly so as to keep the safety gap. Therefore, this area usually becomes the risky zone.

Table 4.3 The Stopping Sight Distance SSD and Weaving Length based on AASHTO (2001).

Source: AASHTO (2001)

	60 kph	**70** kph	**80** kph	**90** kph
SSD (m)	85.42	108.97	128.45	152.64
Weaving L to R (m)	113.66	132.6	151.55	189.43
Weaving R to L (m)	113.66	132.6	151.55	208.38

4.1.4 Traffic Pollution

The existing environment situations during 14 – 16 November 2012 as can be seen at **Table 4.4** were 7.83, 5.67 and 5.10 ppm./hr for CO, 17.88, 20.26 and 22.78 $\mu g/m^3$/24hr for PM_{10} (Particulate Matter less than 10 micrometers in diameter) and 79.6 -dB(A) for Noise. Especially, CO and PM_{10} Level are not more than the standard of air pollution (in particular, 30 ppm./hr for CO and 120 $\mu g/m^3$/24hr for standard of PM_{10}). However, the existing Noise level is upper than 73.0 -dB(A) for standard of noise (L_{10}) (Pollution Control Department Thailand (2012)). In this research, the software optimizes phase and cycle times and can adapt to real-time traffic volumes, this leads to the decreasing of queue length and the increasing of speed of vehicles. Therefore, the environment situations will be improved. **Figure 4.8** will be presented for the Locations of Collected Data of Air and Noise Pollution during 14 – 16 November 2012.

Figure 4.8 Locations of Collected Data of Air and Noise Pollution during 14 – 16 November 2012.

Table 4.4 the collected environmental data at the intersection during 14 -16 November 2012.

Average Speed km/h	Measurement		
	Noise dB(A)	CO PPM/h	PM10 mg/m^3/24h
0	72.0	2.69	17.52
5.01	73.0	2.73	17.03
10.23	74.0	2.78	16.66
21.83	76.8	3.09	14.82
33.78	76.2	4.27	13.08
40.59	78.1	5.50	12.60
50.37	80.4	8.23	13.45

The predicted equations of Traffic Air Emission Models are applied and calibrated of collected data. However, the predicted Traffic Noise Emission Model is compared between the method of UK Department of Transport - Welsh Office (1988), Cheewapattananuwong and Samuels (1997), Samuels and Cheewapattananuwong (1997) and predicted collected data by the statistic methods.

4.1.5 Fuel Consumption

In case of Fuel Consumption, the registration data of license plates of the vehicles, especially car and sedan (4 wheels) in 2010 show that the cars > 2000 cc are 50.423 percent and < 2000 cc are 49.577 percent (Land Transport Department Thailand (2011)). In case of the calculation of fuel consumption model, they were collected data at the case study area and they were calibrated by the statistical methods as described in Chapter 8 (Traffic Emission and Fuel Consumption). As a result, the fuel consumption situations will also be improved.

4.2 DATA COLLECTION

There are three parts of this section, such as Deices and Management System, Data Collection Times – Periods and SQL – Structured Query Language. All are described below;

4.2.1 Devices and Measurement System

The integrated system of all is applied for the Integrated ITS System. Moreover, there are 5 software concepts which were taken into account. They are:

1) Traffic Classified Count and PCU (TCC) by Image Sensing Linking between the CCTVs and Servers.
2) Traffic Management and Adaptive Traffic Signalization System (ADTS) Linking between Servers and Traffic Controllers including Track Motion in CCTVs and Traffic Controller (TSS1 and TSS2).
3) Speed Control (ES) and Lane Changing (LCM) Linking between the CCTVs and Servers.
4) Traffic Noise and Air Emission Model Evaluated within Servers.
5) Fuel Consumption Model Evaluated within Servers.

They are depicted as an integrated system in **Figure 3.1**.

4.2.2 Data Collection Time – Periods

<u>The traffic data collection of tracking vehicles:</u> they must be concerned with the criteria of installation of cameras as described below:
Fine Tuning Parametres in the software adjusts the best parameters in the files. There are several computer languages of the fine tuning parameters as shown in the following part:

videoFile : the file name of VDO file (.avi)
windowsSize : the sizes of windows (for calculation)
threshold : limit of threshold for comparison
minWidth : the width of Objects as designed to be a vehicle
minGap : the length of Object
maxfill : the values of inserting completed Object
mainframe : the frame for the calculation of motion detection
avKept : the Learning of vehicles period
use_sd : the specific mode for comparison, used as mean or sd

s1,s2,s3,s4 : the values of compared types of vehicles

value < s1 ⟹ Motorcycle

s1 value < s2 ⟹ Saloon

s2 value < s3 ⟹ Pickup ,

s3 value < s4 ⟹ 6 Wheels - Truck

value > s4 ⟹ 10 Wheels – Truck or Bus

sleepMil delay time

theta_l the Angle of Camera (0-90 degree)

theta_r the Angle of Camera (0-90 degree)

For Example, the collected data will be shown in the following values**: Vdo1.avi 60 350 600 370 15 0.5 25 30 30 5 30 s -0.8 1.0 1.8 2.0 50 70 5.**

Figure 4.9 shows the variation of traffic volumes as collected by the traffic image sensing software (TCC). These data are examples of traffic volumes on major and minor roads during 4.05 pm to 5.35 pm.

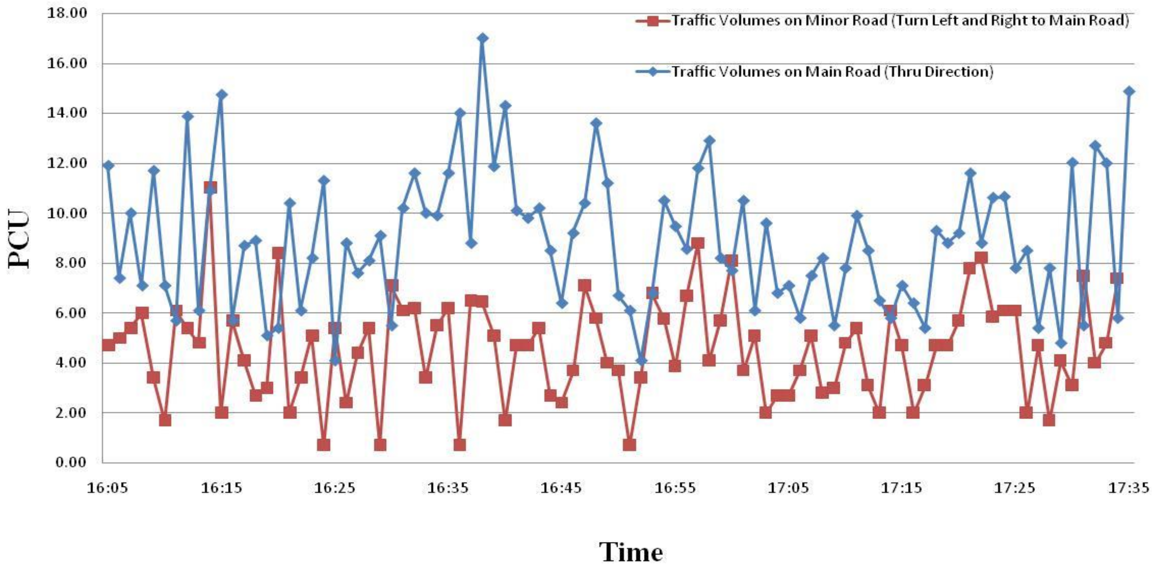


Figure 4.9 the variation of collected traffic data by traffic image sensing software.

Moreover, lane changing data are collected during 3.30 pm to 4.05 pm by the image sensing software (LCSW) as presented in Figure 4.10. As can be seen that the lane changing behavior of Thai drivers are unsafe due to the Average Lane Changing Length < Average Spacing Length < SSD.

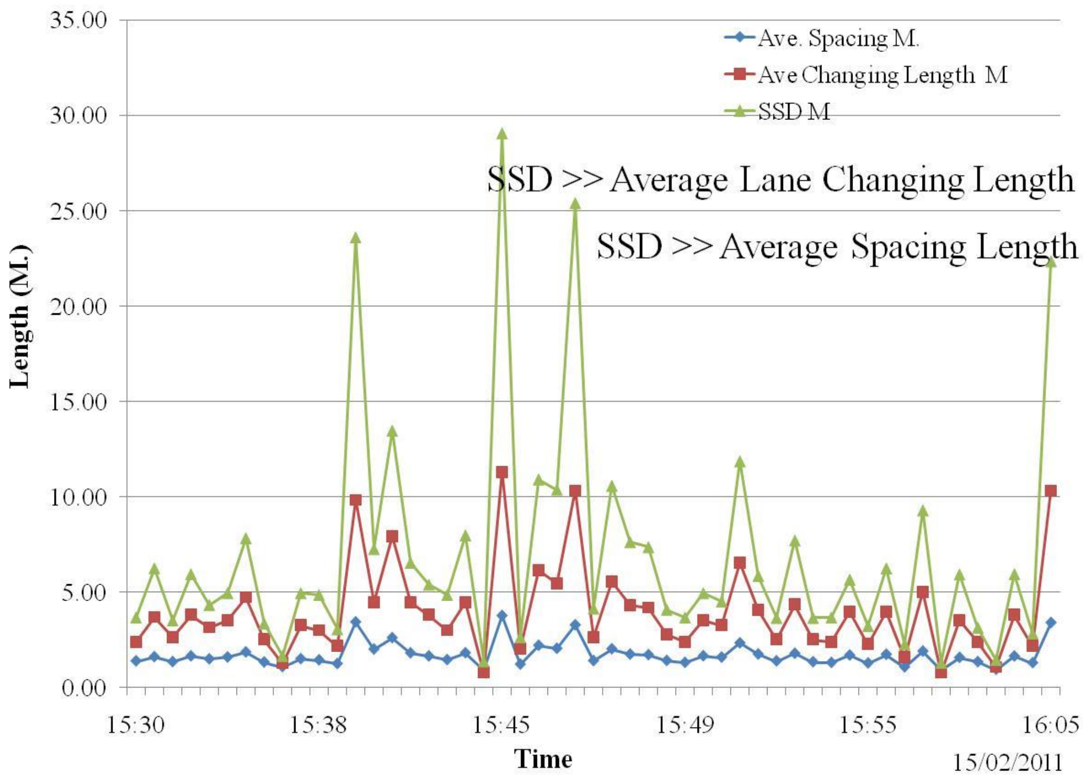


Figure 4.10 the variation of Average Spacing Length, Average Lane Changing Length and SSD during 3.30 pm to 4.05 pm.

Rechecking traffic signalization: the researcher 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 described in the section 3.1.4 (equation 3.1). This leads to the Cycle times at the T and Four- Leg intersections decrease dramatically due to the triggers from the Software in the section 4.2.1. Once again, the triggers of Virtual Loop detect vehicles passing through within 5 seconds (from the calibrated headway during peak hour), otherwise the Loops will signal to the controller promptly to 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. In case of Synchronization Phase, **Figure 4.11** and **Table 4.5** show the minimized effective green times at each leg 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, which are substantially lower than the maximum effective green times of maximum cycle times obtained from SIDRA and Synchro software. The results from image structures with accuracy of 95 % of classified traffic count by the calibration of vehicle dimensions and angle of CCTV camera.

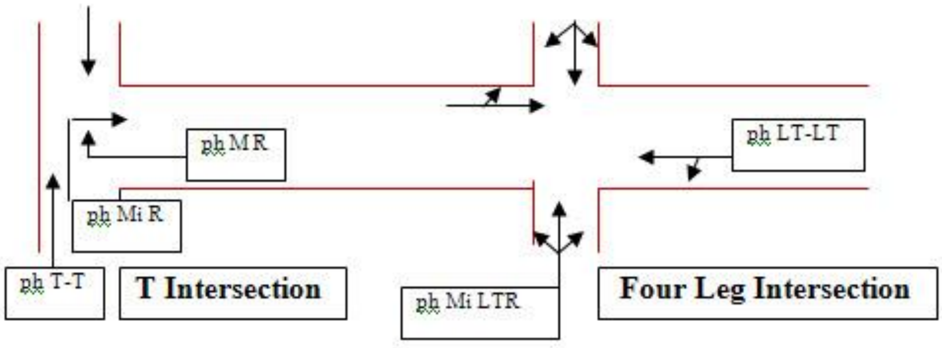


Figure 4.11 Synchronization Phasing between T Intersection and 4 Leg Intersection.

Table 4.5 Minimized Effective Green Times of Each Approach of Two Adjacent Intersections.

T Intersection Phasing	Seconds	Traffic Volumes Average PCU	QCT recheck	4 Legs Intersection Phasing	Seconds	Traffic Volumes Average PCU	QCT recheck	T Int. Cycle Times	T Int. Total PCU	4 Legs Int. Cycle Times	4 Legs Int. Total PCU
ph T-T	30	49	28	ph LT-LT	29	49	28				
ph M R	18	39	18	ph Mi LTR	20	41	20	73	134	49	90
ph Mi R	25	46	25								
ph T-T	34	51	30	ph LT-LT	8	20	8				
ph M R	18	39	18	ph Mi LTR	20	41	20	75	134	28	62
ph Mi R	23	45	23								
ph T-T	30	49	28	ph LT-LT	33	50	30				
ph M R	14	33	14	ph Mi LTR	20	41	20	67	127	53	92
ph Mi R	23	45	23								
ph T-T	10	25	10	ph LT-LT	40	50	30				
ph M R	13	31	13	ph Mi LTR	15	34	15	38	91	55	85
ph Mi R	15	34	15								
ph T-T	24	45	24	ph LT-LT	7	18	7				
ph M R	26	47	26	ph Mi LTR	12	29	12	72	136	19	47
ph Mi R	22	44	22								
ph T-T	25	46	25	ph LT-LT	24	45	24				
ph M R	25	46	25	ph Mi LTR	12	29	12	64	125	36	75
ph Mi R	14	33	14								
ph T-T	18	39	18	ph LT-LT	7	18	7				
ph M R	14	33	14	ph Mi LTR	8	20	8	47	106	15	38
ph Mi R	15	34	15								
ph T-T	19	40	19	ph LT-LT	51	44	22				
ph M R	33	50	30	ph Mi LTR	7	18	7	67	125	58	61
ph Mi R	15	34	15								
ph T-T	15	34	15	ph LT-LT	42	50	29				
ph M R	26	47	26	ph Mi LTR	14	33	14	48	99	56	83
ph Mi R	7	18	7								
ph T-T	23	45	23	ph LT-LT	55	39	18				
ph M R	51	44	22	ph Mi LTR	7	18	7	84	113	62	57
ph Mi R	10	25	10								
ph T-T	21	42	21	ph LT-LT	46	48	26				
ph M R	25	46	25	ph Mi LTR	14	33	14	62	125	60	80
ph Mi R	16	36	16								
ph T-T	29	49	28	ph LT-LT	42	50	29				
ph M R	29	49	28	ph Mi LTR	11	27	11	67	120	53	77
ph Mi R	9	23	9								
ph T-T	21	42	21	ph LT-LT	40	50	30				
ph M R	40	50	30	ph Mi LTR	11	27	11	79	132	51	78
ph Mi R	18	39	18								
ph T-T	31	50	29	ph LT-LT	38	51	30				
ph M R	38	51	30	ph Mi LTR	11	27	11	76	118	49	78
ph Mi R	7	18	7								
ph T-T	7	18	7	ph LT-LT	30	49	28				
ph M R	40	50	30	ph Mi LTR	13	31	13	70	113	43	80
ph Mi R	23	45	23								
ph T-T	32	50	29	ph LT-LT	34	51	30				
ph M R	38	51	30	ph Mi LTR	11	27	11	79	124	45	78
ph Mi R	9	23	9								
ph T-T	24	45	24	ph LT-LT	24	45	24				
ph M R	18	39	18	ph Mi LTR	14	33	14	55	115	38	78
ph Mi R	13	31	13								

Table 4.5 Minimized Effective Green Times of Each Approach of Two Adjacent Intersections (continued).

T Intersection				4 Legs Intersection				T Int.		4 Legs Int.	
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	23	45	23	ph LT-LT	51	44	22				
ph M R	33	50	30	ph Mi LTR	14	33	14	69	126	65	76
ph Mi R	13	31	13								
ph T-T	17	37	17	ph LT-LT	31	50	29				
ph M R	23	45	23	ph Mi LTR	15	34	15	57	119	46	84
ph Mi R	17	37	17								
ph T-T	14	33	14	ph LT-LT	42	50	29				
ph M R	31	50	29	ph Mi LTR	14	33	14	66	125	56	83
ph Mi R	21	42	21								
ph T-T	33	50	30	ph LT-LT	52	43	21				
ph M R	17	37	17	ph Mi LTR	14	33	14	58	108	66	75
ph Mi R	8	20	8								
ph T-T	32	50	29	ph LT-LT	12	29	12				
ph M R	19	40	19	ph Mi LTR	14	33	14	59	111	26	62
ph Mi R	8	20	8								
ph T-T	18	39	18	ph LT-LT	42	50	29				
ph M R	21	42	21	ph Mi LTR	11	27	11	60	124	53	77
ph Mi R	21	42	21								
ph T-T	10	25	10	ph LT-LT	16	36	16				
ph M R	41	50	29	ph Mi LTR	7	18	7	72	118	23	54
ph Mi R	21	42	21								
ph T-T	30	49	28	ph LT-LT	28	48	27				
ph M R	18	39	18	ph Mi LTR	7	18	7	58	113	35	66
ph Mi R	10	25	10								
ph T-T	18	39	18	ph LT-LT	21	42	21				
ph M R	8	20	8	ph Mi LTR	10	25	10	41	94	31	68
ph Mi R	15	34	15								
ph T-T	31	50	29	ph LT-LT	55	39	18				
ph M R	34	51	30	ph Mi LTR	12	29	12	87	144	67	68
ph Mi R	22	44	22								
ph T-T	7	18	7	ph LT-LT	34	51	30				
ph M R	45	48	27	ph Mi LTR	14	33	14	76	111	48	83
ph Mi R	24	45	24								
ph T-T	22	44	22	ph LT-LT	42	50	29				
ph M R	47	47	26	ph Mi LTR	13	31	13	87	129	55	81
ph Mi R	18	39	18								
ph T-T	7	18	7	ph LT-LT	9	23	9				
ph M R	37	51	30	ph Mi LTR	15	34	15	56	98	24	57
ph Mi R	12	29	12								
ph T-T	18	39	18	ph LT-LT	11	27	11				
ph M R	22	44	22	ph Mi LTR	14	33	14	50	107	25	60
ph Mi R	10	25	10								
ph T-T	18	39	18	ph LT-LT	39	51	30				
ph M R	31	50	29	ph Mi LTR	10	25	10	64	123	49	76
ph Mi R	15	34	15								

Table 4.5 Minimized Effective Green Times of Each Approach of Two Adjacent Intersections (continued).

T Intersection				4 Legs Intersection				T Int.		4 Legs Int.	
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	29	49	28	ph LT-LT	36	51	30				
ph M R	53	41	20	ph Mi LTR	9	23	9	105	135	45	74
ph Mi R	23	45	23								
ph T-T	20	41	20	ph LT-LT	19	40	19				
ph M R	28	48	27	ph Mi LTR	10	25	10	64	126	29	65
ph Mi R	16	36	16								
ph T-T	12	29	12	ph LT-LT	31	50	29				
ph M R	16	36	16	ph Mi LTR	11	27	11	52	111	42	77
ph Mi R	24	45	24								
ph T-T	35	51	30	ph LT-LT	35	51	30				
ph M R	24	45	24	ph Mi LTR	14	33	14	70	123	49	83
ph Mi R	11	27	11								
ph T-T	33	50	30	ph LT-LT	16	36	16				
ph M R	8	20	8	ph Mi LTR	9	23	9	50	93	25	59
ph Mi R	9	23	9								
ph T-T	20	41	20	ph LT-LT	11	27	11				
ph M R	53	41	20	ph Mi LTR	9	23	9	90	120	20	50
ph Mi R	17	37	17								
ph T-T	24	45	24	ph LT-LT	43	49	28				
ph M R	50	45	23	ph Mi LTR	12	29	12	82	110	55	78
ph Mi R	8	20	8								

In case of the changing lane and controlled speed of vehicles: the data will be shown in **Table 4.6**. This Table focuses on the traffic risky area when the critical length of changing lane lower than the standard length as mentioned in the section 3.2.3 (**Figure 3.9**). It can be seen that a number of approaching speed of vehicles under the unsafe speeding during the focused times (15:05-16:54) are 18 times from 91 times and the number of changing lane under the risky situations are 3 times from 91 times. Therefore, these situations lead to the traffic accidents as presented at the Chapter 7.

Table 4.6 Changing Lane and Controlled Speed of Vehicles – Situations.

Time	Sum Vehicle	PCU	Average Spacing M	SSD M	Average Speed KPH	Safe 0, Risky 1 Status	Average Changing Lane M	Changing Lane Times	Safe 0, Risky 1 Status
15:05	11	8.90	4.073	4.193	5.38	1	4.99	3	0
15:06	6	5.40	5.093	2.701	3.59	0	4.02	0	0
15:07	6	6.00	6.000	3.296	4.32	0	4.41	3	0
15:08	8	7.10	4.965	3.589	4.67	0	4.60	1	0
15:09	8	7.70	5.682	4.208	5.40	0	5.00	0	0
15:10	5	4.10	4.207	1.844	2.51	0	3.47	2	0
15:12	2	1.70	4.559	0.767	1.08	0	2.79	1	0
15:13	9	8.87	6.995	5.558	6.92	0	5.88	2	0
15:14	7	6.10	4.795	2.991	3.95	0	4.21	0	0
15:15	9	6.90	3.514	2.981	3.94	0	4.20	0	0
15:16	7	11.74	9.279	9.298	10.76	1	8.39	1	1
15:18	3	2.70	5.093	1.300	1.80	0	3.13	2	0
15:19	6	5.70	5.570	2.996	3.96	0	4.21	0	0
15:20	9	6.90	3.514	2.981	3.94	0	4.20	3	0
15:21	6	5.10	4.559	2.410	3.23	0	3.83	0	0
15:22	5	4.40	4.886	2.127	2.87	0	3.65	0	0
15:23	9	8.40	5.417	4.519	5.75	0	5.20	3	0
15:24	7	6.10	4.795	2.991	3.95	0	4.21	3	0
15:25	8	6.20	3.629	2.691	3.58	0	4.02	2	0
15:27	12	9.30	3.629	4.188	5.37	1	4.98	1	0
15:28	3	2.10	2.500	0.762	1.07	0	2.78	2	0
15:29	8	6.80	4.559	3.286	4.31	0	4.40	0	0
15:30	10	7.60	3.421	3.276	4.30	0	4.39	3	0
15:31	6	5.10	4.559	2.410	3.23	0	3.83	1	0
15:32	7	6.10	4.795	2.991	3.95	0	4.21	0	0
15:34	5	3.80	3.421	1.565	2.15	0	3.30	0	0
15:35	11	9.20	4.402	4.508	5.74	1	5.19	3	0
15:36	12	9.60	3.958	4.503	5.74	1	5.19	2	0
15:37	13	10.00	3.550	4.498	5.73	1	5.19	0	0
15:38	10	7.90	3.829	3.579	4.66	0	4.59	3	0
15:39	10	7.60	3.421	3.276	4.30	0	4.39	3	0
15:41	12	9.00	3.278	3.876	5.01	1	4.78	3	0
15:42	4	2.80	2.500	1.025	1.43	0	2.95	0	0
15:43	13	10.00	3.550	4.498	5.73	1	5.19	3	0
15:44	8	7.87	7.122	4.909	6.20	0	5.46	0	0
15:45	12	9.30	3.629	4.188	5.37	1	4.98	2	0
15:46	4	3.10	3.629	1.295	1.79	0	3.12	0	0
15:48	9	7.80	4.744	3.892	5.03	0	4.79	1	0
15:49	10	8.20	4.207	3.886	5.02	0	4.79	3	0
15:50	9	7.50	4.367	3.584	4.67	0	4.59	3	0

Table 4.6 Changing Lane and Controlled Speed of Vehicles – Situations (continued).

Time	Sum Vehicle	PCU	Average Spacing M	SSD M	Average Speed KPH	Safe 0, Risky 1 Status	Average Changing Lane M	Changing Lane Times	Safe 0, Risky 1 Status
15:51	4	3.40	4.559	1.570	2.15	0	3.30	1	0
15:52	9	7.20	3.958	3.281	4.30	0	4.40	0	0
15:53	6	5.40	5.093	2.701	3.59	0	4.02	3	0
15:55	13	10.60	4.151	5.141	6.46	1	5.61	0	0
15:56	9	7.20	3.958	3.281	4.30	0	4.40	0	0
15:57	5	4.70	5.479	2.414	3.24	0	3.84	0	0
15:58	7	6.10	4.795	2.991	3.95	0	4.21	0	0
15:59	5	4.10	4.207	1.844	2.51	0	3.47	2	0
16:00	6	4.80	3.958	2.123	2.87	0	3.65	1	0
16:01	9	7.50	4.367	3.584	4.67	0	4.59	0	0
16:02	7	7.47	7.838	4.915	6.20	0	5.46	3	0
16:03	4	5.56	8.529	3.738	4.85	0	4.69	2	0
16:04	10	8.80	4.886	4.514	5.75	0	5.20	1	0
16:06	13	10.90	4.427	5.469	6.82	1	5.83	1	0
16:07	9	7.20	3.958	3.281	4.30	0	4.40	2	0
16:09	6	5.70	5.570	2.996	3.96	0	4.21	0	0
16:10	11	9.50	4.711	4.828	6.11	1	5.40	0	0
16:11	6	5.10	4.559	2.410	3.23	0	3.83	1	0
16:12	11	8.60	3.721	3.881	5.02	1	4.78	2	0
16:13	6	4.80	3.958	2.123	2.87	0	3.65	0	0
16:14	5	4.10	4.207	1.844	2.51	0	3.47	2	0
16:16	7	5.80	4.310	2.696	3.59	0	4.02	3	0
16:17	9	7.50	4.367	3.584	4.67	0	4.59	0	0
16:18	9	7.20	3.958	3.281	4.30	0	4.40	0	0
16:19	5	3.50	2.500	1.291	1.79	0	3.12	3	0
16:20	8	6.80	4.559	3.286	4.31	0	4.40	0	0
16:22	9	6.90	3.514	2.981	3.94	0	4.20	2	0
16:23	10	8.50	4.559	4.198	5.39	0	4.99	3	0
16:24	6	4.50	3.278	1.840	2.51	0	3.47	3	0
16:25	6	4.80	3.958	2.123	2.87	0	3.65	0	0
16:26	7	6.10	4.795	2.991	3.95	0	4.21	3	0
16:27	6	5.40	5.093	2.701	3.59	0	4.02	3	0
16:28	4	3.40	4.559	1.570	2.15	0	3.30	0	0
16:30	10	7.30	2.979	2.976	3.93	0	4.20	1	0
16:31	8	6.80	4.559	3.286	4.31	0	4.40	0	0
16:35	10	8.20	4.207	3.886	5.02	0	4.79	0	0

Table 4.6 Changing Lane and Controlled Speed of Vehicles – Situations (continued).

Time	Sum Vehicle	PCU	Average Spacing M	SSD M	Average Speed KPH	Safe 0, Risky 1 Status	Average Changing Lane M	Changing Lane Times	Safe 0, Risky 1 Status
16:37	14	11.60	4.310	5.796	7.18	1	6.04	1	0
16:38	9	7.80	4.744	3.892	5.03	0	4.79	1	0
16:39	8	9.62	7.364	6.295	7.71	0	6.37	1	0
16:40	8	8.66	6.775	5.305	6.64	0	5.72	1	0
16:41	9	7.80	4.744	3.892	5.03	0	4.79	3	0
16:42	9	7.50	4.367	3.584	4.67	0	4.59	0	0
16:44	6	5.40	5.093	2.701	3.59	0	4.02	3	0
16:45	9	7.80	4.744	3.892	5.03	0	4.79	3	0
16:46	5	3.80	3.421	1.565	2.15	0	3.30	1	0
16:47	11	12.02	6.684	7.671	9.15	1	7.29	0	1
16:48	7	5.50	3.773	2.405	3.23	0	3.83	2	0
16:49	15	11.70	3.697	5.458	6.81	1	5.82	3	0
16:52	15	12.00	3.958	5.790	7.17	1	6.04	2	0
16:53	7	5.80	4.310	2.696	3.59	0	4.02	3	0
16:54	11	10.87	6.812	6.904	8.36	1	6.78	3	1
				safe		73	safe		88
				risky speed		18	risky changing lane		3
				Total counting		91			

<u>Refer to the Noise and Air Pollution:</u> the noise pollution between the predicted results from the model and the results from the method of UK Department of Transport - Welsh Office (1988), Cheewapattananuwong and Samuels (1997), Samuels and Cheewapattananuwong (1997). In addition, the predicted CO and PM_{10} Level-models will be compared with the collected data from the Pollution Control Department, Ministry of Natural Resources and Environment, Thailand. Table 4.4 shows the collected environmental data especially the traffic noise and air pollution at the intersection during 14 -16 November 2012.

<u>In case of fuel consumption:</u> the collected fuel consumptions of 1600, 1800, and 2000 cc will be proposed at the **Table 4.7**, **4.8**, and **4.9**. The predicted equations will be applied for the collected data as compared and calibrated by the statistical methods. All of the results will be presented with the average speed of each green times, in addition, the results show that fuel consumption and pollution levels have improved since the installation of the ITS system as presented in the Chapter 8.

Table 4.7 Fuel Consumption of 1.6 Toyota Corolla Attis

	Actlual Used (ml/sec)		
Mean Speed	1600 cc		
km/hr	L/100KM	Length (KM)	Duration (min)
0.00	22.00	3.0	27.30
5.00	19.20	3.0	24.50
10.00	17.00	3.0	21.40
15.00	12.50	3.0	15.00
20.00	9.50	3.0	9.50
25.0	8.20	3.0	8.20
41.0	5.82	3.0	5.40
42.0	5.71	3.0	5.30
48.0	5.23	3.0	4.75
49.0	5.23	3.0	4.67
50.0	5.34	3.0	4.60
51.0	5.53	3.0	4.53
52.0	5.62	3.0	4.46
53.0	5.72	3.0	4.40
55.0	5.73	3.0	4.28
57.0	5.82	3.0	4.17
59.0	6.00	3.0	4.10
60.0	6.16	3.0	4.00
63.0	6.17	3.0	3.87
64.0	6.33	3.0	3.81
65.0	6.33	3.0	3.78
65.0	6.33	3.0	2.76
66.0	6.34	3.0	3.73
67.0	6.41	3.0	3.68
70.0	6.50	3.0	3.57
72.0	6.44	3.0	3.50
73.0	6.86	3.0	3.46
78.0	6.88	3.0	3.32
79.0	6.95	3.0	3.27

Table 4.8 Fuel Consumption of 1.8 Mercedes Benz

Mean Speed	Actlual Used (ml/sec)		
	1800 cc		
km/hr	L/100KM	Length (KM)	Duration (min)
0.00	25.00	3.00	27.20
8.00	24.44	3.00	24.00
9.00	21.84	3.00	22.00
12.00	16.64	3.00	16.00
14.00	14.41	3.00	14.00
16.00	12.74	3.00	12.00
18.00	11.44	3.00	11.20
24.00	9.01	3.00	8.70
25.00	8.86	3.00	8.40
27.00	8.43	3.00	7.60
30.00	7.98	3.00	7.00
32.00	7.69	3.00	6.70
36.00	7.20	3.00	6.10
38.00	7.11	3.00	5.90
40.00	7.04	3.00	5.60
44.00	6.62	3.00	5.00

Table 4.9 Fuel Consumption of 2.0 Mercedes Benz

Mean Speed	Actlual Used (ml/sec)		
	2000 cc		
km/hr	L/100KM	Length (KM)	Duration (min)
0.00	27.00	3.00	27.10
5.00	25.10	3.00	25.40
10.00	21.20	3.00	20.20
15.00	13.61	3.00	12.60
18.00	11.88	3.00	11.00
35.00	7.00	3.00	6.14
43.00	6.74	3.00	5.19
44.00	6.82	3.00	5.09
57.00	5.99	3.00	4.20
57.00	5.99	3.00	4.16
60.00	6.08	3.00	4.00
61.00	6.24	3.00	3.95
62.00	6.48	3.00	3.90
63.00	6.63	3.00	3.86
65.00	6.71	3.00	3.78
67.00	6.71	3.00	3.70
69.00	6.86	3.00	3.64
72.00	7.35	3.00	3.52
73.00	7.97	3.00	3.48
75.00	8.02	3.00	3.40
76.00	8.02	3.00	3.38

4.2.3 SQL – Structured Query Language

The researcher has arranged the equipments, network system, and developed software as mentioned above. The Time Series Data, Clustering Techniques, and K-Nearest Neighbors will be taken into account for the Learning and Classified samples. Moreover, the checking of vehicle direction or the way part of vehicle in case of traffic accident can be tracked with the applied times series data. In case of the Learning and Classified samples, the vehicles run past the Virtual Loop detector at the first starting software, the vehicles and the risk of a crash occurring event will be learnt and classified as shape and path of vehicles. After learning and classifying vehicles, the software will operate under the criteria as outlined above. **Figure 4.12** shows the process of Learning and Classified Samples:

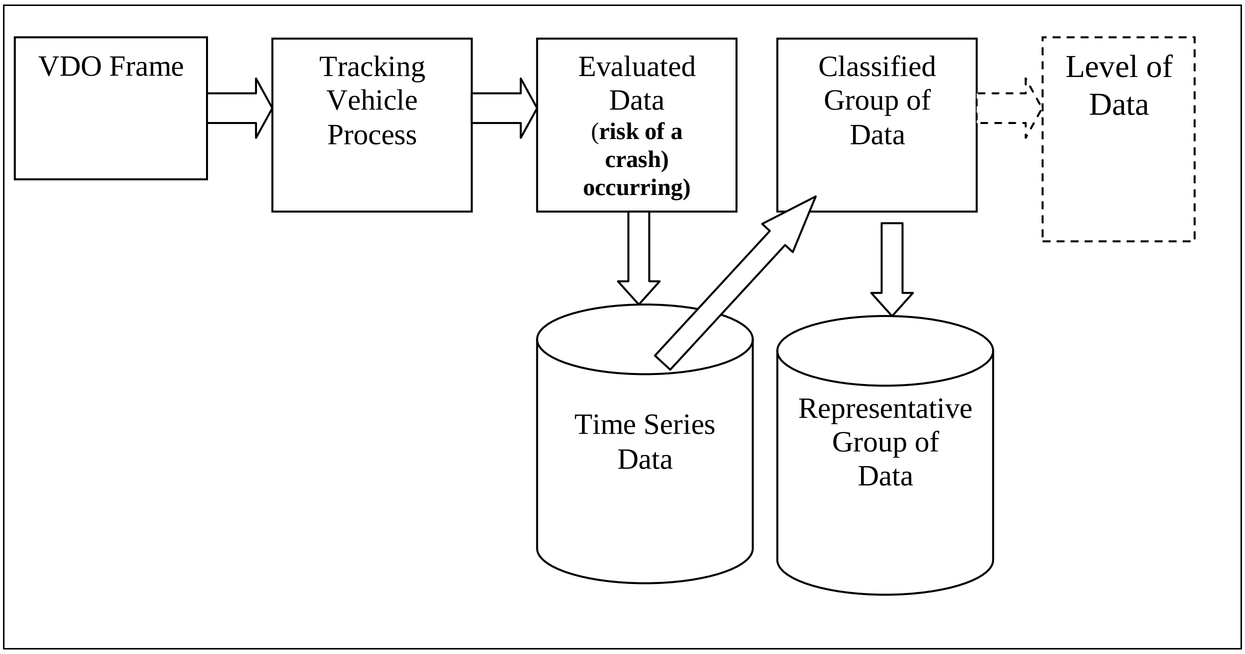


Figure 4.12 Process of Learning and Classified System

From **Figure 4.12**, the learning of traffic accidents or the risk of a crash occurring is tracked on the VDO frame which is selected and changed into 2 dimensions with the time series data. These data will be grouped and measured of length by dynamic time warping.

Chapter

5

INSTALLATION AND IMPLEMENTATION

5.1 DURATION OF IMPLEMENTATION

More than 10 years, the researcher has studied and developed an Innovative Card, Traffic Classified Count, Traffic Synchronization and Simulation, Lane Changing and Speeding Software, Signal Commanding to VMS and Traffic Controller by the Innovative Card and Sizes of Letter in VMS Software. The duration of implementation will be explained in the following part.

2000 Traffic Volume Survey and Feasibility Study as shown in **Figure 5.1**.

2002 Traffic Volume Survey and Prediction of Trip Generation for Detailed Design as illustrated in **Figure 5.2 and 5.3**.

2004 Opening New Road.

2007 RSA for New Road.

2010 Red Light Running (RLR) Detection System as described in **Figure 3.3, 3.4** and **5.7**.

2011 Lane Changing and Speeding Warning System as described in **Figure 3.15, 3.16, 5.8** and **5.9**.

2012 Traffic Accident Monitoring System.

2013 Environmental Impact and Fuel Consumption Assessment System as presented in **Section 5.3.3**, **Table 5.7** and **5.8**.

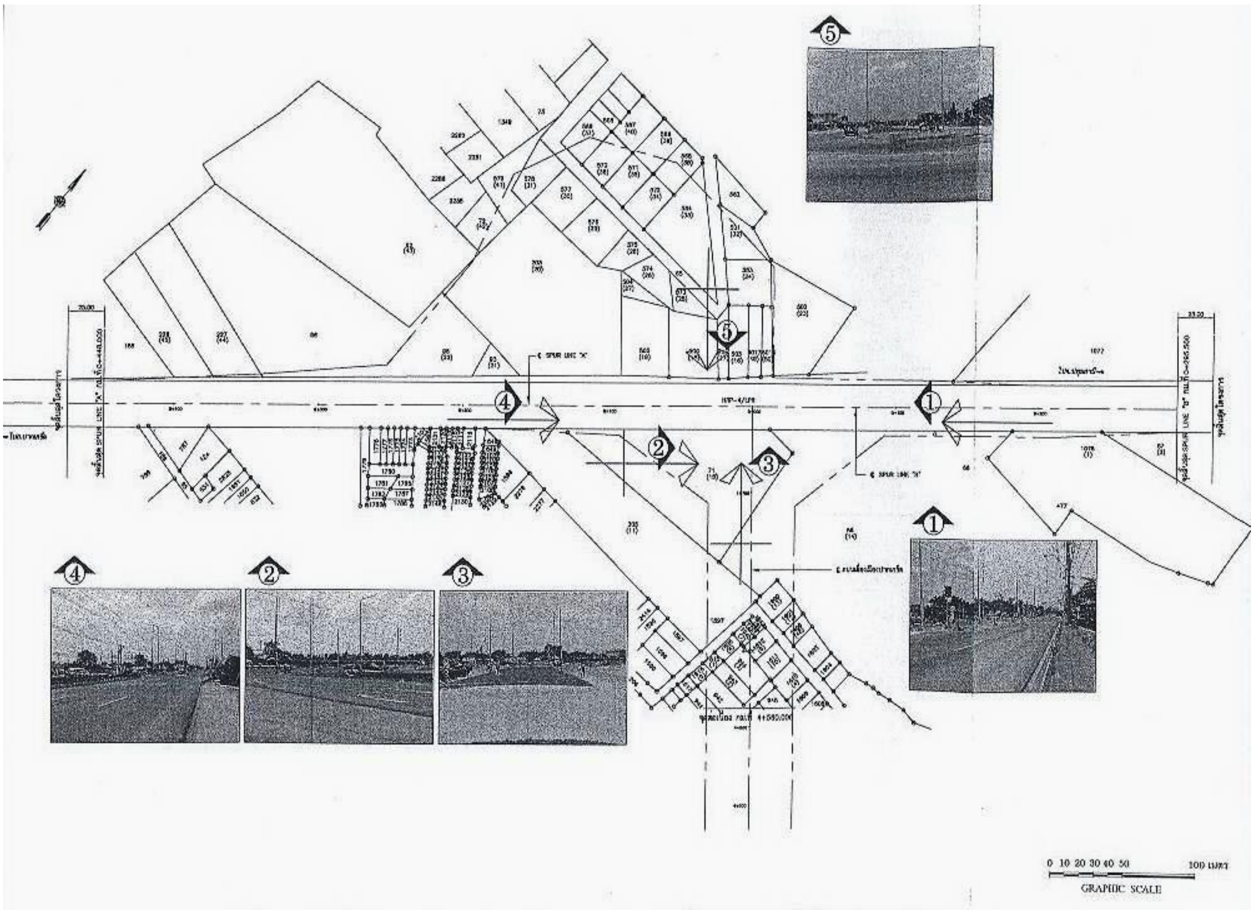
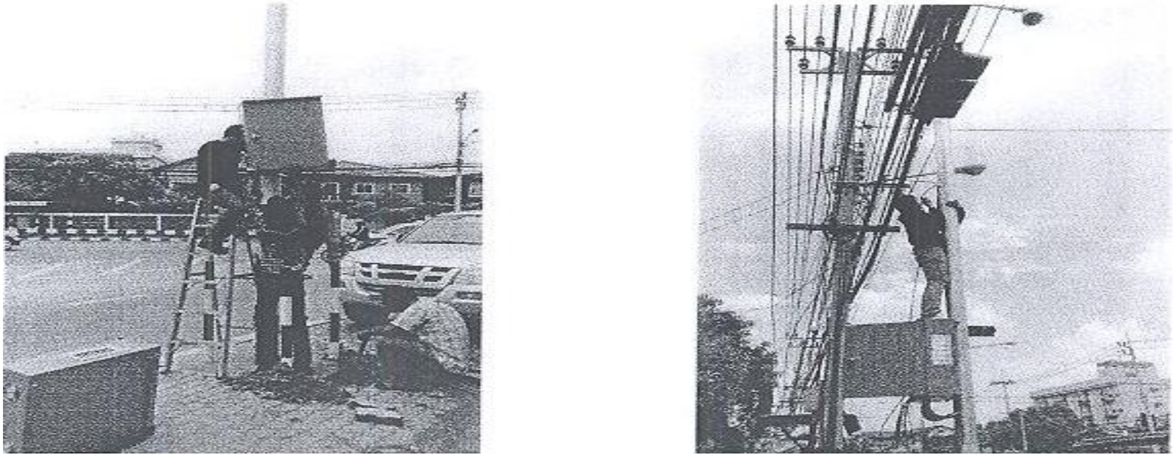


Figure 5.1 Details of Land Acquisition Survey

5.2 INSTALLATION OF DEVELOPED SYSTEM

This thesis is proposed to utilize the image sensing concept which is shown the traffic classified counting. Moreover, the traffic volumes will be used to calculate and evaluate signal phasing and cycle times for adaptive synchronization. In this operation, two closed-circuit television cameras and electronic equipment installed at each intersection were used to track vehicles passing through virtual loops. After the implementation of this locally developed ITS technology, traffic flow improved significantly and the number of accidents caused by red light running has decreased dramatically.

The installation of equipments, telecommunication networks and traffic controllers: they were installed at the case study intersections as shown at the **Picture 5.1** and **5.2**.



Picture 5.1 the Installed Housing of Telecommunication Networks and CCTV at the Intersections

Picture 5.2 the Installed Traffic Controllers at the Intersections

Traffic volumes at many intersections in suburban Bangkok, Thailand, are at saturation level; this saturation creates long delays, which lead to driver frustration (Department of Highways, 2012). The fixed time of many existing traffic controllers in suburban Bangkok has exacerbated the situation. The queuing drivers become even more frustrated when they see an approach with few vehicles getting more green time than necessary; the long cycle times further aggravate the situation, especially when drivers are in a rush. A common cycle time is often set for all periods. Phases and cycle times of these intersections are not designed for traffic synchronization (T and 4 Leg Intersections). Many drivers try to speed through the intersection during the dilemma times to avoid long delays. In this study, vehicle actuated traffic controllers and the authors' new traffic management software are used. The software optimizes phase and cycle times and can adapt to real-time traffic volumes.

After finished installation, the traffic classified count data at the major road will be collected on a day by day basis so as to predict the traffic volumes and this data will be sent to the server as can be seen in **Figure 5.2**.

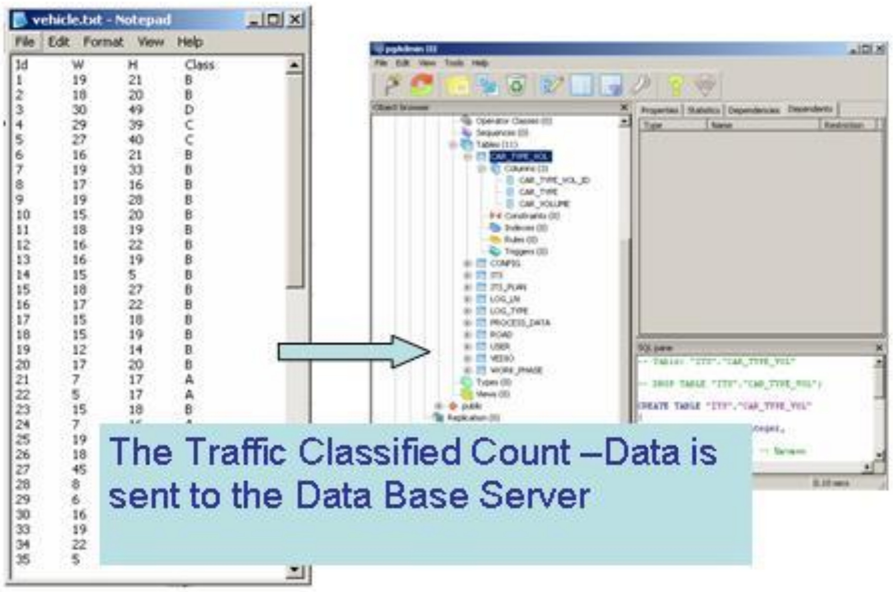


Figure 5.2 The sending of traffic counting data (inbound direction) to the Server.

<u>The compliance of traffic controller after the traffic engineering evaluation:</u> the comply of software is calculated for Traffic Phasing and Cycle Times and it will be send to Traffic Controller by the 16 computer base-data passing through the internet network (to see **Figure 5.3**).

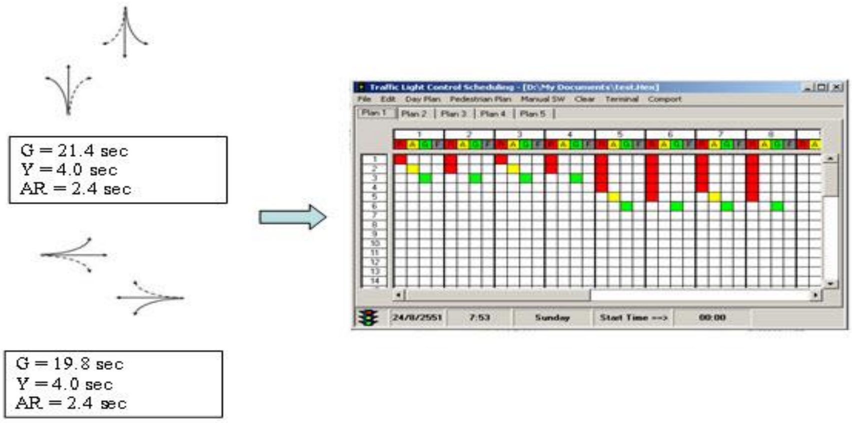


Figure 5.3 The results of traffic management at intersection and Phase Co-ordination.

5.3 NUMERICAL IMPLEMENTATION

5.3.1 Traffic Signalization

aaSIDRA (compute the optimum cycle times and phasing at intersections): the hourly volumes, as well as the intersection geometry are input to the software. The delay time per vehicle at intersection is particular to evaluate traffic situation at intersections. Delay to a vehicle is the difference between interrupted and uninterrupted travel times through the intersection. The average delay predicted by aaSIDRA is for all vehicles, queued and unqueued. Based on this definition, the total (aggregate) delay is the product of average delay and the total demand flow rate. Moreover, aaSIDRA Guide Book states that "the delay to a vehicle which decelerates from the approach cruise speed to a full stop (due to a reason such as a red signal, a queue ahead, or lack of an acceptable gap), waits and then accelerates to the exit cruise speed is considered to include the delay due to a deceleration from the approach cruise speed down to an approach negotiation speed and then to zero speed, idling time, acceleration to an exit negotiation speed along the negotiation distance, travelling the rest of the negotiation distance (if any) at the constant exit negotiation speed, and then acceleration to the exit cruise speed". **Table 5.1** describes the results of aaSIDRA Software and the length measurement.

Table 5.1 shows that Delay Times from SIDRA is 62.10 seconds/vehicle and the Observed Delay Times is 55.00 seconds/vehicle. The 7.1 seconds/vehicle of Delay Times differs by nearly 12.90 percent. The evaluation of Delay Times results will be described in the next paragraph. The following table presents in the SIDRA and Observe data at the 4 Leg intersection.

Table 5.2 illustrates that Delay Times from SIDRA at the 4 Leg intersection is 214.80 seconds/vehicle and the Observed Delay Times is 200.00 seconds/vehicle. The difference is 14.80 seconds/vehicle or 7.40 percent.

Table 5.1 Calculation of Delay Times at T or 3 Leg Intersection.

Calibration	SIDRA	Observe
	Major Flow	Major Flow
Delay/Veh. (sec./veh.)	62.10	55.00

Table 5.2 Calculation of Delay Times at 4 Leg Intersection.

Calibration	SIDRA	Observe
	Major Flow	Major Flow
Delay/Veh. (sec./veh.)	214.80	200.00

Trafficware and CORSIM simulation (for fine tuning phasing and cycle times): there are several software packages available to perform micro simulation for the various types of facilities. In this research, the Trafficware and CORSIM Software are taken into consideration. TRAFFICWARE was privately developed and is the simulation partner to Synchro. Since Trafficware and Synchro use the same interface, there is no need to input additional data when transferring from Synchro to Trafficware. In case of the signalized intersections, the simulation software gives a reasonable approximation of the expected conditions when properly calibrated. The trial running of simulation software (Trafficware, SIDRA, and Observation) is divided into 5 times for T and four Legs intersections. Each time is run starting from 1 time to 9 times as presented in **Table 5.3** and **5.4**.

Table 5.3 Calculation of Delay Times from TRAFFICWARE and SIDRA at T Intersection.

Calibration Delay / vehicle or (Seconds / vehicle)	Trafficware	SIDRA	Observed
	Major Flow	Major Flow	Major Flow
Run No.1	59.50	62.10	55.00
Run No.3	70.50	62.10	55.00
Run No.5	69.10	62.10	55.00
Run No.7	61.10	62.10	55.00
Run No.9	59.20	62.10	55.00

Table 5.4 Calculation of Delay Times from TRAFFICWARE and SIDRA at 4 Leg Intersection**.**

Calibration Delay / vehicle or (Seconds / vehicle)	Trafficware	SIDRA	Observed
	Major Flow	Major Flow	Major Flow
Run No.1	188.20	214.80	200
Run No.3	145.30	214.80	200
Run No.5	280.70	214.80	200
Run No.7	201.60	214.80	200
Run No.9	305.60	214.80	200

It can clearly be seen that the Delay Times of simulation running from software quite like the results from aaSIDRA, Trafficware and Observation. Therefore, the traffic factors such as cycle times and queuing length are presented in Chapter 6.

5.3.2 Traffic Synchronization (Offset Times)

In case of the offset time between the T and 4 Leg intersections, the offset times are calculated based on the ARRB method (Akcelik, 1989). The offset time for 460 meters is 34 seconds at 60 km/hr. The maximum cycle times during peak hour for the 3-phase of T intersection and the 2-phase of 4 Leg intersection are 150 and 90 seconds respectively. The details of these concepts will be described in the next parts:

Once again, The Maximum of the Offset Times is 34 seconds at the speed - 60 km./hr. If the traffic volumes increase drastically, the traffic controller at the nodes or intersections will adapt the traffic phasing and cycle length automatically. In case of the over speeding (60 km./hr.), the traffic sensors of the software will track and sending the data to the traffic controller and will command the restricted words on VMS – Variable Messages Sign. This concept will present in Chapter 7.

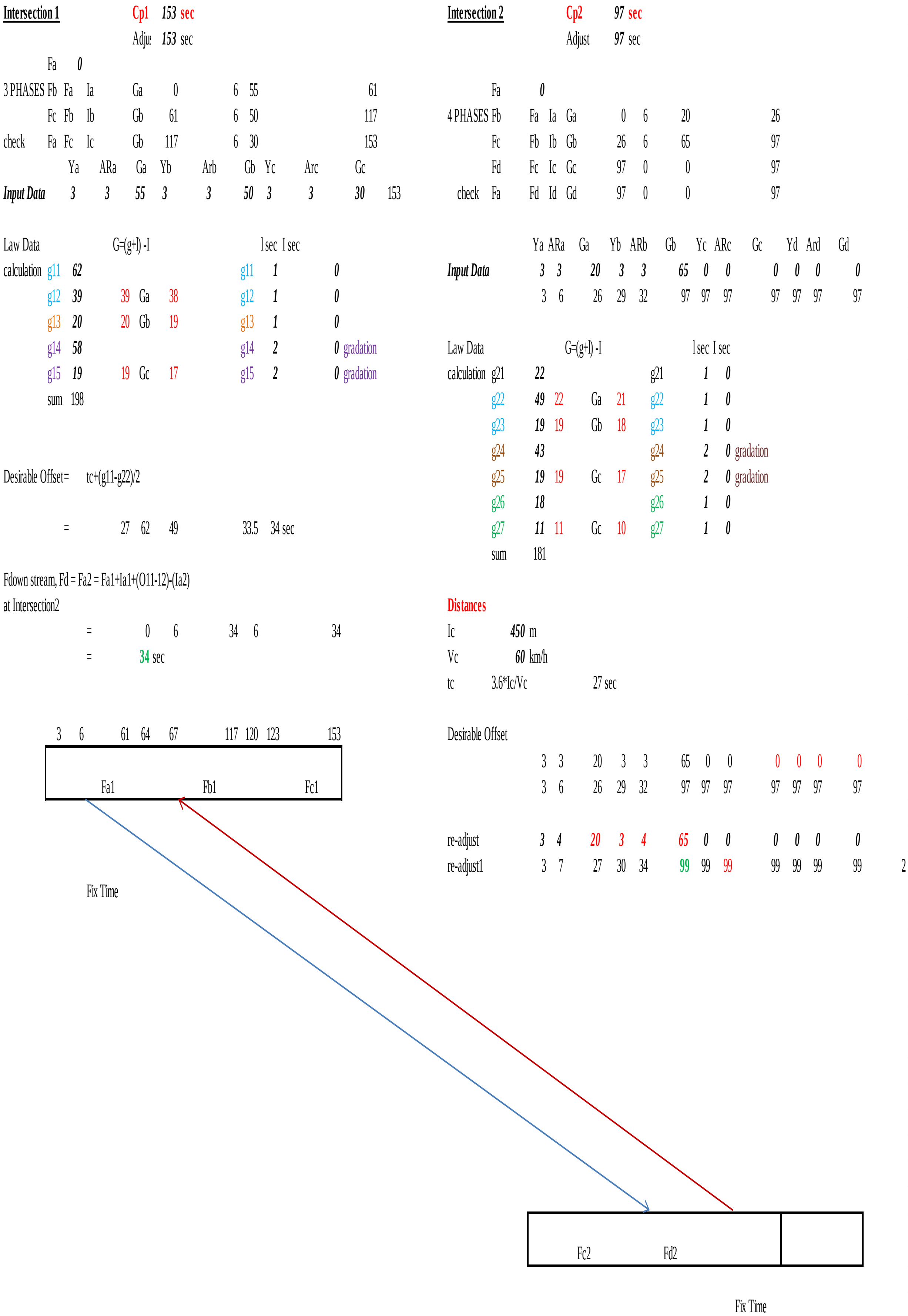


Figure 5.4 Calculation of Offset Times between two intersections (Case Study).

5.3.3 Rechecking Traffic Signal Cycle Times and Phasing

There are two concepts of traffic signal synchronization. One is the rechecking of traffic signalization at each intersection in order to reduce the cycle times and the rechecking of the offset times or Green Wave. The other is the final rechecking of the QCT (queue clearance times). The QCT is applied for the rechecking of the actual effective green times. The details of these concepts will be proposed in the next paragraph.

Traffic Signalization Techniques: parameter setting and sequence of 3 Phasing for the T or 3 Leg intersection and 2 Phases at the 4 Leg intersection are illustrated in **Figure 3.3**. It is seen that movements at the T intersection are in 6 directions with two left turn movements as free flow. Sensors 1 and 4 detect vehicles passing the Virtual Loops and send the signalized data to the traffic controller. For the 4 Leg intersection, movements are in 10 directions and two of them are free flow left turn. Another two sensors, number 2 and 3 are employed to detect vehicles and send the data to another controller. The details of sensors as mentioned above will be explained in the Section 3.4. For the T intersection, cycle times are varied based on traffic volumes at different periods. During peak hours, for vehicles passing through the Virtual Loop with headways within 5 seconds (from real-times data), the characteristic of traffic flow is steady state/steady flow. Therefore, the cycle time is extended up to the maximum green times of J1A, J1B and J1C (from calculation of SIDRA and Synchro) as shown in **Figure 3.4**.

In case of the 4 Leg intersection, phases J2A and J2B are also the same as the J1A, J1B, and J1C's concepts. However, the evaluation of the optimization of cycle times of main direction flows and offset times (J2B, J2A, and J1A) is done by the synchronization model and is described in the evaluation of traffic signalization concepts. From **Figure 3.4**, it is apparent that the movements at the T intersection are in 6 directions, 2 movements of left turn directions are free flow. There are 2 sensors which detect vehicles when passing the Virtual Loops and send the signalized data to traffic controller. In case of the 4 Leg intersection, there are 10 directions and two of them are left turn –free flow or unprohibited. There are also two sensors to detect vehicles and send the data to another traffic controller. In addition, the Normal and Additional Phases Algorithm under the pseudo code is presented in the Appendix and the following parts will described these Phases.

Normal Phase Algorithm: All Red Times stage, that is 3 seconds, is the First Sequence of Phasing. The next stage (J1A) is provided and set the maximum green times about 67 seconds based on the calculation from SIDRA and Trafficware. If there is no vehicle passing the virtual loop detector within 5 seconds, the JIA Phase will be stopped promptly. The Amber Times (2 seconds) and All Red Times (3 seconds) will be proposed after JIB Phase comes. This Phase is fixed the green times due to the fact that there is not a Virtual Loop detector in this direction. Furthermore, the green times, that is dependent on the range of peak and off peak times, is 20 – 50 seconds based on a virtual loop detector. The J1C Phase is the last Phase of this cycle length and the green times is varied from 20 and 35 seconds owing to the maximum 50 seconds of green times as predicted from SIDRA and Trafficware.

<u>Additional Phase Algorithm</u>: The J2B Phase or Major Direction is set for the maximum green times about 65 seconds as calculated from SIDRA and Trafficware. Once again, if there is no vehicle passing the loop, the J2A on Minor Direction will be taken into account. The green times of J2A Phase, that is varied under the controlling of Virtual Loop detector, is 27 seconds of the maximum of the effective green times. The offset times, that is 34 seconds of the maximum times, is calibrated between inbound and outbound direction. The offset times or Green Wave Model will be shown in **Figure 5.5**. Moreover, the details of these concepts will be shown in Chapter 6.

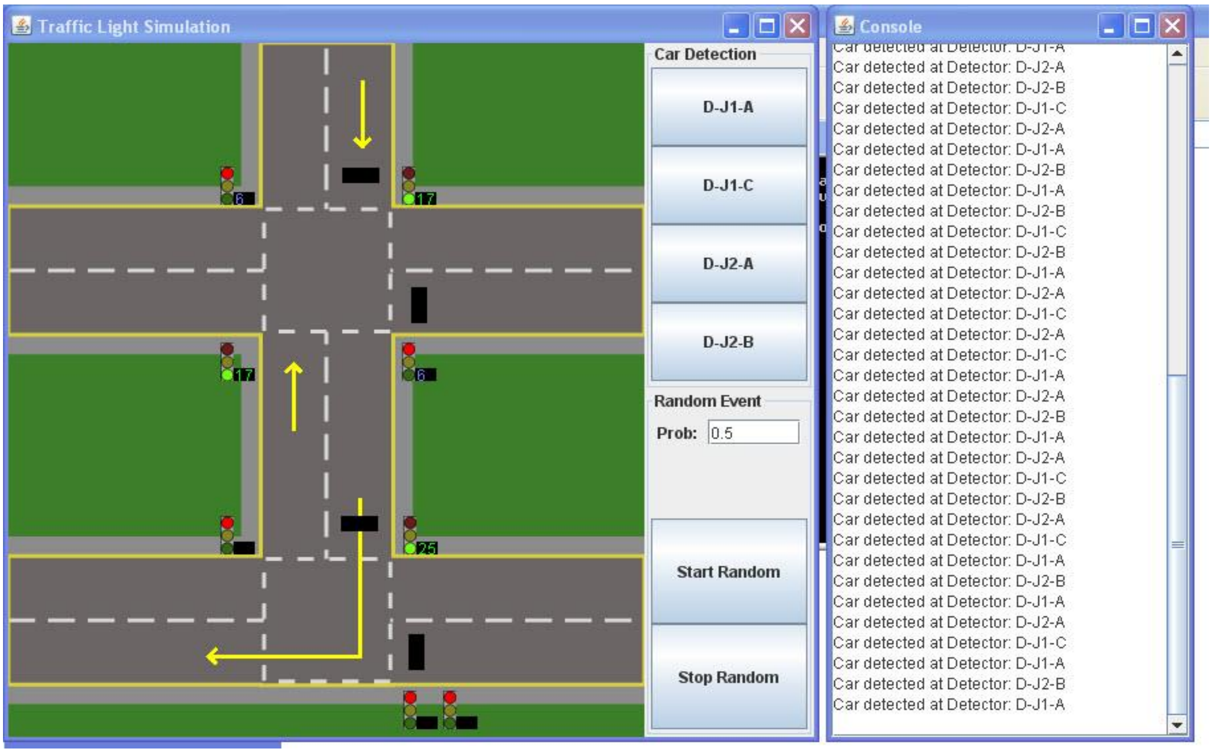


Figure 5.5 the Offset Times or Green Wave Concept including Simulation Model**.**

The results of the traffic factors as mentioned above will be illustrated in the Chapter 4 (Data Collection).

<u>Queue Clearance Times – QCT Techniques:</u> the QCT (queue clearance times) is referred at the previous Chapter (section 2.2.4). The following equation is applied for the calculation of QCT when rechecked and compared with the actual effective green times.

$$QCT = SLT + \left[\frac{(PCU - eff.gr.t/lane)}{(Sat\ Flow/lane - PCU - eff.gr.t/lane)} \right] * (CLT + ART + SLT) \qquad \text{(Refer to eq. 2.12)}$$

Source: Synchro version6 (1993-2005)

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.

5.3.4 Lane Changing and Controlled Speed

Due to this tracking method, the environment of calculation uses *the high technique*. Therefore, the high technique tracks each Blob promptly in the real-time. The new process can reduce the resources and will be illustrated in **Figure 3.16** (Chapter 3). Normally, the application of tracking objects is used by the Blob Tracking Techniques as mentioned in section 3.3.5. The separated objects are extracted from the background VDO. Moreover, the continuing objects must be checked and rechecked by one piece of tracking in the same size. Otherwise, the object will be cut into another piece or another vehicle. **Figure 5.6** and **Figure 5.7** show the Pseudo Code of the tracking system and speed of vehicles.

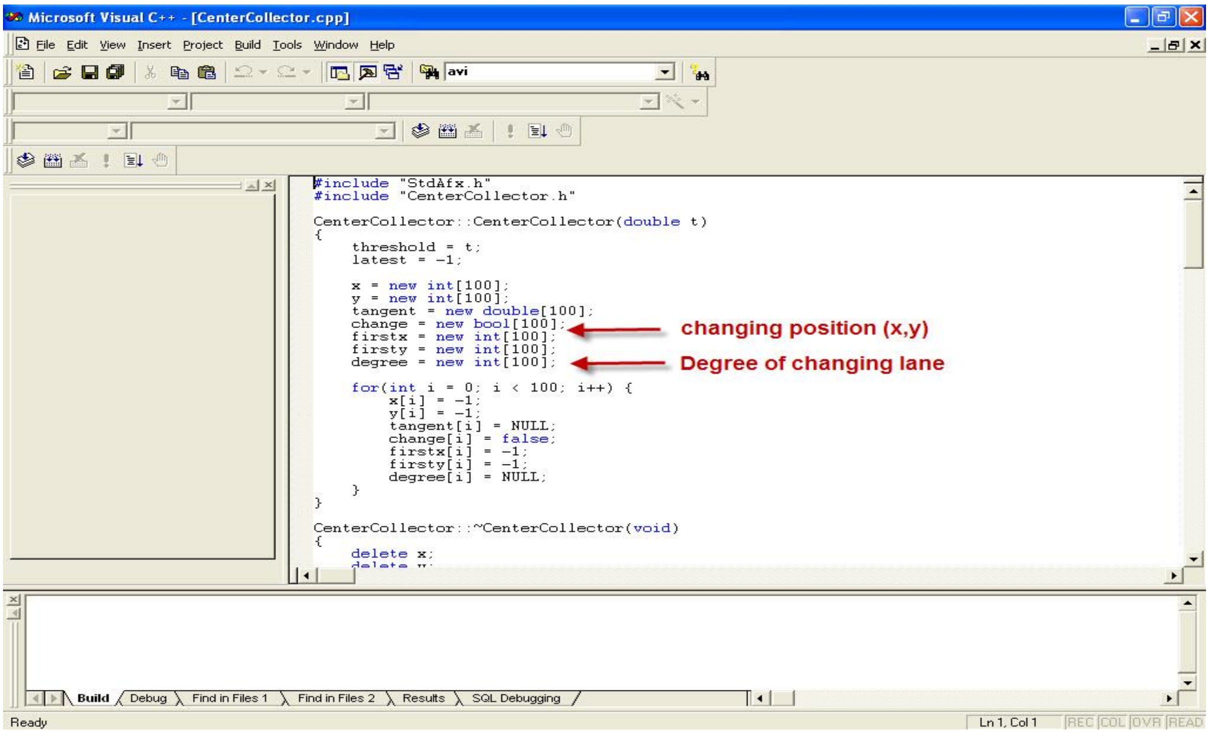


Figure 5.6 the coding software of the variable of changing position and degree of lane changing.

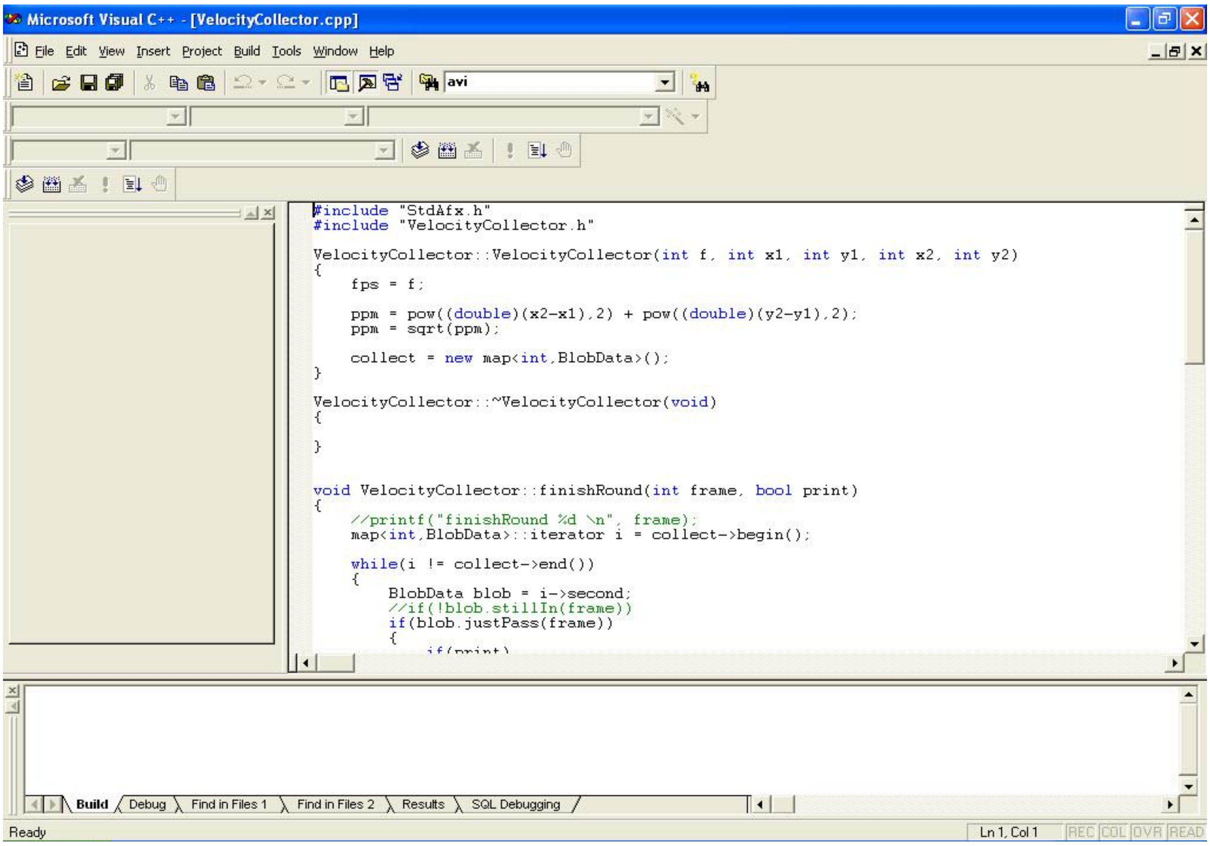


Figure 5.7 Parameter of Speed.

Furthermore, **Figure 5.8** shows the use of Blob Technique for tracking of vehicle-path and speed of vehicles.

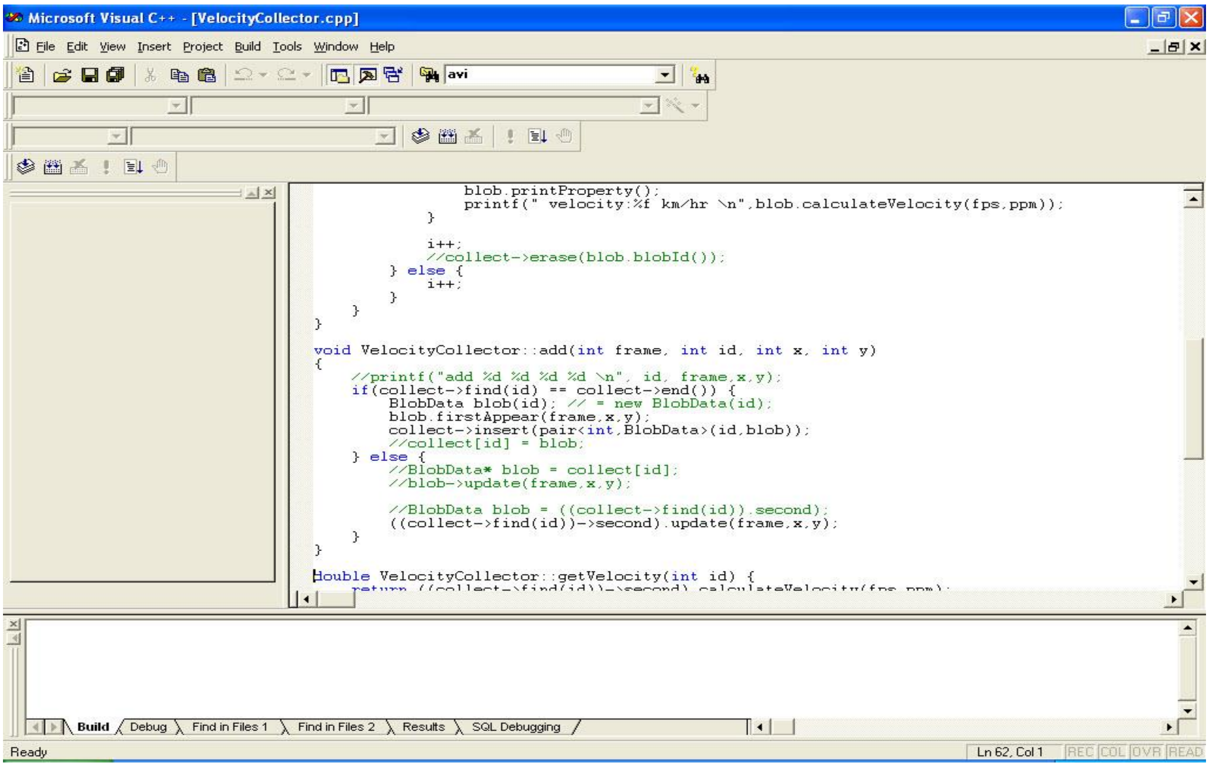


Figure 5.8 the application of Blob Technique for lane changing and controlled speed**.**

5.3.5 Telecommunication System

Type of Command in SQL: SQL is supported between the personal computer and the mainframe system. Moreover, the subdivision of SQL is divided into three sections;

1) Data Definition Language: DDL is used for creating tables or deleting tables.
2) Data Manipulation Language: DML is used to insert, delete and revise data.
3) Data Control Language: DCL protects systems such as the calling data from several users at the same time with strict security.

Type of Data in SQL: SQL defines the data type in each column. For example, the first column is the type of vehicles or character column, and the second column is the number of vehicles or the values of vehicles. The three types of SQL are presented in the following items.

1) Character column

   Fixed-Length Character is used as "char (n) or character (n)" and (n) is the fixed length of data with a maximum number of (n) 255 characters.

   Variable-Length Character is used as "varchar (n)" and (n) is the unfixed length of data and the maximum number of (n) characters is 4,000.

2) Numeric

   Decimal is used as "dec (m,n) or decimal (m,n)", (m) is the number including decimal point and (n) is the number after the decimal point.

   Intege (int) which is the ± values or a 10-digit number, is between -2,147,483,648 and +2,147,483,647.

   Smallint, which is the ± values or 5-digit number, is between –32,768 and +32,768.

   number (n) is possibly used for the number with or without the decimal point.

3) Others

   Date/Time is used in several types such as, yyyy-mm-dd (1999-10-31) dd.mm.yyyy (31. 10.1999) or mm/dd/yyyy (10/31/1999).

The Application of SQL: DBMS, which is very simple to use, is divided into two parts; one is interactive SQL and embedded SQL. Interactive SQL can command to the equipment especially the calling data on monitor for the result such as, calling the ROADNAME and ROADCAP from the table "CAPACITYTAB" as described below.

```
SELECT ROADNAME, ROADCAP
FROM CAPACITYTAB;
```

Table 5.5 Table of CAPACITYTAB**.**

ROUTENO	ROADNAME	ADDRESS	ROADCAP
0001	Paholyothin	Chiengrai	0.67
0003	Sukhumvit	Trad	0.78
0004	Phetchakasem	Songkhla	0.55
0002	Mitrapab	Ubonrajchatanee	0.47
0310	Sangchuto	Kanjanaburi	0.88

The results after the application of command are shown below.

Table 5.6 Table of after application of command.

ROADNAME	ROADCAP
Paholyothin	0.67
Sukhumvit	0.78
Phetchakasem	0.55
Mitrapab	0.47
Sangchuto	0.88

5.4 FIELD IMPLEMENTATION

5.4.1 Software and Equipment for Traffic Signalization and Synchronization

As a result, the system is composed of several elements such as, Adaptive Traffic Signalization Diagram, CCTV Cameras, Router, MPeg4 Encoder, IP Converter, Telecommunication Line, and Virtual Loop Detector Concepts, PCU Factor, and Optimum Phasing and Cycle Times. Before implementation of traffic synchronization software, the traffic synchronization simulation will be taken into consideration as shown in **Figure 5.5**. Finally, the cycle times and phases of coordination will be proposed to the traffic controller. Furthermore, the coding of tracking vehicles, such as the classified vehicles in Virtual Loop detectors, the linking of signal from Virtual Loop to traffic control, the simulation of traffic synchronization before the setup software with the traffic controllers at the intersections, traffic board controller, details of phasing and cycle times are described in **Figure 5.9**.

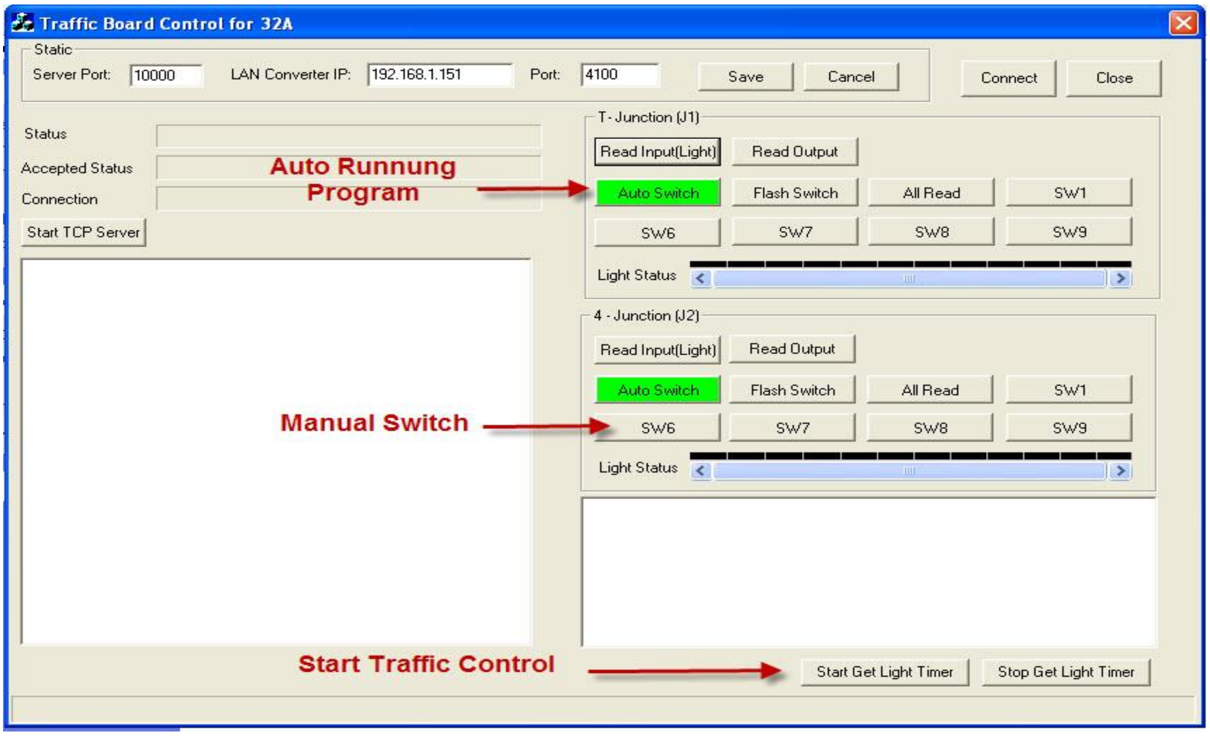


Figure 5.9 Traffic Board Controllers for the Automatic and/or Manual Application.

Cycle times at the T and Four Leg intersections decreased dramatically due to the triggers from Virtual Loop detectors. The triggers detect vehicles passing through the Virtual Loop within 5-7 seconds. If no vehicle passes through the loop after 5-7 seconds, it will sync with the controller which promptly changes the light from green to red times. The effective green times of each direction at the both intersections are substantially lower than the maximum effective green times of maximum cycle times as calculated by aaSIDRA and Synchro software. The maximum for the T intersection is 150 seconds and the Four Leg intersection 90 seconds. Furthermore, a number of phases at the T and Four Leg intersections are 3 and 2 respectively. It is observed that effective green times and cycle times decreased substantially compared to the optimum cycle times as obtained from aaSIDRA and Synchro software. **Figure 3.4, 3.5** and **5.5** show that J2A Phase is synchronized with J1A phase and the offset time (34 seconds). This leads to minimized effective green times on each approach to the intersections.

5.4.2 Software and Equipment for Vehicle Lane Changing and Speeding Manoeuvre

The following Figure presents the starting of parameter values of this system, such as the size and location of analyzed window, the shortest gap of vehicles, the threshold percentage of pixel to hold for counting of the same vehicle, etc. The application of this technique will use the frame of smaller window of VDO. This leads to the analysis of proper figure in this frame by sending the figure in the process so as to separate the vehicle from the background. The next step is to identify each vehicle and to transfer the data to the changing lane vehicle system as presented in **Figure 3.16**. The process of this mentioned method is applied to the *statistic model* which is under the Library of Open CV. The Library that is the Open Source is used by researchers worldwide. As a result, the Foreground Image is segregated from the background as shown in **Figure 3.17**.

Figure 3.17 (a) and **(b)** show the tracking vehicle sent to the server data so as to count the number of changing lane vehicles. The changing lane vehicle is a function of the width and angle of the changing lane vehicle by the average width and angle of vehicle which is parameter (P). Therefore, it implies to the Number of Car Stat (P→Number of Car Stat) and it leads to the number of changing lane vehicle.

The Blob Tracking Techniques, the process of dynamic time warping and K-Nearest Neighbors method are taken into consideration. The objects of the location in 2 dimensions (x and y axis) data are changed into the time series data by the chosen points of time. In addition, the parameter of lane width, speed limit, gap of vehicle, and the Virtual Loop or tracking block will be illustrated in Chapter 7. The recorded traffic volumes after the process of image sensing are to count the changing lane vehicles and the software process will be taken into account. The recorded data will be transferred to the system by SQL standard.

5.4.3 Software for Vehicles Emission and Fuel Consumption

<u>In case of the emission models of vehicles:</u> the models before improvement of traffic synchronization, which are 3.00 km/hr for average speed, are applied and calibrated from the collected data as shown in

the section 4.2.2 by the statistic methods. The details of emission models including the fitting equations will be illustrated in the Chapter 8.

In case of fuel consumption: **Table 5.7 and 5.8** show the evaluation of collected data of the prices list of petrol from July 2011 to June 2012. In addition, the composition of vehicles by types of fuel consumption in Thailand (Ministry of Energy, 2012) will be representative for the passenger car unit of all vehicles as taken into consideration. The details of the results from the fuel consumption models will be also presented in the Chapter 8.

Table 5.7 Data of the prices list of petrol during July 2011 to June 2012.

Prices of Fuel during July 2011 to June 2012

Month	Gasohol E10 Octane 91	Gasohol E10 Octane 95	Gsohol E20	Gsohol E85	Benzyl Octane 91	Benzyl Octane 95	Diesel HSD	LPG	NGV
Jul-11	35.62	38.12	34.68	22.52	42.41	48.37	29.99	18.13	8.50
Aug-11	34.55	37.07	33.05	21.95	43.02	46.24	29.51	18.13	8.50
Sep-11	33.29	36.31	32.08	21.82	36.31	40.22	28.06	18.13	8.50
Oct-11	32.94	35.97	31.94	21.68	35.97	39.95	28.83	18.13	8.50
Nov-11	32.23	34.11	31.23	21.18	35.26	39.43	28.92	18.13	8.50
Dec-11	31.66	33.41	30.66	20.78	34.69	38.83	29.12	18.13	8.50
Jan-12	34.59	36.34	33.59	22.02	37.62	41.65	30.45	18.13	8.50
Feb-12	36.77	38.52	35.77	22.85	39.80	43.81	31.31	18.13	8.50
Mar-12	38.27	40.02	37.27	23.87	41.85	45.82	32.12	18.13	8.50
Apr-12	38.58	40.33	37.58	23.98	43.21	47.16	31.99	18.13	8.50
May-12	36.66	38.41	35.50	22.73	41.91	45.86	30.51	18.13	8.50
Jun-12	35.23	36.98	33.83	21.53	40.87	44.82	29.65	18.13	8.50
Average	**35.03**	**37.13**	**33.93**	**22.24**	**39.41**	**43.51**	**30.04**	**18.13**	**8.50**
Source: Ministry of Energy (2012)								**12**	**3.5**
								B/Litre	B/Litre

Table 5.8 Data of the Fuel Composition by Types of Vehicles in Thailand**.**

Percentage of The Fuel Consumption by Type of Vehicles

Vehicle Types	Gasohol E10 Octane 91	Gasohol E10 Octane 95	Gsohol E20	Gsohol E85	Benzyl Octane 91	Benzyl Octane 95	Diesel HSD	LPG	NGV	Average Prices B/Litre
PC (<7 PAX) < 2000 cc	16.1	18.39	1.92	0.08	26.65	0.36	0	12.47	24.03	**26.14**
Van (>7 PAX) > 2000 cc	6.81	7.78	0.81	0.03	11.28	0.15	57.68	5.29	10.17	28.38
Pickup (4 wheels) > 2000 cc							78.87	7.22	13.91	25.04
										26.71

Source: Ministry of Energy (2012)

Chapter

6

TRAFFIC SIGNAL SYNCHRONIZATION

6.1 BEFORE APPLICATION OF ITS TECHNOLOGY

6.1.1 TCC and PCU Convert System by Image Sensing Camera

The results of Collected Traffic Data during 11-13 February 2008, 3:00 pm- 4:00 pm as shown in **Table 6.1**.

Table 6.1 PCU of 5 Types of Vehicles

Passenger Car (PC)	Motorcycle (MC)	Light Truck LT	Bus (B)	Heavy Truck (HT)
1.00	0.70	2.07	3.16	3.82

As can be seen that the PCUs of MC is nearly 1.00 or PC, this is due to the fact that MC-Drivers usually drive their vehicles in the middle Lane as presented in **Figure 6.1**.

Figure 6.1 A MC Driver driving in the middle lane.

6.1.2 The installation of equipments, telecommunication networks and traffic controllers.

After installation of equipments, telecommunication network and Traffic Controllers, the traffic classified count-data were sent to the server to evaluate and calculate the cycle time and phasing as shown in **Figure 6.2**. In addition, the evaluated data will complied and send the signal commanding to a Traffic Controller as illustrated in **Figure 6.3**.

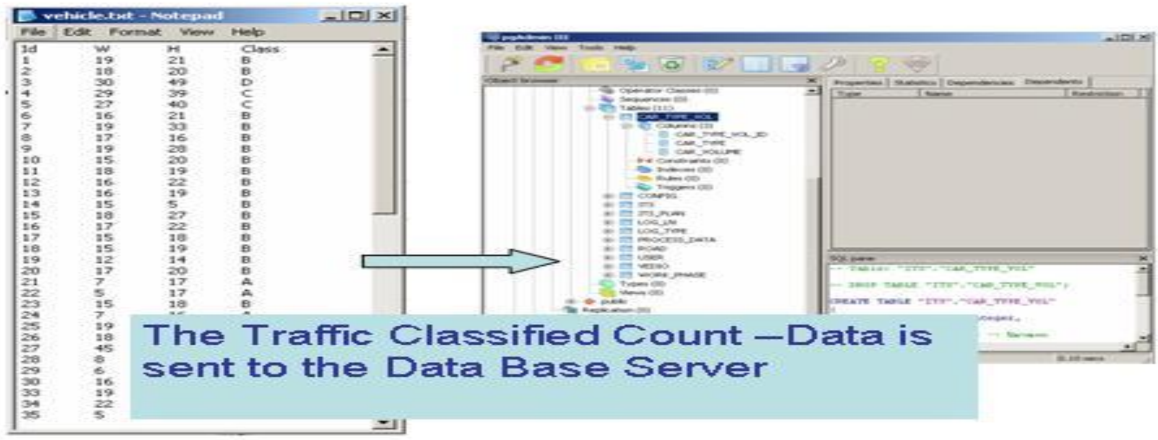


Figure 6.2 Traffic Classified Count-Data sent to the data base server

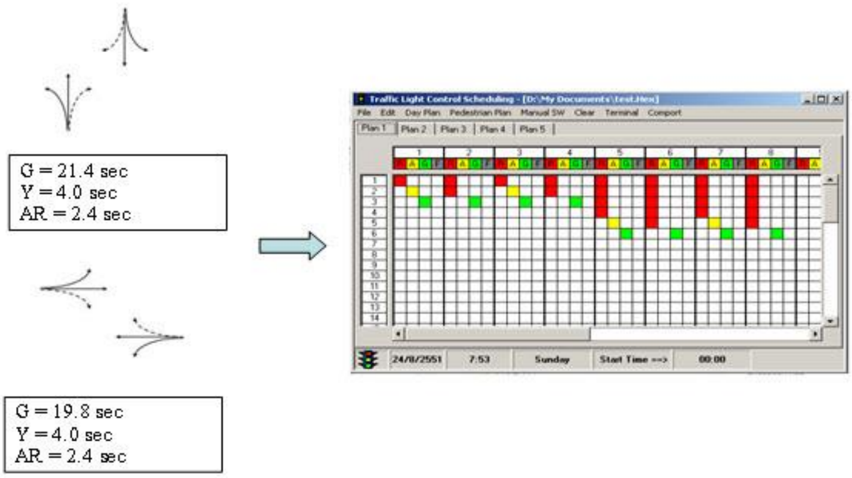


Figure 6.3 A Server will send the signal commanding to a Traffic Controller after Evaluation.

6.2 AFTER APPLICATION OF ITS TECHNOLOGY

In case of the new concepts of the traffic signal synchronization, the extensible green times when vehicles passing a Virtual Loop until the maximum of green times are more important for this concept. Furthermore, the results of real time traffic data collection such as, Cycle Times, Phases, green times, QCT (recheck green times), and traffic volumes flow are illustrated in **Table 4.5**. From these Tables, it can be seen that the effective green times and cycle times decrease substantially when they are compared with the optimum cycle times of SIDRA and Synchro. Moreover, the QCT is nearly the same as the real green times or is lower than the real green times. This leads to reduced green times and can decrease the queue vehicles.

Figure 3.4 (Chapter 3) and **5.7** (Chapter 5) shows that J2-A Phase is linked or synchronized with J1-A Phase and the offset times are 34 seconds. This leads to reduced queue length of vehicles. The Adaptive Traffic Signalization Software at control room will command the controller to get the green wave as presented in **Figure 6.4, 6.5** and **6.6** have also shown about the green wave between two intersections by the joint-phases of J1-C and J2-A. Therefore, these figures indicate the green wave in both directions (the major traffic flows at the intersections) and the using of synchronization phases can remedy the traffic problems at intersections, especially queue lengths. Nevertheless, the turn left/ turn right vehicles on minor road at the 4 Leg Intersection have low traffic volumes when they are compared with the traffic volumes on major road. The low traffic volumes as mentioned before have not affected the green wave on the major road due to the green times on major road at the two intersections.

At night time, the Virtual Loop Detector can detect vehicles when they pass a red Virtual Loop on through traffic lanes on a major road at the 4 Leg Intersection and the green wave on the major road make the green times at the T Intersection as presented in **Figure 6.4**.

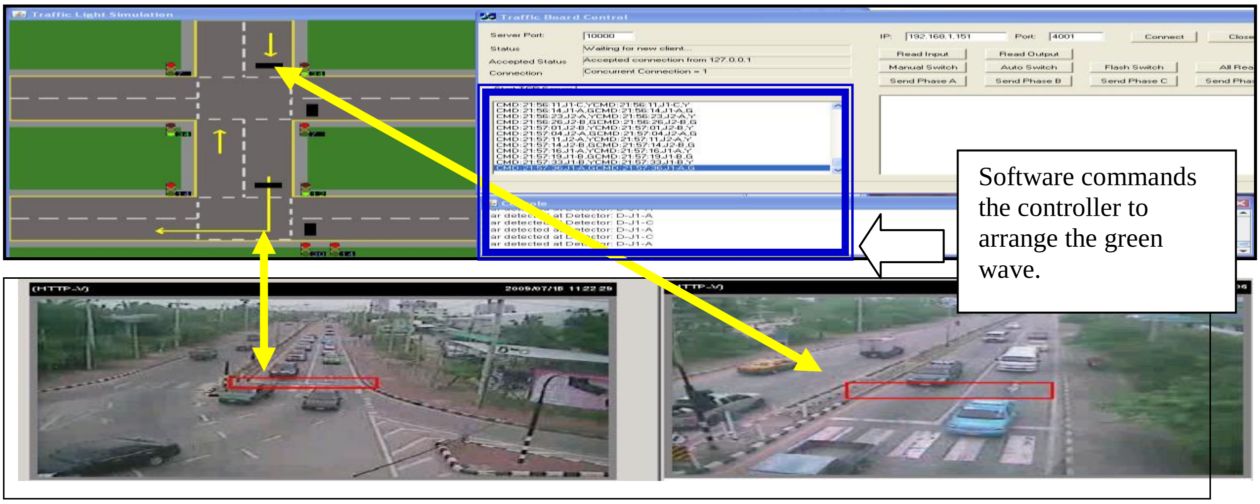


Figure 6.4 Synchronization of J2-B and J1-A phases or green wave phase (34 seconds) can reduce the queue length of vehicles. The Adaptive Traffic Signalization Software at control room commands the controller to provide the green wave as presented in the blue box above.

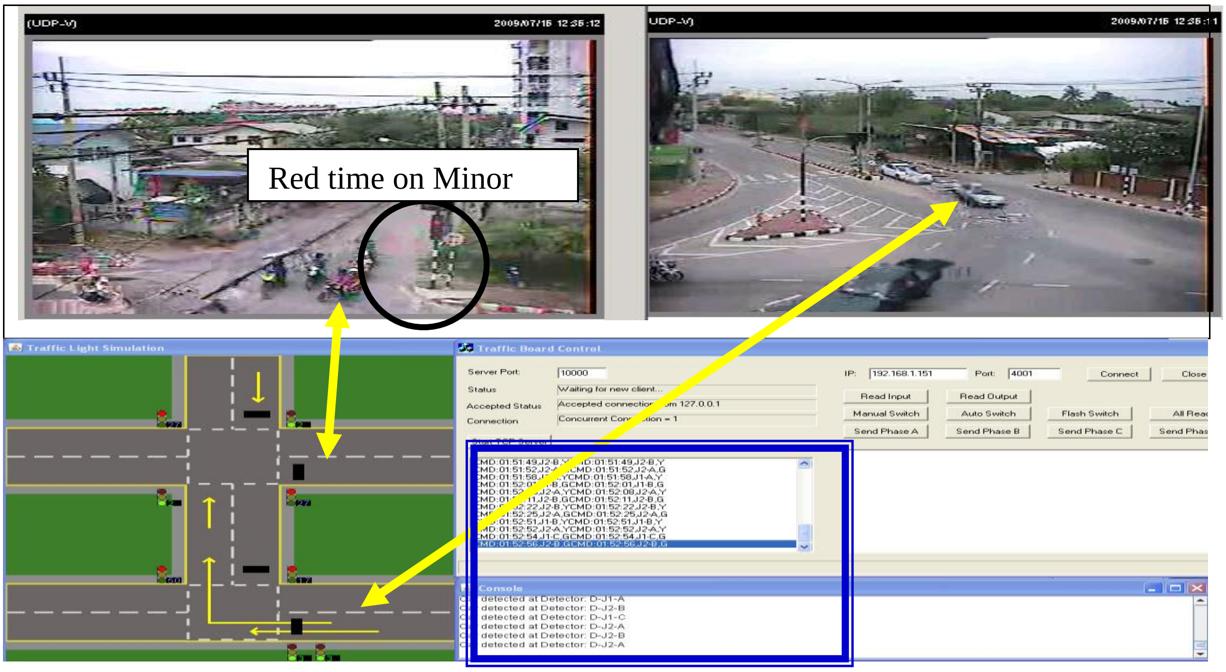
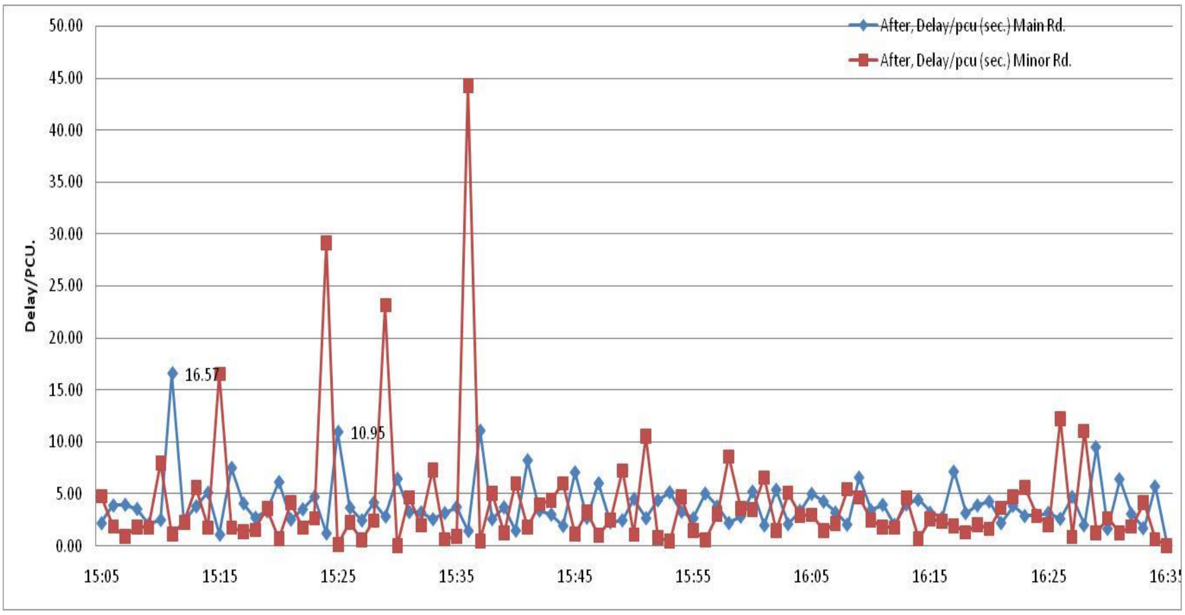


Figure 6.5 J1-C Phase is linked or synchronized with J2-A phase. This state is called 'Green Wave'. The blue box is pointed for the command of traffic controller to do the synchronization.

Figure 6.6 J1-C Phase at the T Intersection and J2B Phase at 4 Leg Intersection at Night Time.

<u>The Results of Traffic Factors After Application of ITS Technology</u>: Delay/PCU on Main and Minor road (collected on Tuesday, 15/02/2011) after application of ITS technology are lower than 60 seconds of Delay/PCU before application as presented in **Figure 6.7**.



Time

Figure 6.7 the improvement of Delay/PCU after application of ITS technology

Average Speeds on Major road after implementation during 3.05 pm to 4.35 pm increase substantially when compared with the average speed before implementation as illustrated in **Figure 6.8**.

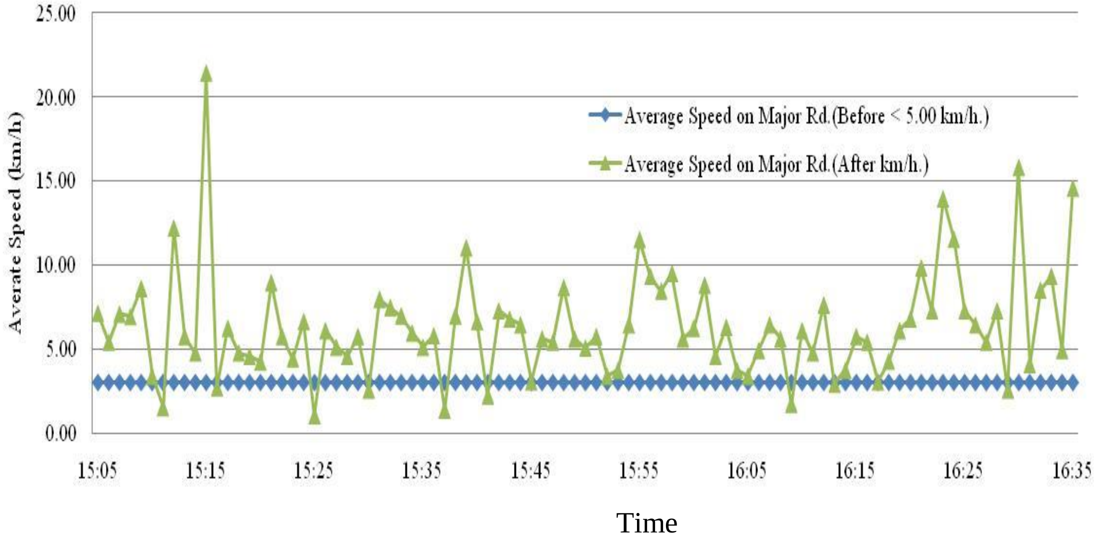


Figure 6.8 the improvement of average speed after application of ITS technology.

Figure 6.9 shows that the effective green times on Major road after application of ITS technology decrease dramatically when compared with the 55 seconds of green times of Fixed Time System.

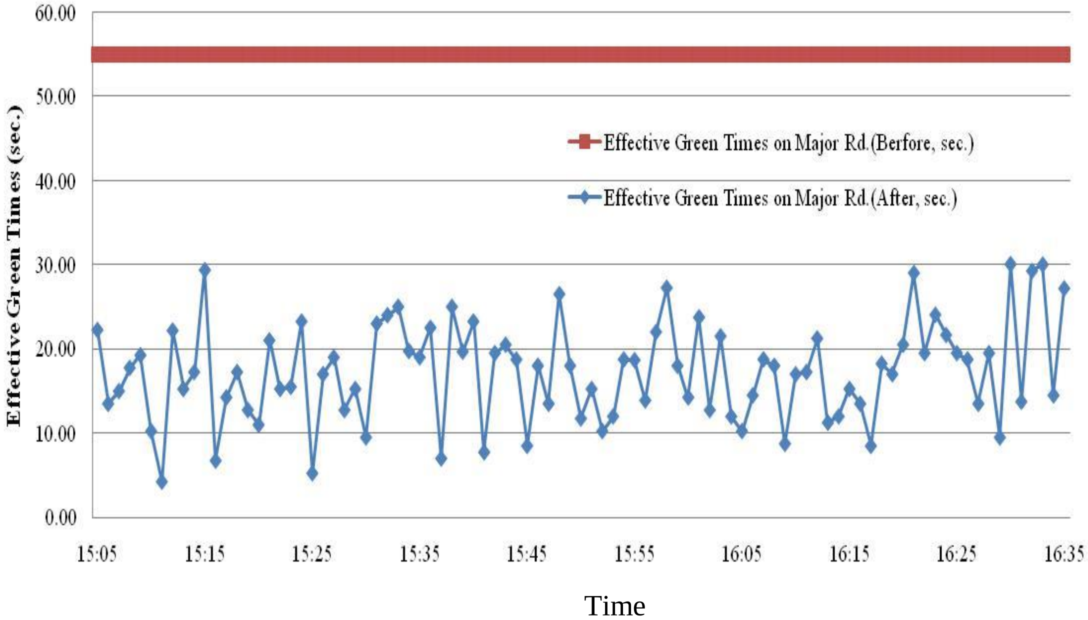


Figure 6.9 the improvement of effective green times after application of ITS technology

The average Queue Lengths on Major and Minor road during 3.05 m to 4.35 pm after improvement are lower than 45 metres when the Queue Length before application of ITS technology are 150 metres. The following Graph shows the results of Queue Length of Vehicles after implementation.

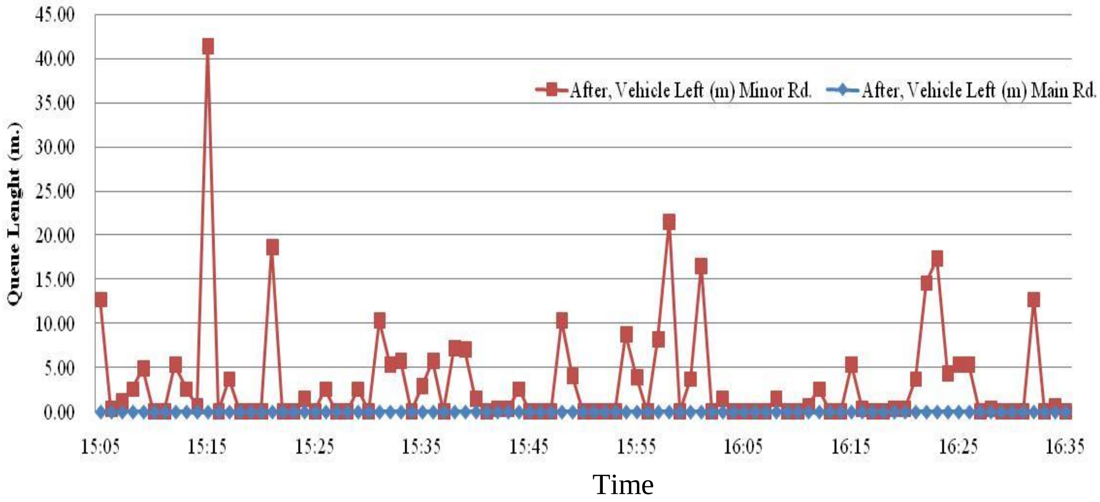


Figure 6.10 the improvement of Queue Length after application of ITS technology

6.3 TRAFFIC ACCIDENTS

The number of accidents, especially those relating to disobedience of signal, decreased dramatically after the installation of the full system (only traffic synchronization) in September 2008. It is seen from the collected data during September 2008 to 2009 (January – June) that there were 3 accidents from drunk driving, but there were none from disobedience of traffic light. In the event of an accident, the software would check the traffic volume prior to the accident and recheck again in the next cycle times. If it is still unusual (i.e. low traffic volumes), the software will promptly change to another phase and concurrently send off a message to administrators and the traffic engineering director. As a result, the effective green times or cycle times is substantially reduced. This leads to the reduction in travel times for road users and the resulting reduction of fuel consumption and cost.

The accident data, especially those arising from the disobedience of traffic signal, decrease dramatically. Collected data from May – June 2010 show that the number of accidents (speeding on amber and all red times) was 1 per month. Moreover, during the time of accident, the vehicles, which pass the Virtual Loop, are lower than during the normal times. The software will check the traffic volumes at the previous times and it will wait for the next cycle times, if it is still an abnormal case, the software will change to another Phase immediately. Furthermore, messages are promptly sent to administrators and directors. As a result, queue length at the two intersections decrease substantially as presented in **Table 6.1**.

Table 6.2 Comparison between before and after use of the adaptive traffic signalization.

Cycle Times max. (sec.)	**5+6- 150, 5+7 – 90**
Number of Phasing	**3, 2**
Before Queue (m)	**420.0, 890.0**
After Queue (m)	**0 – 125.0, 0 – 155.0**

Note: The values (x, y) are values x of the T Intersection and values y of the 4 Leg Intersection- values.

6.4 FITTING OF EMPIRICAL EQUATIONS (OFF-LINE)

Traffic data collected since September 2008 (real-time), such as the Average Speed v (kph) and the Effective Green Time g_e (seconds) were evaluated by statistical theories; the fitted curve model and equations are shown in the following equations:

$$v = 1.16115 \times \lambda - \frac{1.36164}{\cos(125.776\lambda)} \tag{6.1}$$

$$g_e = 12.7998 \times (52.923 \times e^{0.0056\lambda}) - 635.59 \tag{6.2}$$

where λ is the arrival rate defined as (PCU/min). The correlation coefficients for both the equations are 0.910 and 0.821, respectively.

The effective green times applies only to the main R (J1A) movement, and minor movements, LTR (J2A and J2B). Average speed is calculated for the traffic Lane Changing as described in the next Chapter.

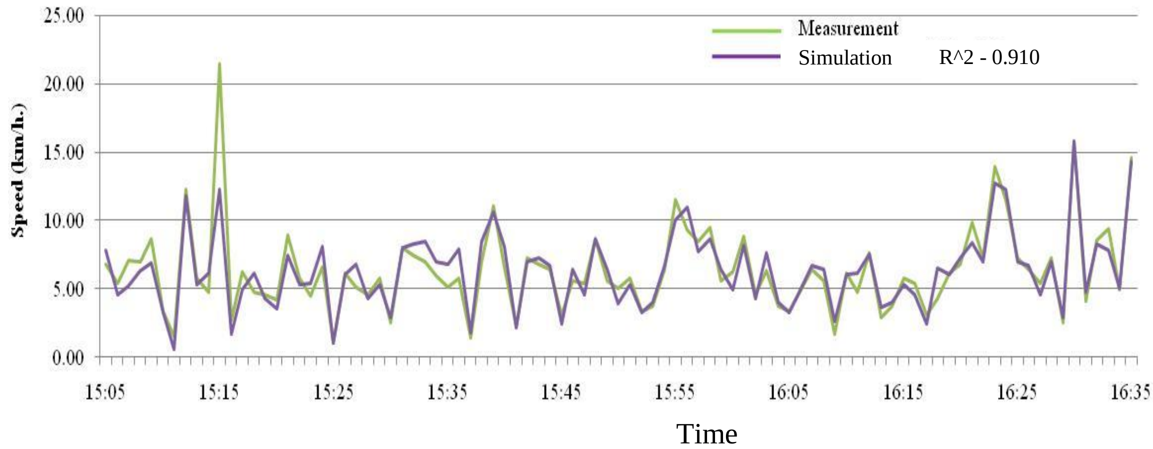


Figure 6.11 average speed compared with simulated model

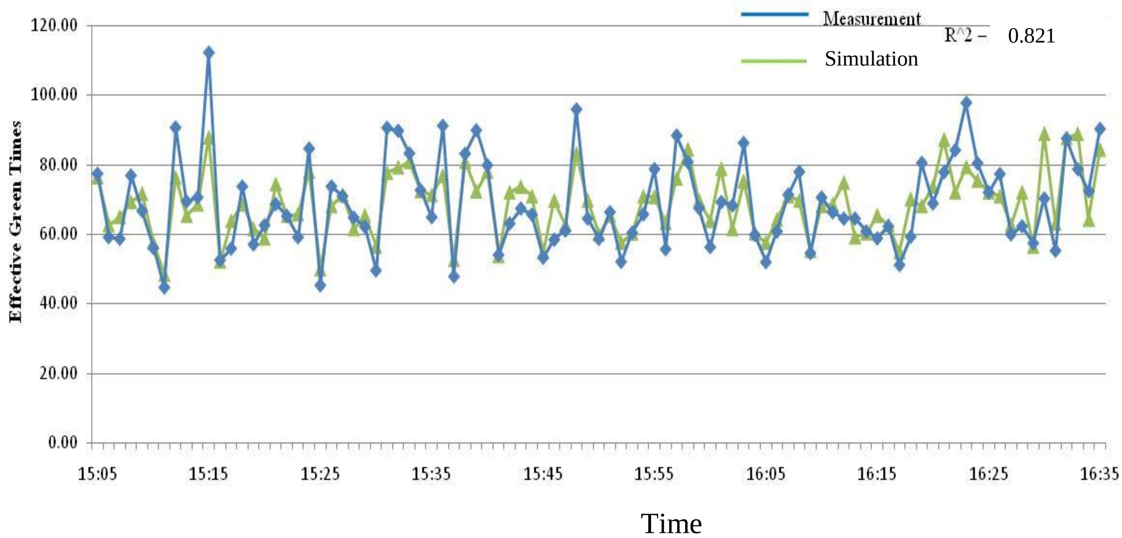


Figure 6.12 Effective Green Times compared with simulated model

6.5 RESULTS OF EVALUATION

The results from image structures with accuracy of 95% of classified traffic count: the calibration of vehicle dimensions and angle of CCTV camera are shown in **Figure 6.13.** The rectangular box or Virtual Loop is the area for traffic counting where vehicles flow through. Traffic counting and classification start with the dimensions of vehicles. The developed software for image sensing can calculate and evaluate the frames of images. The classified traffic count uses trial and error to obtain the accurate dimensions of each vehicle. In this research, the CCTV cameras were used for several functions; the cameras count traffic volumes on major roads during off-peak and peak hours and also count the volumes on minor roads. Therefore, a Virtual Loop in a camera has two functions, one as a loop detector (traffic sensor by trigger) and another as a classified traffic counter.

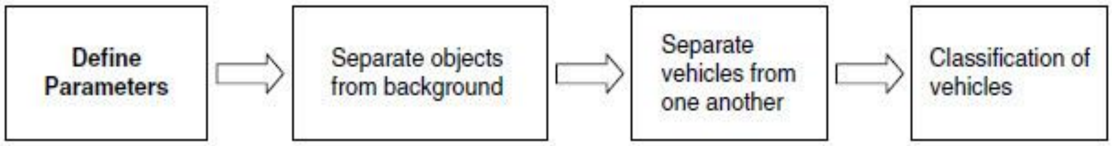


Figure 6.13 the Calibration of Vehicle Dimensions**.**
Source: Cheewapattananuwong et al., (2011)

In the case of the trigger, traffic data and signals are transferred to controllers for computation of the headways. If there is no vehicle passing through the Virtual Loop within 5 second, the signal will command the traffic controllers to change the green phase to amber and then red.

Results Obtained from Adaptive Traffic Signalization Software: Cycle times at the T and 4 leg intersections decrease dramatically because of the triggers from the Virtual Loop detectors. The triggers detect vehicles passing through the Virtual Loop within 5 seconds. If no vehicle passes through the loop after 5 seconds, the triggers will sync with the controller, which promptly changes the light from green to red. The effective green times of each direction at both intersections are substantially lower than the maximum effective green times of maximum cycle times as calculated by aaSIDRA and Synchro. The maximum for the T intersection is 150 seconds and for the 4 Leg intersection, 90 seconds. Furthermore, the number of phases at the T intersections and 4 Leg intersections are three and two, respectively. It is observed that effective green times and cycle times decrease substantially compared with the optimum cycle times as obtained from aaSIDRA and Synchro. **Table 6.2** shows that the J2-A phase is synchronized with the J1-A phase, and the offset time is 34 seconds. Effective green times on each approach of the intersections are thus minimized. Furthermore, the number of remaining vehicles (depicted as PCU equivalents left) is lowest. The Adaptive Traffic Signalization Software at the control center commands the controllers to provide the green wave, as presented in the blue box in **Figure 6.4, 6.5 and 6.6**, which also shows the green wave between the two intersections by the joint phases of J1-C and J2-A. From **Table 6.2**, it is seen that the green wave in both directions and the use of synchronized phases can mitigate the traffic problems at the two intersections, especially the long queue. Because volumes of left-turn and right-turn vehicles on minor roads at the 4 Leg intersection are lower than volumes on the major road, turn volumes on minor roads have little effect on the green wave on the major road. For example, for the traffic data from Monday, June 7, 2010, the arrival rate was calculated from the effective green times on the major phase and the 95 seconds offset model; the image-sensing software measures the number of PCU equivalents remaining, as shown in **Table 6.2**.

Table 6.3 Simulation of Cycle Times at 95 seconds Related with PCU Equivalents Left.

Source: Cheewapattananuwong et al, (2011)

Time	Arrival Rate (λ) (PCU/Min)	Average Headway (s/veh-PCU)	Average Speed (km/hr)	95-s Model (using offset)	PCU Equivalent Left
15.54	7.50	8.00	6.45	75.65	0.00
15.55	7.47	8.03	11.53	85.76	0.00
15.56	5.56	10.79	9.33	69.43	0.00
15.57	8.80	6.82	8.46	79.75	0.00
15.58	10.90	5.50	9.50	69.64	0.00
15.59	7.20	8.33	5.61	72.22	0.00
16.00	5.70	10.53	6.25	64.92	0.00
16.01	9.50	6.32	8.81	88.87	0.00
16.02	5.10	11.76	4.58	54.70	0.00
16.03	8.60	6.98	6.30	75.81	0.00
16.04	4.80	12.50	3.74	59.10	0.00
16.05	4.10	14.63	3.40	60.10	0.00

The Offset or Green Wave Concept: The offset time-phase or Green Wave Phase is proposed for vehicles passing from one intersection to the another such as, the group of direction flows in 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 are calculated using the ARRB method (Akcelik, 1989**).** For the J2-B and J2-A to J1-A direction, 34 seconds of offset time is obtained and it is subtracted with the amber and all red times of 7 seconds. Therefore, 27 seconds of offset time is proposed for the green wave phase. For the J1-C to J2-B direction, the 28 seconds is obtained from the difference of 34 seconds (offset time) and 6 seconds (3 second amber and 3 second all red times). Furthermore, the incremental time of the J1-A phase is between 0.5 and 0.8 times of the green times of the J2-B phase, based on traffic volumes and calibration of filed data. Calculation of actual red time is obtained from the effective green, amber, and all red times. For example, the maximum effective green and amber times (during off peak) at the 4 Leg intersection of the minor road are 12 seconds and all red times are 3 seconds. The total actual all red times of major road is computed as 15 seconds**.**

Chapter

7

LANE CHANGING AND SPEEDING

7.1 AFTER APPLICATION OF ITS TECHNOLOGY

7.1.1 Road Conditions

In case of the evaluation concepts of controlling speed and Lane Changing model (see **Figure 3.15** and **5.8)**, the 1st car waiting for u turn at the intersection had an effect on the following car (2nd car). In order to avoid the long waiting time, the driver of the 2nd car pulled the car out to change lane; this sudden movement caused the next driver (3rd car) in the adjacent lane to brake suddenly. This sort of behavior is quite common for Thai drivers who attempt the risky maneuver to avoid the long waiting times during the red periods and during the waiting U Turn periods. However, the action taken by the driver of the 3rd car will be safe if the SSD is less than the average spacing length as can be seen in **Figure 7.1**. Normally, the speed of vehicle approaching an intersection is more than 45 kph. This leads to the increasing number of accidents in the risky areas, 100 m from the stop line. Evaluation of traffic safety at the intersections in terms of the risk probability which depends on speed is shown in **Figure 7.2**.

Figure 7.1 GAP Length of two vehicles measured by Image Sensing in the area considered as risky zone.

From **Figure 7.1**, it can be seen that the Lane Changing vehicle moved into the gap which is smaller than SSD. It causes the following vehicle to stop suddenly so as to keep the safety gap. Therefore, this area usually becomes the risky zone.

Figure 7.2 Risky Zone of Lane Changing traffic at 80 metres before stop line**.**

7.1.2 Traffic Situations

For a critical situation day, several factors, including angle of Lane Changing, starting and final speed, average Lane Changing Length and Stopping Sight Distances (SSD) are presented and compared with accident data. Key data from **Table 7.1** show that there were two crashes within a 40 minute period from 3:15 pm to 3:50 pm on Monday 7 June, 2009. Some drivers were in a hurry to pick up their children at school so they swiftly changed lane to find the nearest space to the stop line during the red period. When the tracked data such as, the angle of Lane Changing (degree), final speed (v_f), and average Lane Changing length (ACLL) are compared with the average spacing length (ASL) and SSD using the criteria of traffic safety at intersections as stated earlier and in the next part, it can be seen why the two crashes occurred.

Table 7.1 Accident data caused by lane changing during 3.05 pm to 4.05 pm on Monday 7th June 2010.

Time	Degree	vf (kph)	ACLL (m)	ASL (M)	SSD M	Accidents
15:16	41.501	9.472	5.03	11.530	8.42	
15:16	67.953	4.059	1.08	14.957	1.30	
15:17	43.310	8.980	4.63	16.031	7.59	
15:17	45.219	8.488	4.24	17.771	6.13	
15:19	32.206	12.533	7.52	15.732	14.28	1
15:19	45.219	8.488	4.24	11.906	7.45	
15:20	46.619	8.144	3.97	11.906	6.25	
15:20	70.227	3.715	0.65	8.202	1.18	
15:21	44.061	8.783	4.48	14.957	7.99	
15:21	46.013	8.291	4.08	11.224	7.10	
15:22	47.443	7.947	3.81	14.957	5.40	
15:23	51.150	7.110	3.16	15.732	4.75	
15:23	52.073	6.913	3.01	11.224	4.86	
15:24	39.127	10.161	5.59	14.443	10.68	
15:24	51.150	7.110	3.16	12.987	5.16	
15:26	60.776	5.240	1.33	11.647	2.65	
15:26	62.774	4.896	1.16	12.563	2.27	
15:27	30.984	13.026	7.92	11.224	13.43	
15:27	36.975	10.835	6.14	10.754	10.89	
15:27	47.443	7.947	3.81	8.202	5.40	
15:28	36.477	10.998	6.27	11.647	9.94	
15:28	39.787	9.965	5.43	23.366	9.29	
15:28	51.150	7.110	3.16	11.906	5.16	
15:29	38.641	10.309	5.71	11.906	10.99	
15:29	48.285	7.750	3.66	15.563	6.18	
15:30	56.225	6.077	2.40	13.804	3.41	
15:31	48.073	7.799	3.70	14.326	5.21	
15:33	54.469	6.421	2.65	14.957	3.53	
15:34	47.443	7.947	3.81	12.987	5.95	
15:34	51.150	7.110	3.16	16.708	5.16	
15:35	48.928	7.602	3.54	13.619	4.95	
15:36	42.757	9.128	4.75	12.987	7.04	
15:36	55.214	6.274	2.54	17.975	3.65	
15:37	65.763	4.404	1.28	15.732	1.57	
15:38	50.471	7.258	3.28	13.804	4.95	
15:38	52.073	6.913	3.01	12.987	4.10	
15:39	57.784	5.781	2.19	14.326	3.07	
15:41	25.857	15.445	9.86	25.715	23.61	
15:41	44.061	8.783	4.48	27.982	6.55	
15:42	30.927	13.049	7.94	16.031	15.37	
15:42	44.061	8.783	4.48	14.523	7.99	
15:43	47.443	7.947	3.81	12.987	5.40	
15:43	52.073	6.913	3.01	18.275	4.48	
15:44	44.061	8.783	4.48	15.454	7.99	
15:44	67.953	4.059	0.79	14.957	1.38	
15:45	22.741	17.315	11.33	12.208	25.47	
15:45	58.851	5.585	2.05	12.987	3.05	
15:46	36.927	10.850	6.15	13.804	9.70	
15:46	39.620	10.014	5.47	14.142	9.38	
15:47	24.730	16.077	10.36	14.326	25.41	
15:47	54.469	6.421	2.65	12.987	3.53	
15:48	39.291	10.112	5.55	8.202	9.55	
15:48	44.829	8.587	4.32	14.957	6.95	
15:48	45.416	8.439	4.20	11.530	7.36	
15:49	53.495	6.618	2.79	14.957	4.43	
15:49	56.225	6.077	2.40	10.754	3.68	1
15:50	48.928	7.602	3.54	12.987	4.95	

The author has been developing the Lane Changing Software to check the speed before and after Lane Changing. Furthermore, the Lane Changing Lengths are compared with the SSD as can be seen in **Figure 7.3**.

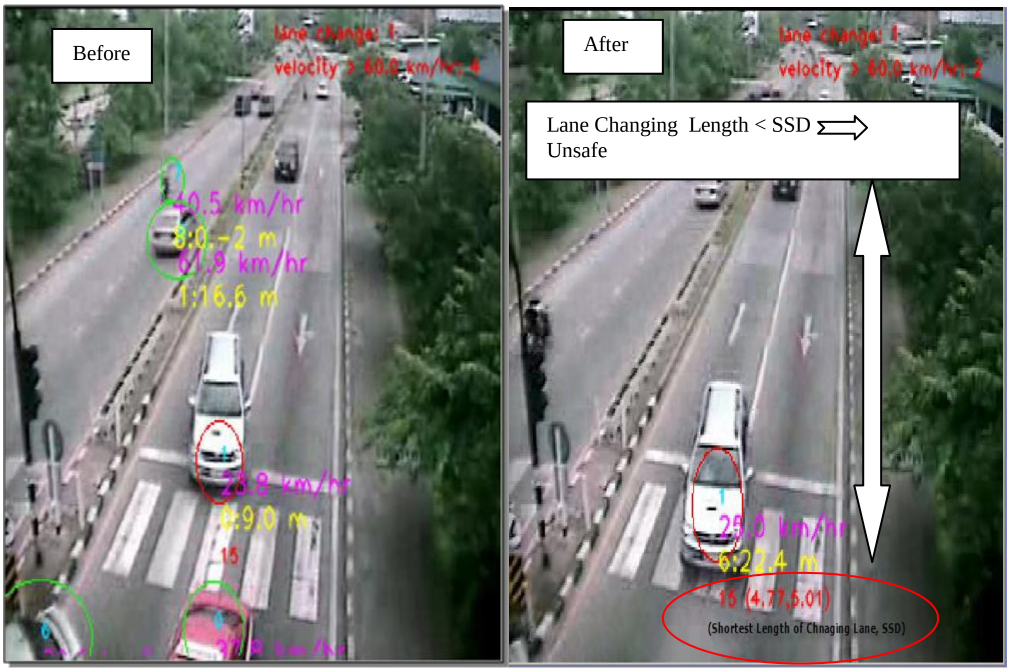


Figure 7.3 Degree of Lane Changing, Starting and Final Speed, Gap and SSD**.**

From **Figure 7.3**, it can be seen that the Lane Changing Vehicle moved into the gap which is smaller than SSD as described in **Table 4.3** (Stopping Sight Distance (SSD) and Weaving Length based on AASHTO, 2001)**.** The developed software showed the shortest length of Lane Changing and SSD so as to remedy the traffic accidents at the risky area. It leads to the following vehicle stopping promptly so as to keep the safety gap. For example, from **Figure 7.3**, the gap length before Lane Changing is 9.0 meters. While the car is Lane Changing, the Lane Changing Length (4.77 metres) is lower than the SSD (5.01 meters). Therefore, it poses a chance of accident. However, the front vehicle (pink car) gap length is 22.4 metres from the rear vehicle (white car). The image sensing software will detect the risky behavior, send the information to the VMS which will apply the 'Control Speed' or 'No Lane Changing' message. If the drivers behavior is deemed save, the image sensing software will relay no message as presented in **Figure 7.4** (Collected Data on Friday, 11 February 2011 during 4.30 pm – 5.30 pm).

Figure 7.4 Controlled Speed and Lane Changing by Variable Message Sign (VMS)**.**

Table 7.2 Collected traffic changing lane and speed data during installed VMS (11/02/2011).

Mitigation Scenarios	**Number of Lane Changing Vehicles**	**Number of Over Speed Vehicles**	**Decreasing Percentage (%)**
W/O VMS	47	192	
Wt VMS “No Fine”	29	139	-38.30,-27.60
Wt VMS “Fine”	20	118	-62.45,-38.54

As can be seen by the results from **Table 7.2**, number of Vehicles Lane Changing and over speeding increased without VMS. However, the number of these situations decreased substantially when stalling the VMS and proposing the command on the sign ‘Please Keep Your Lane Otherwise, Fine 500 Thai Baht’.

7.2 FITTING OF EMPIRICAL EQUATIONS (OFF-LINE)

7.2.1 Evaluation concepts of lane changing model (off-line)

An evaluation is carried out for the traffic data collected since September 2009. The empirical formulas for the Average Spacing M and the Average Length of Lane Changing (L) are described as follows:

$$M = \max\left[0.454652 + \frac{0.269666 \times v}{\operatorname{atan}(\lambda)}, \quad 8.20255\right] \tag{7.1}$$

$$L = 2 \times \frac{\sqrt{(V_f \times \frac{1000}{3600})^2}}{9.81(0.025 + 0.15)} \times D_m \times \cos(\frac{\theta}{180} \times 3.14592) \tag{7.2}$$

$$V_f = 0.0572063 * \theta + 1.33585 * L + \sin(L) + \frac{0.0694052 * \theta}{L} \tag{7.3}$$

$$SSD = 0.0896671 * V^2{}_f \tag{7.4}$$

where λ is the arrival rate defined as (PCU/sec). The correlation coefficients for the equations are 0.999, 0.989, 0.924, and 0.997, respectively.

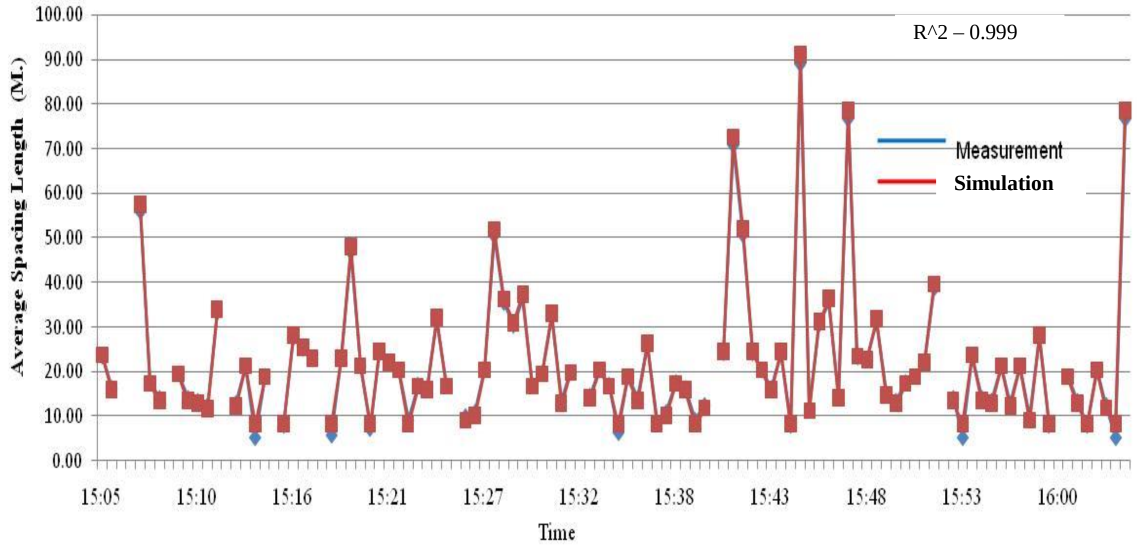


Figure 7.5 Average Spacing Length by measurement compared with Simulated Model

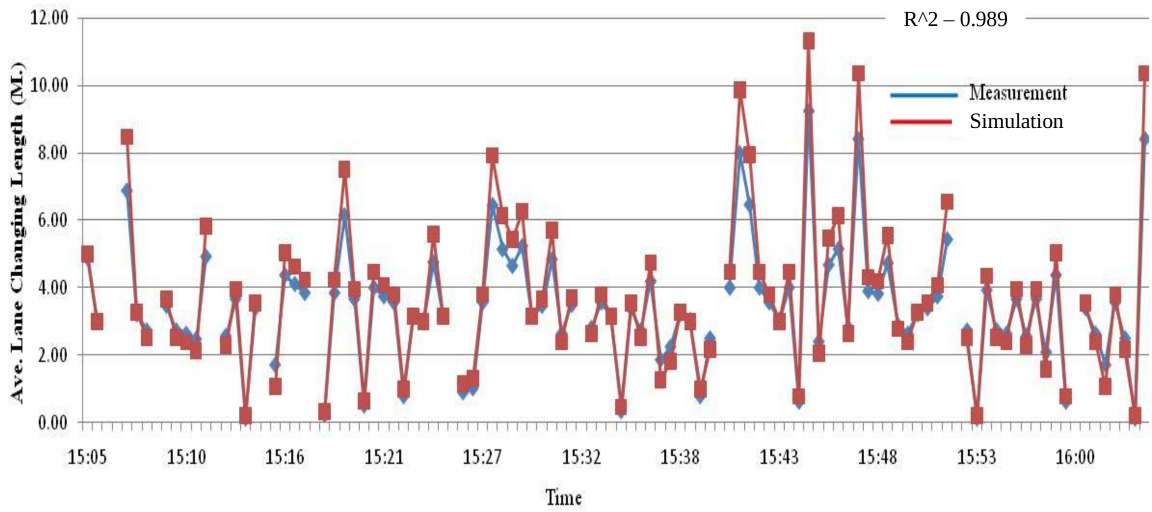


Figure 7.6 Average Lane Changing Length by measurement compared with Simulated Model

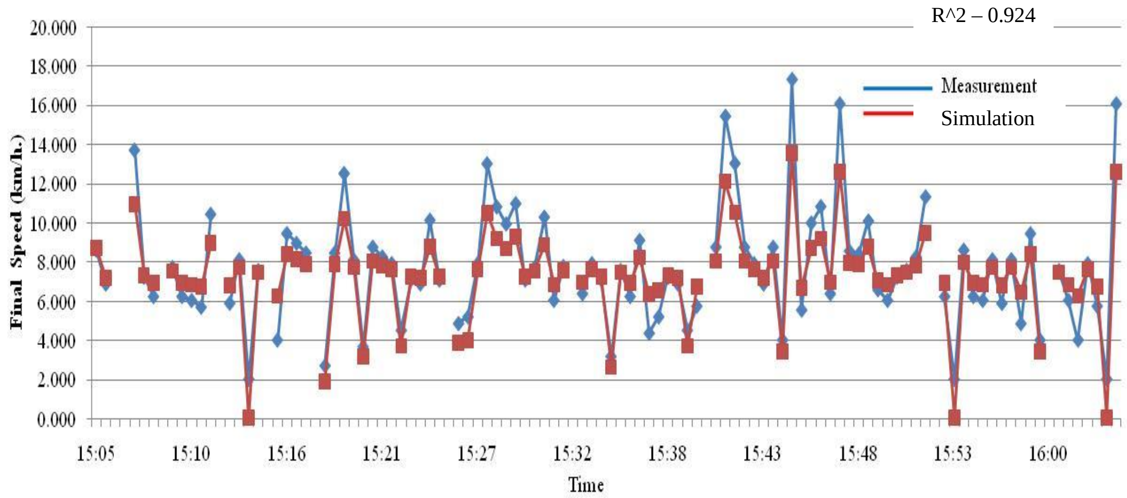


Figure 7.7 Final Speed by measurement compared with Simulated Model

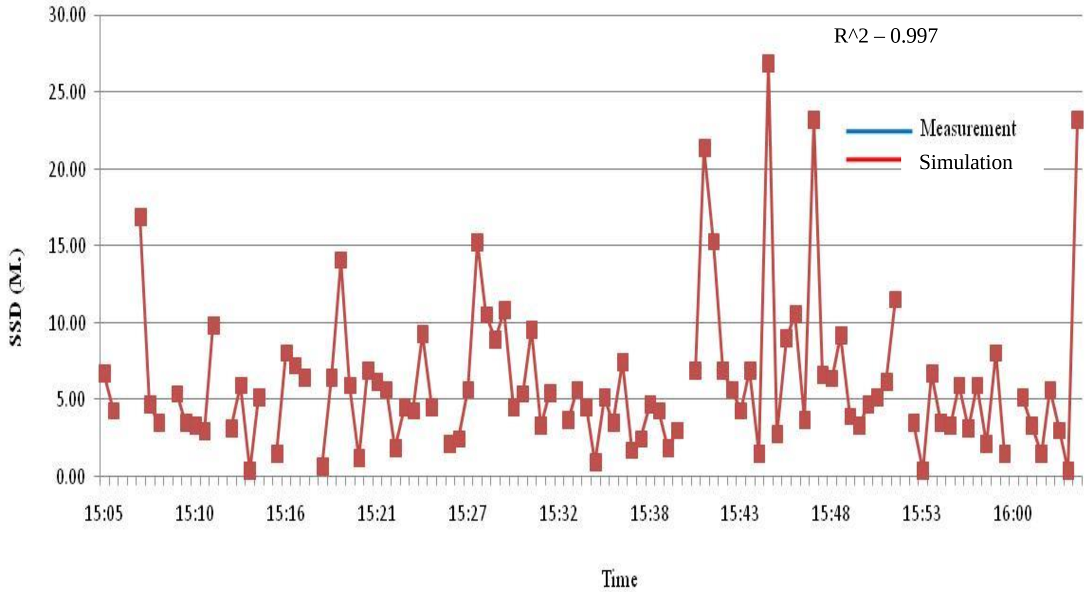


Figure 7.8 Final SSD by measurement compared with Simulated Model

7.2.2 Evaluation concepts of controlling speed and lane changing model

The 1st car waiting for U Turn at the intersection had an effect on the following car (2nd car). In order to avoid the long waiting time, the driver of the 2nd car pulled the car out to change lane; this sudden movement caused the next driver (3rd car) in the adjacent lane to brake suddenly. This sort of behavior is quite common for Thai drivers who undertake the risky maneuver to avoid the long waiting times during the red periods and during the waiting U Turn periods. However, the action taken by the driver of the 3rd car will be safe if the SSD is less than the average spacing length as can be seen in the bottom right centre of **Figure 7.3**.

Normally, the speed of vehicle approaching an intersection is more than 45 kph. This leads to the increasing number of accidents in the risky areas, 100m from the stop line. Therefore, the researchers set the criteria for traffic safety at intersections as:

$$\text{Average Spacing Lenght} > \text{Average Lane Changing Lenght} > SSD \tag{7.5}$$

7.3 RESULTS OF EVALUATION

Evaluation of traffic safety at the intersections in terms of the accident risk probability depends on speed. Equations 6.1 to 6.5 were used to predict traffic safety at the intersections, in terms of risk probability which depends on speed were applied and the results are shown in **Table 7.3**. In case of probability, the simulation concept, especially the application of random numbers, is taken into consideration. The random numbers of the angle of Lane Changing (θ), starting speed of Lane Changing (v_s) and final speed of Lane Changing (v_f) are substituted into Equations 7.1 to 7.5 as described in **Figure 7.9** and **Table 7.3**.

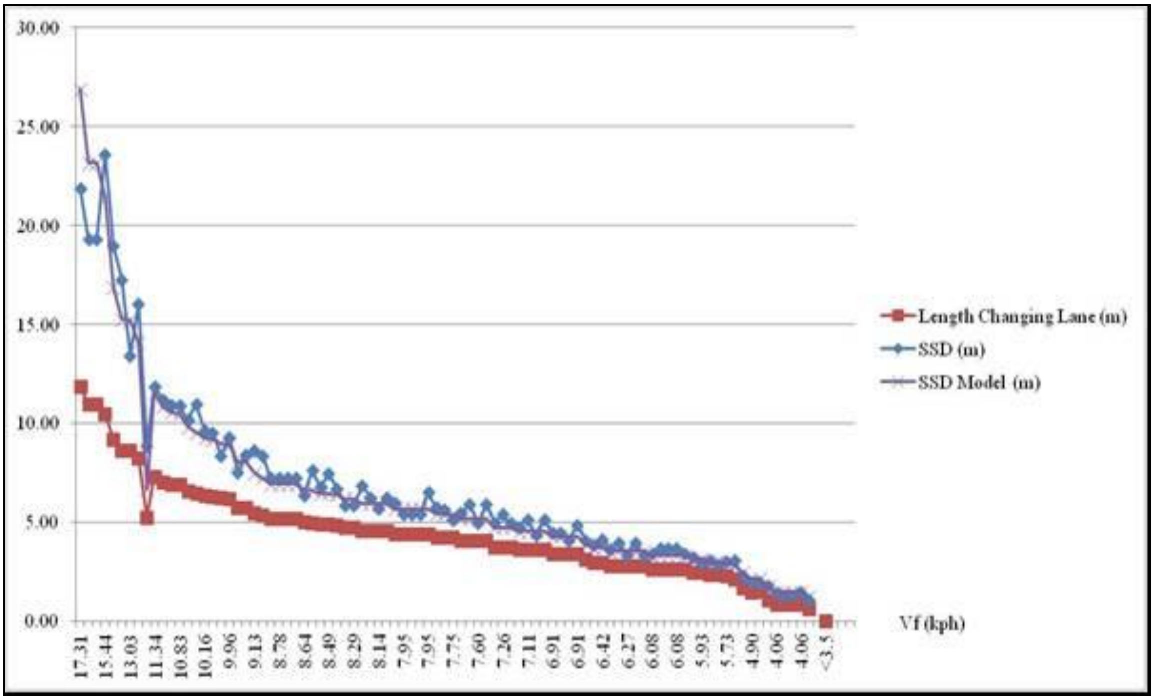


Figure 7.9 Simulation of Length of Lane Changing , SSD (AASHTO) and SSD Model in metres compared with the speed Vf (kph).

Table 7.3 Evaluation of traffic safety at the intersections in terms of risk**.**

Before and After Situation of Traffic Safety	Probability
Speed Limit in Urban Area	
Before Treatment Approach Speed ≥ 60 kph	
Probability of having a crash (Risky)	0.962
Probability of not having a crash (Safe)	0.038
Probability Gap for Changing Lane	0.006
Simulation with no lane changing within 100 m	
After Treatment Speed Control 45 kph	
Probability having a crash (Risky)	0.118
Probability of not having a crash (Safe)	0.882
Probability Gap for Changing Lane	0.009
Simulation with no lane changing within 100 m	
After Treatment Speed Control 30 kph	
Probability having a crash (Risky)	0.004
Probability of not having a crash (Safe)	0.996
Probability Gap for Changing Lane	0.004

As can be seen from **Figure 7.9**, drivers' bad behavior by Lane Changing is lower than SSD – Stopping Sight Distances of AASHTO and the Developed Model. This leads to the unsafe Lane Changing behaviour of Thai Drivers. The results from **Table 7.3** are further described. In case of probability, the simulation concept especially, the application of random numbers is taken into consideration. The random numbers of the angle of Lane Changing (θ), starting speed of Lane Changing (v_s) and final speed of Lane Changing (v_f) are substituted into Equations 7.1 to 7.5. Before the treatment (intersection approach speed ≥ 60 kph), the probability of no gap for lane changing is between 0.00 and 0.02, and the probability of having a crash is very high at 0.95 to 0.98, while the probability of not having a crash is very low at 0.02 to 0.06. After the treatment (control speed ≤ 45 kph), the probability of no gap for lane changing is between 0.002 and 0.015; the probability of having a crash is substantially reduced to between 0.05 and 0.15, and of not having a crash is dramatically increased to between 0.55 and 0.95. Furthermore, when the probability of no gap for lane changing after treatment (control speed ≤ 30 kph) is between 0.000 and 0.015 the probability of crash risk is further reduced to between 0.002 and 0.015, and the probability of not having a crash is further increased to between 0.990 and 0.999. It is thus clear that lower speed can substantially mitigate the traffic crash situation at the two piloted intersections.

In case of Traffic Accidents, the number of RLR accidents after Implementation of ADTS decreases to be zero in 2010. The number of Lane Changing and Speeding after Implementation of LCSW reduces to be zero in 2011 as shown in **Figure 7.10**.

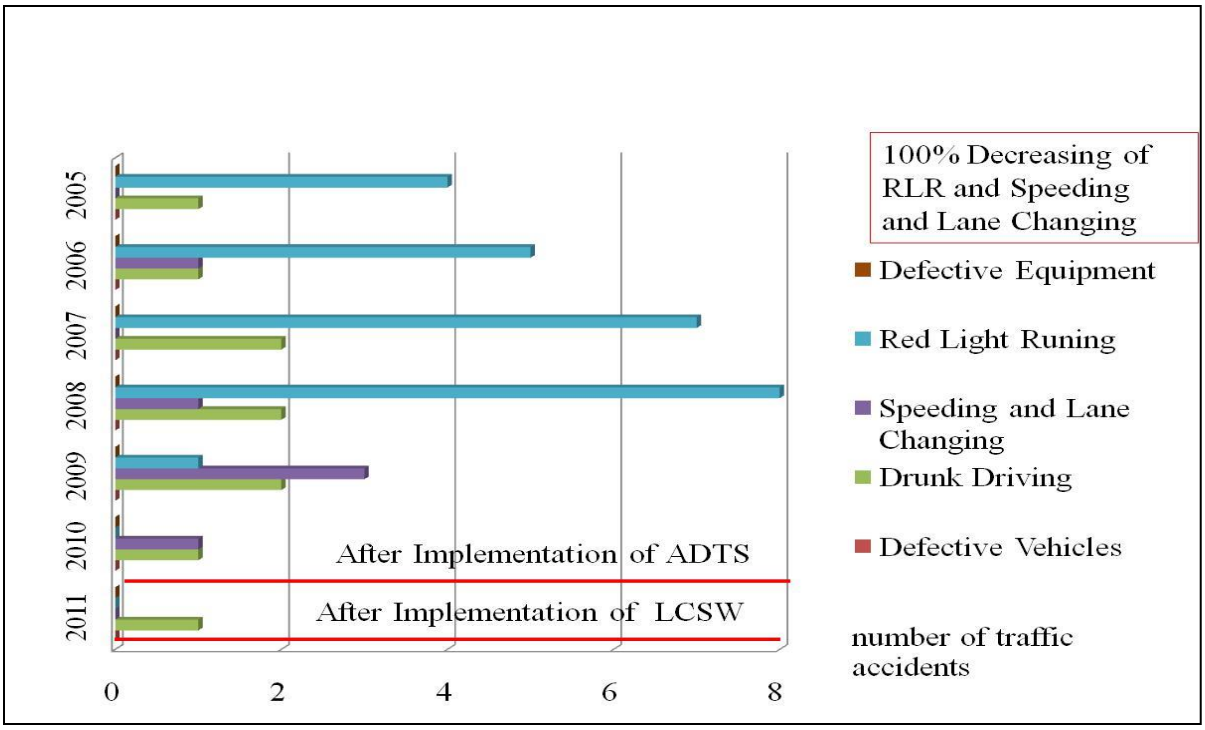


Figure 7.10 Decreasing of Traffic Accidents after Implementation of ADTS and LCSW.

Chapter

8

VEHICLE EMISSION AND FUEL CONSUMPTION

8.1 APPLICATION OF ITS TECHNOLOGY

8.1.1 Traffic Pollution

For the present study, the existing Noise, CO and PM_{10} data in 2012 were measured at the case study intersections. **Table 4.7** shows the Collected Environmental Data at the Intersection during 14-16 November 2012 as already described in Chapter 4. It is clearly seen that the CO and PM_{10} Emission Model Levels were lower than the standard of Pollution Control Department Thailand which are 30.00 PPM/hr. and 120.00 mg/m^3/24hr, respectively. Nevertheless, the Noise Pollution Levels during speed from 0 to 10.76 km/hr, which are slightly upper than the standard (73.0 dB(A)), are from 72.0 to 74.7 dB(A). This has an effect on the patients who were hospitalized due to exposure to air and noise pollution. They presented signs of decreased oxygen saturation (increasing need for oxygen support therapy), elevated blood pressure, increased heart and respiration rate, and insufficient or disturbed sleep.

8.1.2 Noise and Air Pollution

The predicted equations of traffic air emission models are derived and calibrated from the collected data by the statistic methods. However, the predicted traffic noise emission Model is compared between the method of UK Department of Transport - Welsh Office (1988), Cheewapattananuwong and Samuels (1996), Samuels and Cheewapattananuwong (1997). In case of the predicted data before traffic signalization improvement, the average speed of vehicles was derived from the calculation of

SIDRA and TRAFFICWARE. This is due to the fact that the collected traffic data did not include the speed when approaching the intersections. Therefore, CO level, PM_{10} and Noise Level will be predicted from the same speed as described in the next section. For example, the emission CO, PM_{10} and Noise Levels at 3.05 pm are 2.74 ppm/hr, 17.01 $\mu g/m^3/24$ hr and 73.0 dB(A), respectively.

8.1.3 Fuel Consumption

A number of fuel price lists have been collected from July 2011 to June 2012. The equivalent of fuel prices are two types; 26.14 Baht/Litre for PC (4 wheels < 2.0 L) and 26.71 Baht/Litre for PC (4 wheels > 2.0 L). In case of the predicted data before traffic signalization improvement, the collected fuel consumption data include the average speed when approaching the intersections can be seen in **Table 4.8, 4.9 and 4.10**. Therefore, fuel consumption level will be predicted from the same speed as explained by the equations in the section 8.2 (Fitting Empirical Equations). For instance, the fuel consumption of vehicle for PC (4 wheels < 2.0 L) and PC (4 wheels > 2.0 L) are 25.595 l/100 km and 20.728 l/100 km, respectively.

8.2 FITTING OF EMPIRICAL EQUATIONS

8.2.1 Vehicle and Noise Emission Model

Air and Noise Pollution

CO Prediction

CO based on Speed < 21.83 Km/hr.

$$CO = 2.69 + 0.00923 * Speed + 3.956e-5 * Speed^3 - 0.000447 * Speed^2 \quad (8.1)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.0000

where Speed is Speed (Km/hr).

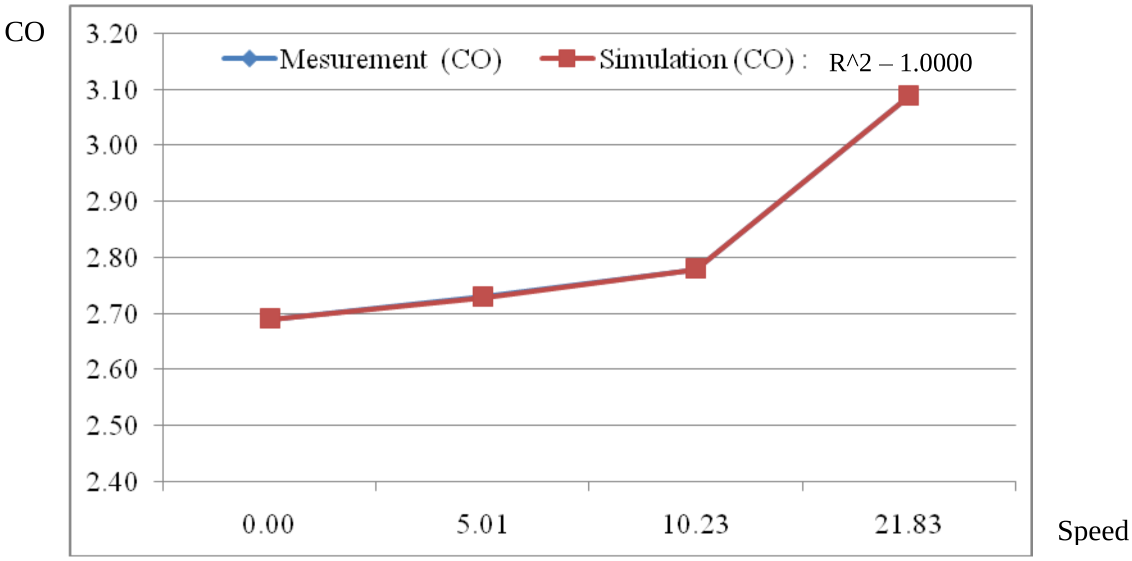


Figure 8.1 CO levels of speed < 21.83 Km/hr. by measurement compared with Simulated Model

CO based on Speed > 21.83 Km/hr.

$$CO = 2.501 + 0.02127 * Speed + 5.517e-5 * Speed\text{^}3 - 0.0009433 * Speed\text{^}2 \quad (8.2)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.0000

where Speed is Speed (Km/hr).

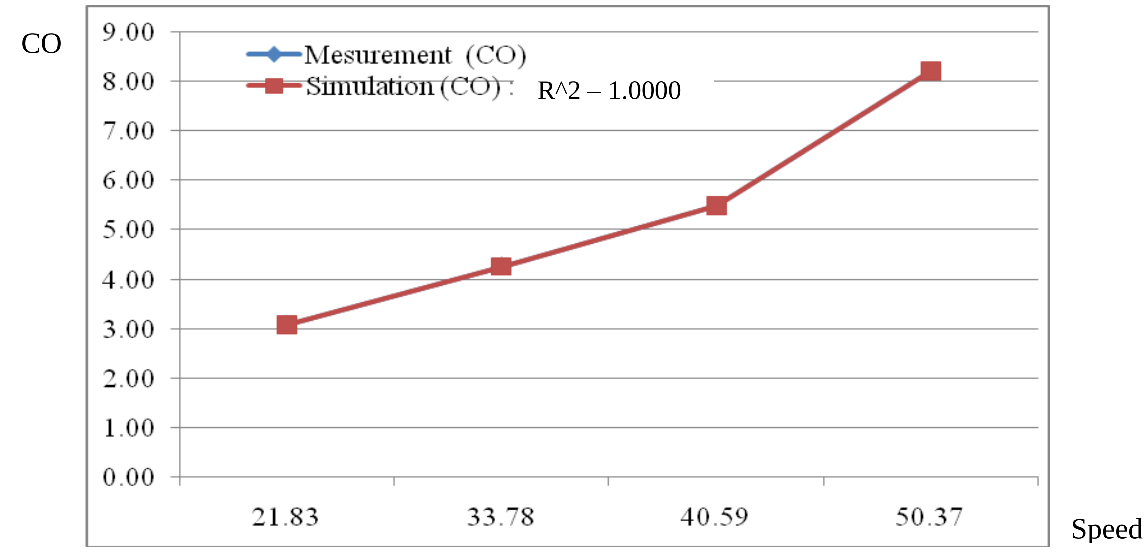


Figure 8.2 CO levels of speed > 21.83 Km/hr. by measurement compared with Simulated Model

PM_{10} Prediction

PM_{10} based on Speed <21.83 Km/hr.

$$PM_{10}(\mu g / m^3 / 24\,hr) = 17.52 + 0.008111 * (Speed\ km/hr)\text{^}2 - 0.1294 * (Speed\ km/hr) - 0.0003595 * (Speed\ km/hr)\text{^}3 \quad (8.3)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 1.0000

where Speed is Speed (Km/hr).

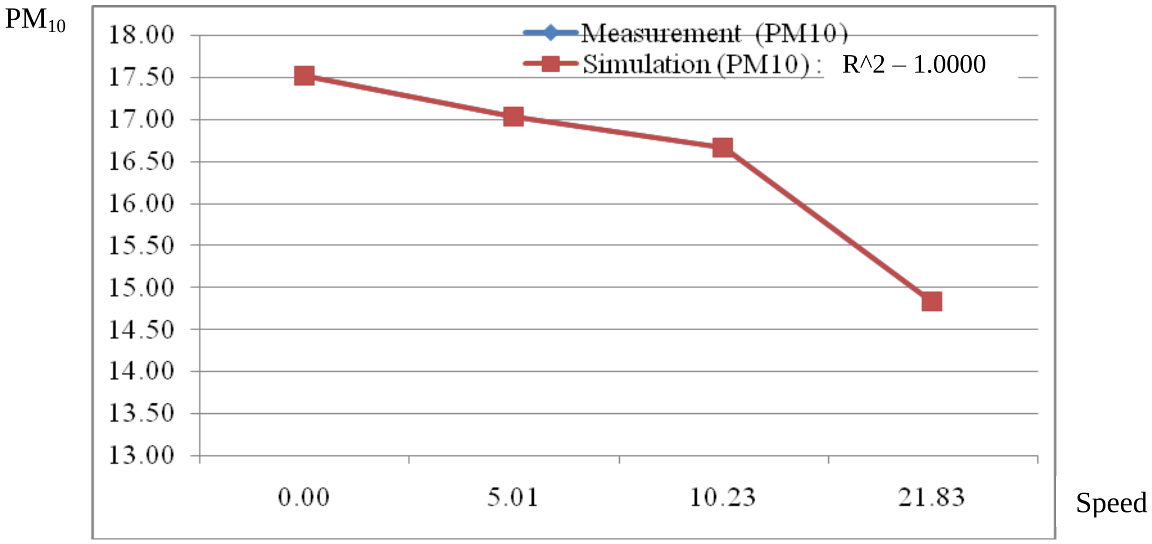


Figure 8.3 PM_{10} levels of speed < 21.83 Km/hr. by measurement compared with Simulated Model

PM$_{10}$ based on Speed >21.83 Km/hr.

$$PM_{10}(\mu g/m^3/24\,\text{hr}) = 16.62 + 0.0719*(\text{Speed km/hr}) + 0.0001543*(\text{Speed km/hr})^3 - 0.01044*(\text{Speed km/hr})^2 \quad (8.4)$$

R^2 Goodness of Fit Correlation and Correlation Coefficient = 0.9998

where Speed is Speed (Km/hr).

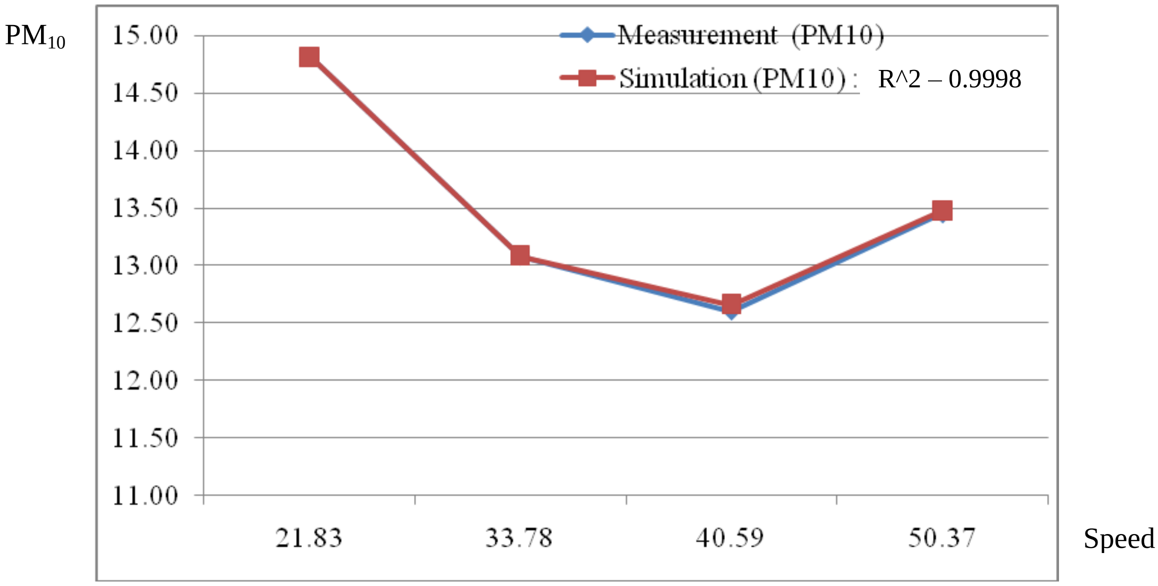


Figure 8.4 PM$_{10}$ levels of speed >21.83 Km/hr. by measurement compared with Simulated Model

Noise Prediction

Noise – L$_{10}$ (1 hr) based on Speed <21.83 Km/hr.

$$Noise\ \text{dB(A)} = 72 + 0.2631*\text{Speed} + 0.0003989*\text{Speed}^3 - 0.01069*\text{Speed}^2 \quad (8.5)$$

R^2 Goodness of fit and Correlation Coefficient = 1.0000

where Speed is Speed (Km/hr).

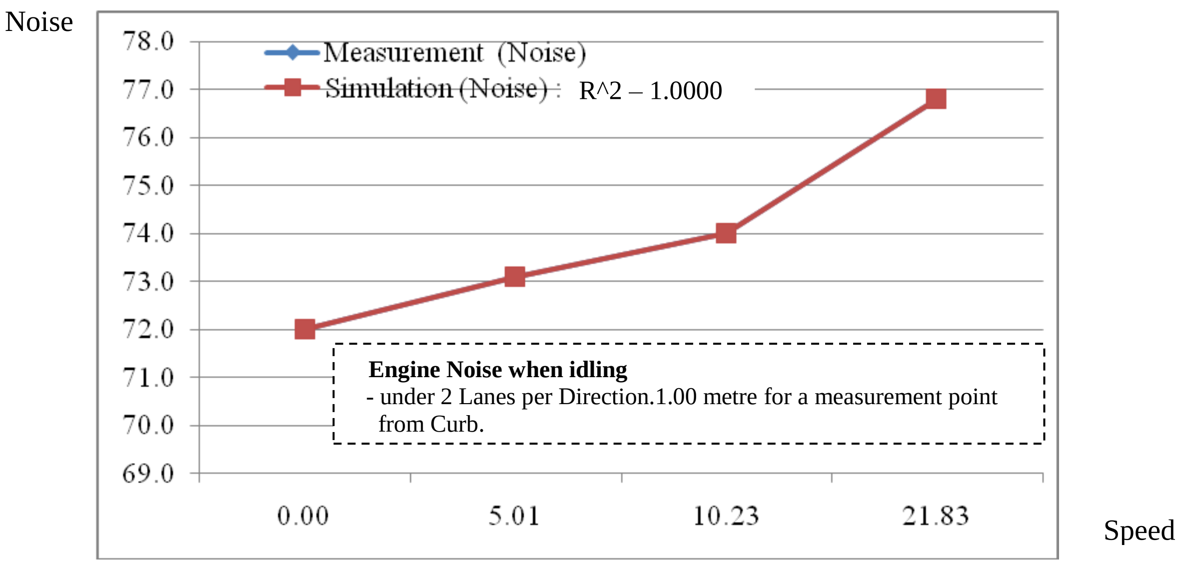


Figure 8.5 Noise L$_{10}$ levels of speed <21.83 Km/hr. by measurement compared with Simulated Model

Noise – L_{10} (1 hr) based on Speed >21.83 Km/hr.

$$Noise\ dB(A) = 104.7 + 0.04776*Speed^2 - 2.272*Speed - 4.827e-6*Speed^4 \quad (8.6)$$

R^2 Goodness of fit and Correlation Coefficient = 0.9995

where Speed is Speed (Km/hr).

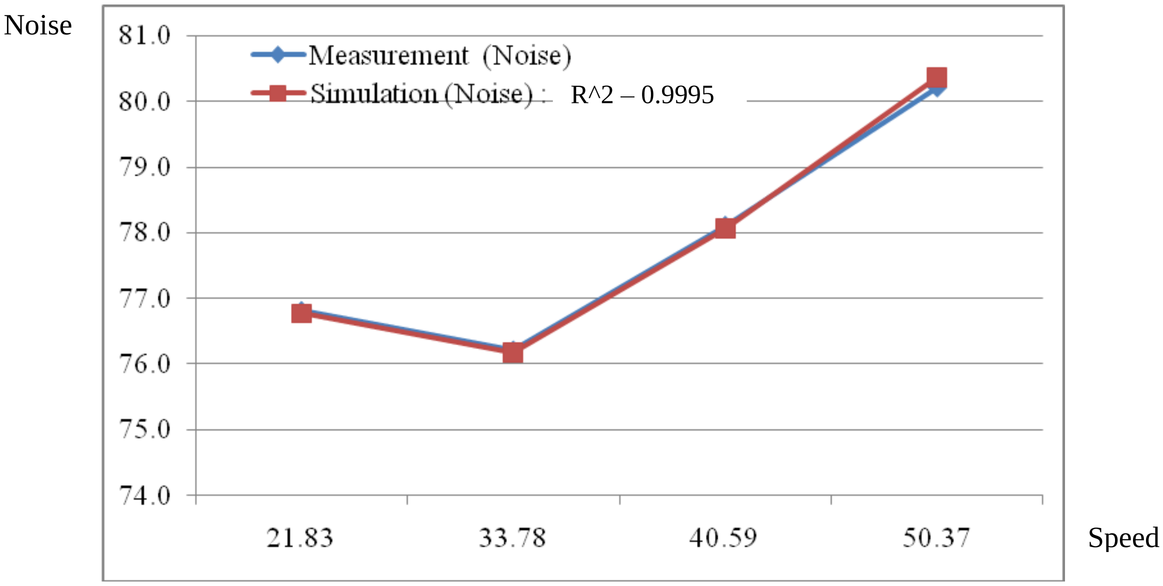


Figure 8.6 Noise L_{10} levels of speed >21.83 Km/hr. by measurement compared with Simulated Model

As can be seen in the following table, the speed has an effect on predicting CO, PM_{10} and Traffic Noise Level. Details of the results are illustrated in **Table 8.1** and **Figure 8.8, 8.9** and **8.10**.

<u>In case of CO Level</u>: the CO levels slightly increase when compared with CO levels before application of ITS Technology. This is due to the fact that emission CO levels from vehicles at intersections rise gradually from 2.69 PPM/hr. at idling time to 2.78 PPM/hr. at 10.76 km/hr. However, the CO Levels are lower than the standard of CO Level (30 PPM/hr.) in Thailand.

<u>In case of PPM Level:</u> the PPM Levels somewhat fall when compared with PPM Levels before application of ITS Technology. This is owing to the fact that emission PPM levels from vehicles at intersections decrease gradually from 17.52 mg/m^3/24h at idling time to 16.61 mg/m^3/24h at 10.76 km/hr. Moreover, the PM_{10} Levels in Nonthaburi Province are higher than the standard level (120 mg/m^3/24h) as shown in **Figure 8.7**. Therefore, the PM_{10} Levels including traffic volumes at intersection that, are measured during the idling times, still distribute at the intersection area during red times and the CO levels decrease slightly during green times owing to the velocity of wind from vehicle-movements.

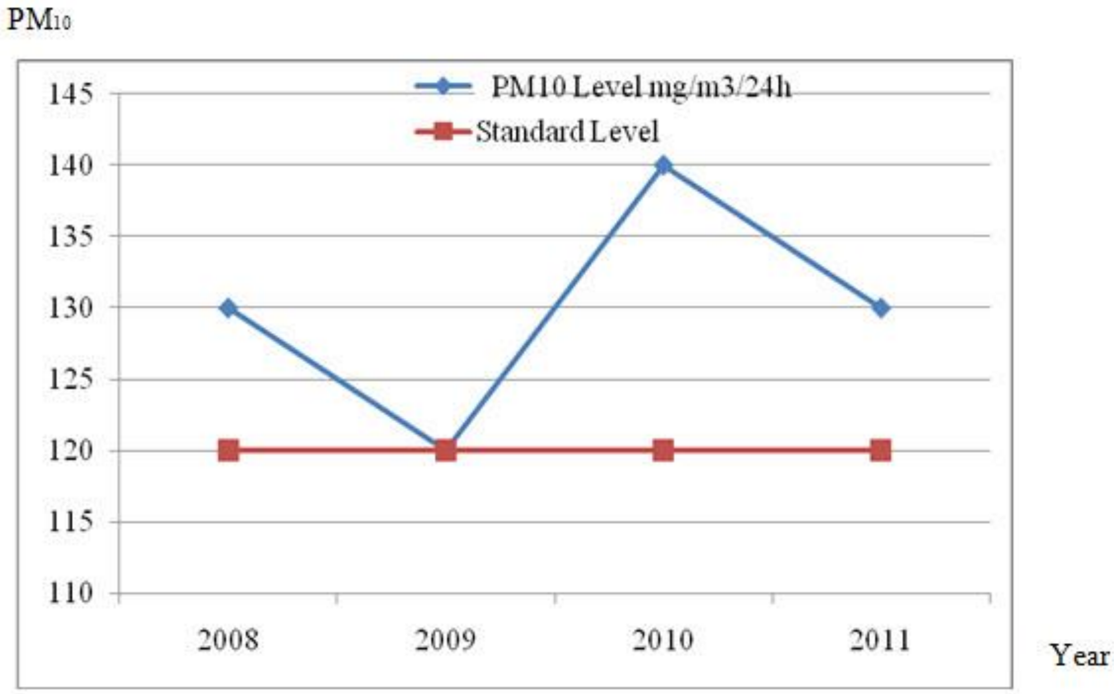


Figure 8.7 the Measurement of Noise Levels during 2008 to 2011.

In case of Noise Level: the measured noise levels during idling times (15/02/2011: 3.05 pm - 4.35 pm) that, are 72.0 dB(A), are 1 dB(A) lower than the standard noise level (73 dB(A)). Furthermore, the noise levels increase substantially during green times or acceleration time. Thus, the noise levels after application of ITS technology are higher than the noise levels before application of ITS technology.

Table 8.1 Predicting CO, PM_{10} and Traffic Noise Level based on the Average Speed

	Before Improvement	After Improvement	Before Application of ITS Technology	After Application of ITS Technology	Before Improvement	After Improvement	Before Application of ITS Technology	After Application of ITS Technology
Time	Average Speed	Average Speed	(CO)	(CO)	(PM10)	(PM10)	(Noise)	(Noise)
	Km/Hr	Km/Hr	ppm/hr	ppm/hr	mg/m^3/24hr	mg/m^3/24hr	dB(A)	dB(A)
			30 ppm/hr	30 ppm/hr	120 mg/m^3/24hr	120 mg/m^3/24hr	73.0 dB(A)	73.0 dB(A)
15:05	3.00	5.38	2.71	2.73	17.2	17.0	72.7	73.2
15:06	3.00	3.59	2.71	2.72	17.2	17.1	72.7	72.8
15:07	3.00	4.32	2.71	2.72	17.2	17.1	72.7	73.0
15:08	3.00	4.67	2.71	2.73	17.2	17.1	72.7	73.0
15:09	3.00	5.40	2.71	2.73	17.2	17.0	72.7	73.2
15:10	3.00	2.51	2.71	2.71	17.2	17.2	72.7	72.6
15:12	3.00	1.08	2.71	2.70	17.2	17.4	72.7	72.3
15:13	3.00	6.92	2.71	2.75	17.2	16.9	72.7	73.4
15:14	3.00	3.95	2.71	2.72	17.2	17.1	72.7	72.9
15:15	3.00	3.94	2.71	2.72	17.2	17.1	72.7	72.9
15:16	3.00	10.76	2.71	2.79	17.2	16.6	72.7	74.1
15:18	3.00	1.80	2.71	2.71	17.2	17.3	72.7	72.4
15:19	3.00	3.96	2.71	2.72	17.2	17.1	72.7	72.9
15:20	3.00	3.94	2.71	2.72	17.2	17.1	72.7	72.9
15:21	3.00	3.23	2.71	2.72	17.2	17.2	72.7	72.8
15:22	3.00	2.87	2.71	2.71	17.2	17.2	72.7	72.7
15:23	3.00	5.75	2.71	2.74	17.2	17.0	72.7	73.2
15:24	3.00	3.95	2.71	2.72	17.2	17.1	72.7	72.9
15:25	3.00	3.58	2.71	2.72	17.2	17.1	72.7	72.8
15:27	3.00	5.37	2.71	2.73	17.2	17.0	72.7	73.2
15:28	3.00	1.07	2.71	2.70	17.2	17.4	72.7	72.3
15:29	3.00	4.31	2.71	2.72	17.2	17.1	72.7	73.0
15:30	3.00	4.30	2.71	2.72	17.2	17.1	72.7	73.0
15:31	3.00	3.23	2.71	2.72	17.2	17.2	72.7	72.8
15:32	3.00	3.95	2.71	2.72	17.2	17.1	72.7	72.9
15:34	3.00	2.15	2.71	2.71	17.2	17.3	72.7	72.5
15:35	3.00	5.74	2.71	2.74	17.2	17.0	72.7	73.2
15:36	3.00	5.74	2.71	2.74	17.2	17.0	72.7	73.2
15:37	3.00	5.73	2.71	2.74	17.2	17.0	72.7	73.2
15:38	3.00	4.66	2.71	2.73	17.2	17.1	72.7	73.0
15:39	3.00	4.30	2.71	2.72	17.2	17.1	72.7	73.0
15:41	3.00	5.01	2.71	2.73	17.2	17.0	72.7	73.1
15:42	3.00	1.43	2.71	2.70	17.2	17.4	72.7	72.4
15:43	3.00	5.73	2.71	2.74	17.2	17.0	72.7	73.2
15:44	3.00	6.20	2.71	2.74	17.2	16.9	72.7	73.3
15:45	3.00	5.37	2.71	2.73	17.2	17.0	72.7	73.2

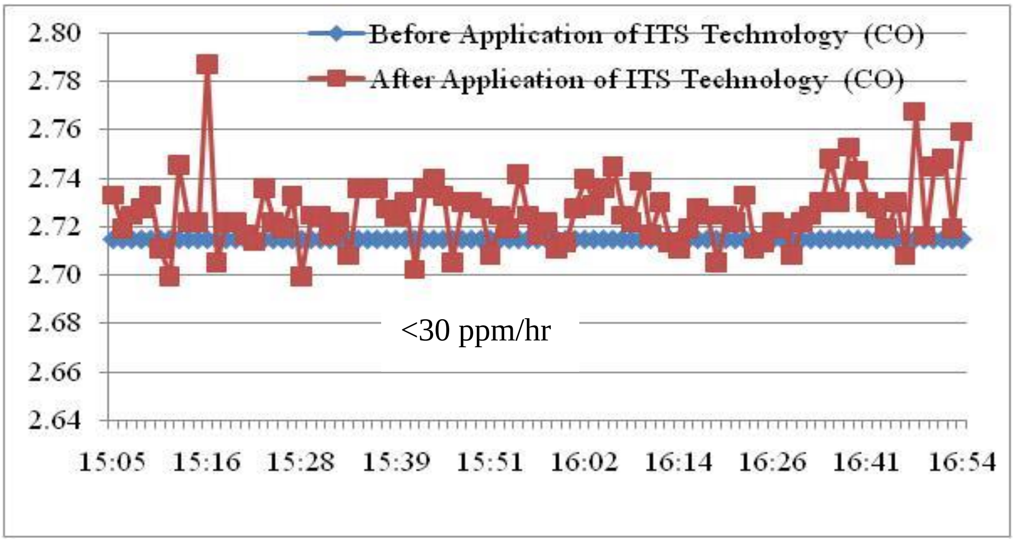


Figure 8.8 CO Levels after application ITS Technology slightly increase when compared with CO Levels before Improvement.

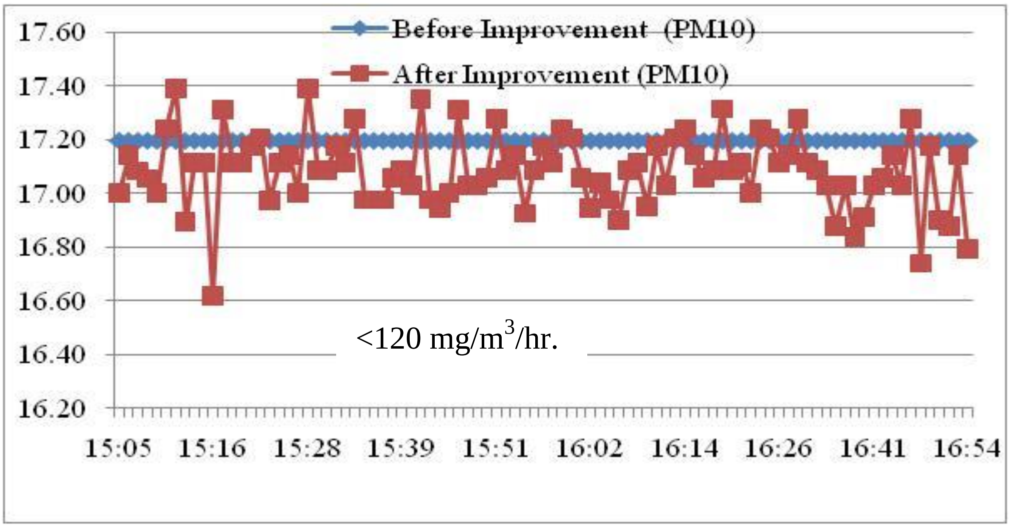


Figure 8.9 PM_{10} Levels after Improvement decrease somewhat when compared with **PM_{10}** Levels before Improvement.

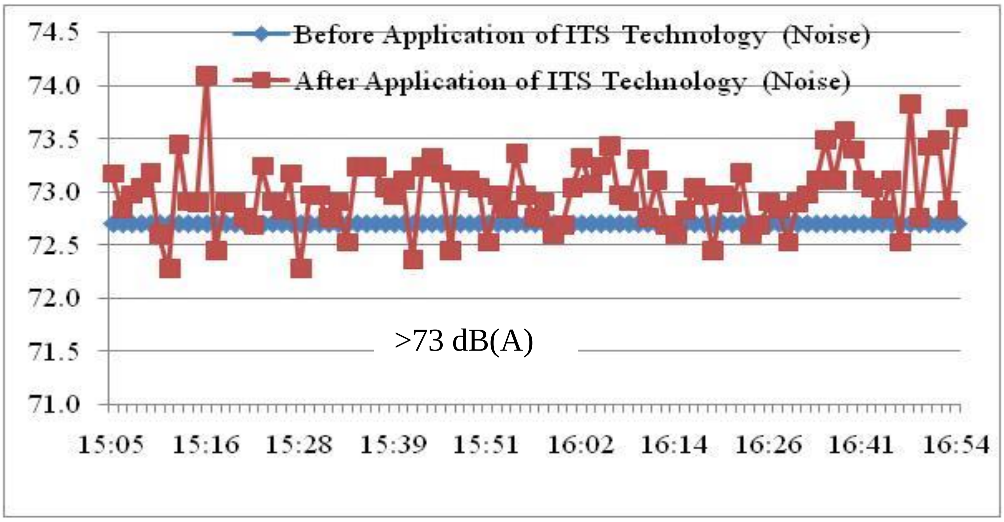


Figure 8.10 Noise Levels after application ITS Technology increase somewhat when compared with Noise Levels before Improvement.

8.2.2 Fuel Consumption Model

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.

$$F = 21.94 - 0.2699*S - 0.05226S^2 + 0.002685*S^3 - 5.401e^{-5}*S^4 + 5.069e^{-7}*S^5 - 1.843e^{-9}*S^6 \quad (8.7)$$

$$F = 19.21 + 0.1414*\max(S.65.12) - \frac{0.66}{\tanh(S - 14.64)} - \max(1.713 + \sqrt{0.1338 + S}, \min(S, 23.4) - 2.121) \quad (8.8)$$

where F is the Fuel Consumption (L/100 km), S is Speed (km/h).
The correlation coefficients for the equations are 1.00 and 1.00, respectively.

Figure 8.11 Fuel Consumption < 2.0L by Measurement compared with Simulated Model

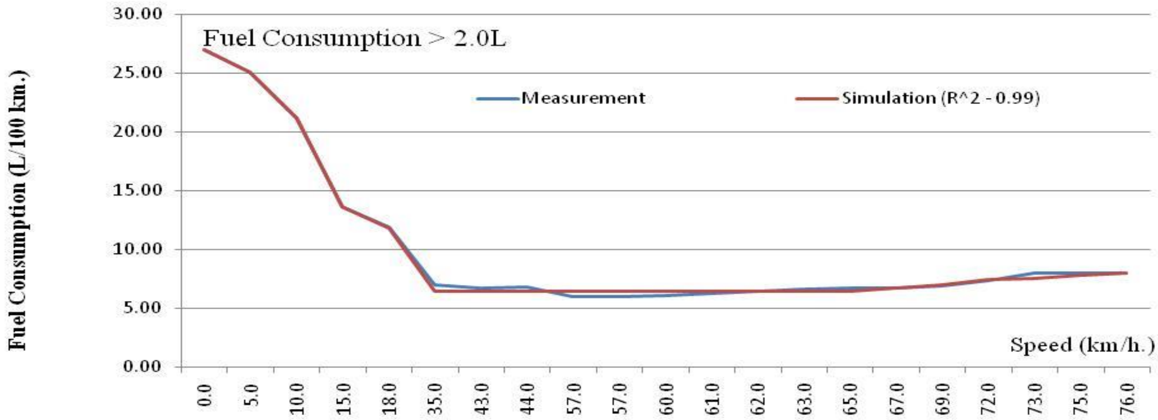


Figure 8.12 Fuel Consumption > 2.0L by Measurement compared with Simulated Model

Table 8.2 and **Figure 8.13 and 8.14** show the before and after situation of fuel consumption for passenger car of <2,000 cc and >2,000 cc.

Table 8.2 Comparison of Fuel Consumption before-and-after Traffic Improvement (15/02/2011: 3.05 pm - 4.35 pm).

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

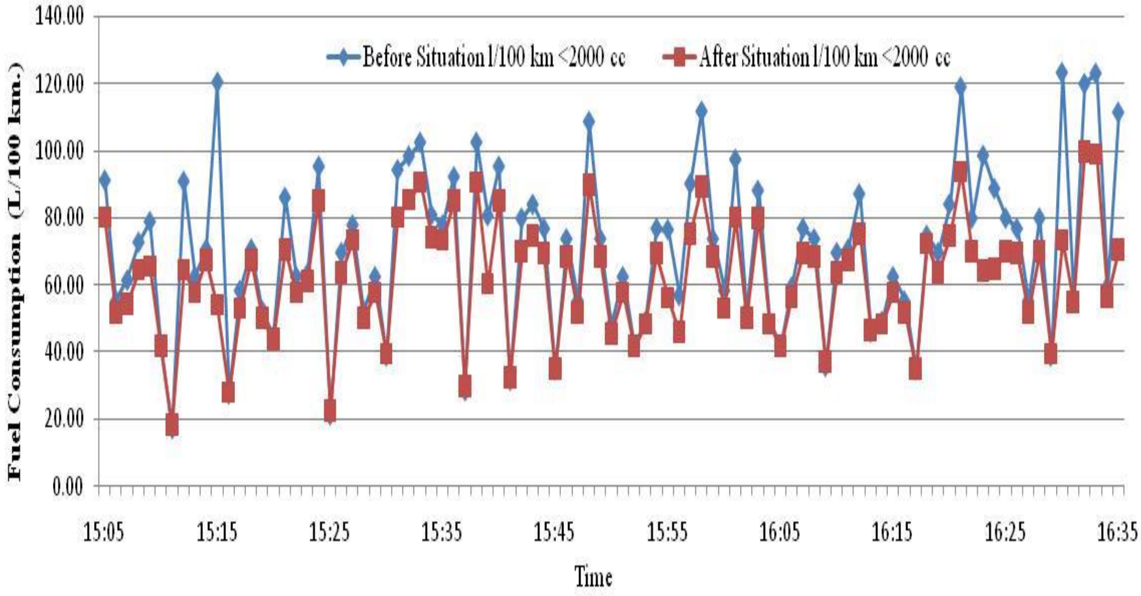


Figure 8.13 Comparison of Fuel Consumption (< 2000 cc) Before and After Traffic Improvement.

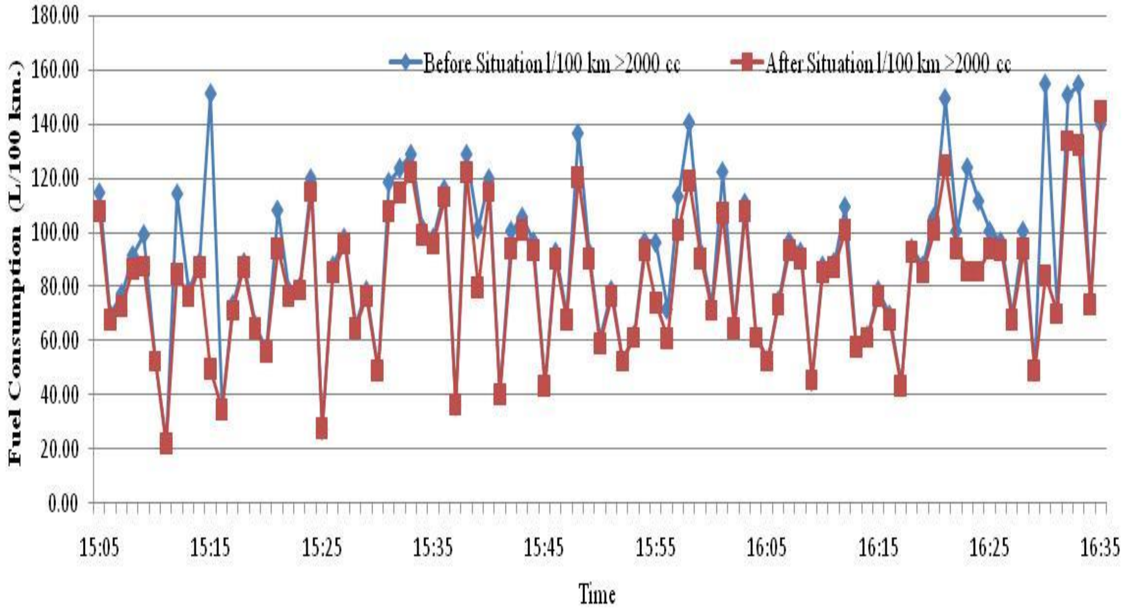


Figure 8.14 Comparison of Fuel Consumption (> 2000 cc) Before and After Traffic Improvement.

From **Table 8.2, Figure 8.13** and **8.14**, the fuel consumption levels of Passenger Car with capacity > 2,000 cc and <2,000 cc show significant reduction after the ITS improvement. 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.

8.3 RESULTS OF EVALUATION

8.3.1 The calculation of traffic noise and air pollution.

The calculation was based on the Transport and Road Research Laboratory and the Department of Transport (UK Department of Transport - Welsh Office, 1988). Furthermore, the results of the noise emission model as followed by the concepts of Cheewapattananuwong and Samuels (1996) are taken into consideration. The results of traffic noise and air pollution are compared with the measurement data and the compared results are nearly closed values. As a result, these lead to the predicted noise at the **Table 8.1**. In case of the standard noise level, 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).

8.3.2 The petrol price list and the composition of vehicles by types of fuel

The evaluation of collected data of the prices list of petrol from July 2011 to June 2012 is added to the composition of vehicles by types of fuel consumption in Thailand (Ministry of Energy, 2012) as illustrated in **Table 8.3 and 8.4**.

Table 8.3 the prices list of petrol from July 2011 to June 2012

Month	Gasohol E10 Octane 91	Gasohol E10 Octane 95	Gsohol E20	Gsohol E85	Benzyl Octane 91	Benzyl Octane 95	Diesel HSD	LPG	NGV
Jul-11	35.62	38.12	34.68	22.52	42.41	48.37	29.99	18.13	8.50
Aug-11	34.55	37.07	33.05	21.95	43.02	46.24	29.51	18.13	8.50
Sep-11	33.29	36.31	32.08	21.82	36.31	40.22	28.06	18.13	8.50
Oct-11	32.94	35.97	31.94	21.68	35.97	39.95	28.83	18.13	8.50
Nov-11	32.23	34.11	31.23	21.18	35.26	39.43	28.92	18.13	8.50
Dec-11	31.66	33.41	30.66	20.78	34.69	38.83	29.12	18.13	8.50
Jan-12	34.59	36.34	33.59	22.02	37.62	41.65	30.45	18.13	8.50
Feb-12	36.77	38.52	35.77	22.85	39.80	43.81	31.31	18.13	8.50
Mar-12	38.27	40.02	37.27	23.87	41.85	45.82	32.12	18.13	8.50
Apr-12	38.58	40.33	37.58	23.98	43.21	47.16	31.99	18.13	8.50
May-12	36.66	38.41	35.50	22.73	41.91	45.86	30.51	18.13	8.50
Jun-12	35.23	36.98	33.83	21.53	40.87	44.82	29.65	18.13	8.50
Average	**35.03**	**37.13**	**33.93**	**22.24**	**39.41**	**43.51**	**30.04**	**18.13**	**8.50**
								12 B/Litre	**3.5** B/Litre

Source: Ministry of Energy (2012)

Table 8.4 the equivalent fuel prices for PC < 2.0L and >2.0L

Vehicle Types	Gasohol E10 Octane 91	Gasohol E10 Octane 95	Gsohol E20	Gsohol E85	Benzyl Octane 91	Benzyl Octane 95	Diesel HSD	LPG	NGV	Average Prices B/Litre
PC (<7 PAX) < 2000 cc	16.1	18.39	1.92	0.08	26.65	0.36	0	12.47	24.03	**26.14**
Van (>7 PAX) > 2000 cc	6.81	7.78	0.81	0.03	11.28	0.15	57.68	5.29	10.17	28.38
Pickup (4 wheels) > 2000 cc							78.87	7.22	13.91	25.04
										26.71

Source: Ministry of Energy (2012)

Therefore, The equivalent fuel prices are two types; 26.14 Baht/Litre for PC (4 wheels < 2.0 L) and 26.71 Baht/Litre for PC (4 wheels > 2.0 L).

8.3.3 The Comparison of Fuel Consumption between before and after situation

A number of fuel price lists have been collected between July 2011 and June 2012. The equivalent of fuel prices of 4 wheels < 2.0 L and > 2.0 L are 26.14 Baht/Litre and 26.71 Baht/Litre, respectively. The saving of fuel consumption between before and after situations is presented in **Table 8.5**.

Table 8.5 Comparison of fuel consumption per PCU between before and after Situations.

Details of Fuel Consumption	Before		After	
Total Fuel Consumption	4,215.39	L/100KM	2,288.01	L/100KM
Total Cost	111,517.77	B/100 KM	108,371.42	B/100 KM

As can be seen from **Table 8.5**, the total fuel consumption (L/100 KM) during 3:05 pm – 4:35 pm or during peak hour compared between before and after improvement of traffic situations at the intersections are 4,251.39 L/ 100 KM and 2,288.01 L/ 100 KM, respectively. Therefore, the cost of fuel consumption decrease substantially due to the fact that the traffic signal synchronization can save the driver’s cost about 3,146.35 Thai Baht/ 100 KM within 90 minutes.

Chapter

9

CONCLUSIONS

9.1 RESEARCH CONTRIBUTIONS

9.1.1 Road Conditions

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 author 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 researcher has developed and tested the ITS technology system:

- TCC – More accurate counting for TUK-TUKS and SAMLAW and 2 PTZ cameras per an intersection.
- ADTS – More accurate ticker and headway within 5 seconds by VLD and to promptly remedy by Minute Based Assessment
- LCSW – More Real Time Warning Message on VMS and Double Counting of Speeding and Predicting SSD by V_f (Final Speed).

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. Moreover, an innovative card and developed software completely applied for the traffic controllers have been perfectly operated more than 3 years.

Since congestion and accidents at intersections are serious problems in suburban Bangkok, the DRR has studied the causes in order to find the most effective solution. The study found that the main causes of the problems were deficient equipment, red light running and drunk driving. Several policies were formulated to remedy the situation. Therefore, the complete installation of traffic changing and over speed model, VMS and new software were taken into account.

Among these, the installation of an adaptive traffic VMS, and new software has proved to be highly effective. After the system installation, the over speed and lane changing has improved significantly especially the number of accidents at the intersection also shows decreasing trend, even though the period of data collection is still short (within 60 minutes). It is seen from the collected data that there was no accident from lane changing and over speed running, but one from drunk driving in 2011. In case of drunk driving, the researcher has contacted the traffic police so as to set up a mobile checking point police station. The researcher is convinced that the number of drunk- driving accidents decrease drastically. Consequently, the life of Thai drivers will be safe and their property will not be damaged from the traffic situation at the intersection.

The application of the model has enabled the reduction in the number of crashes; in particular, speeding and lane changing crashes decreased substantially in 2011. The application of speeding and lane changing image sensing concepts enables the sending of signal to the VMS. On the VMS, there are three types of warning messages: 'PLEASE REDUCE SPEED', 'PLEASE KEEP TO YOUR LANE', and 'NOT KEEPING TO THE LANE INCUR 500 BAHT FINE'. When there was no warning message on the VMS, the number of Lane Changing and speeding vehicles were 47 and 192 per hour respectively. It was found that the warning message announcement "Fine 500 Baht" has been effective in reducing the number of lane changing and speeding vehicles down to 20 and 118 per hour.

9.1.2 Traffic Situations

The installation of an adaptive traffic signalization system, equipment, and new software has proved to be highly effective. After the system installation (measured on Tuesday, 15/02/2011: 3.05 pm - 4.35 pm), vehicle delays in terms of long queue lengths has improved significantly from 987.3 meters under the fixed time control to 155 meters with the adaptive control or the decreased queue length on main and minor road are 100 and 97 percent, respectively. Moreover, delays on main and minor road decrease 94 and 93 percent and the decreased green times is not used 69 percent on main road.

The researchers will further refine the lane changing model to effectively deal with the speed and prohibit the lane changing by the use of ITS technology. The life of Thai drivers will be safer and their property will also be safer due to a reduction in the number of traffic violations occurring at the intersections. In addition, the decreased lane changing on main road (measured on Friday, 11/02/2011: 4.30 pm – 5.30 pm) is 62.45 percent and the decreased speeding on main road is also 38.34 percent.

9.1.3 Traffic Accidents

After installed ITS Systems, a number of accidents, especially RLR during 2009 to 2010 decreased substantially (from 8 to 3 road crashes and referred to in Figure 6.5). It is seen from data collected so far during 2009 to 2011 (January to June) that there was no accident from red light running, but three from drunk driving and two from speeding to change lane. In other words, a number of traffic accidents reduce from 11 to 1. The increasing trend of accidents caused by drivers' speeding to change lane and using mobile phone while driving have emerged as an important traffic problem. After the finished and applied Controlled Speed and Lane Changing Software at the CCTVs, the number of accidents as focused on the drivers' speeding to change lane fell dramatically (from 3 to 0 road crashes). However, the researcher has finished work on the tracking of Vehicle Lane Changing and done further work on the use of ITS Technology to detect speed and monitor drivers' use of mobile phone while driving. Implementing the technology to deter the use of mobile phone while driving is ongoing.

9.1.4 Traffic Pollution

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 Noise Levels before and after application of the technology were conducted. Real Time and Minute Base Assessment of Traffic Pollution show that the technology has had a positive impact in reducing the adverse effects of congestion.

In case of the average CO Levels, the levels slightly increase. This is owing to the fact that the CO emission starts from 2.69 ppm/hr at idling situation and the measured speeds during 3.05 pm to 3.45 pm on Tuesday, 15 February 2011 are between 1.07 to 10.76 km/h. This leads to the CO levels, which are changed between 2.70 to 2.79 ppm/hr, increase 0.39 percent after application ITS technology. However, they are lower than the standard of CO Level (30 pm/hr).

In case of the average PM_{10} Levels, the levels decrease somewhat. This is owing to the fact that the PM_{10} emission starts from 17.52 mg/m^3/24h at idling situation and the PM_{10} levels, which are changed between 17.39 and 16.62 mg/m^3/24h, decrease 0.60 percent after application ITS technology. Moreover, they are lower than the standard of PM_{10} Level (120 mg/m^3/24h).

In case of Noise Levels, the levels increase slightly. This is owing to the fact that the Noise emission starts from 72.0 dB(A) at idling situation and the Noise levels, which are changed between 72.3 and 74.1 dB(A), increase 0.35 percent after application ITS technology. However, they are slightly higher than the standard of Noise L_{10} Level (73 dB(A)).

In addition, the researcher has 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.

9.1.5 Fuel Consumption

In case of fuel consumption (measured on Tuesday, 15/02/2011: 3.05 pm - 4.35 pm), the percentage of fuel consumption between before and after situation decreased substantially. For example, the engine > 2000 cc and < 2000 cc are 8.048 and 12.736 percent respectively. In addition, the measurement of fuel consumption before improvement is 4,251.39 L/ 100 KM and the fuel consumption after improvement is 2,288.01 L/ 100 KM. Therefore, the traffic signal synchronization can save the driver's cost about 3,146.35 Thai Baht/ 100 KM within 90 minutes.

9.2 RECOMMENDATIONS FOR FUTURE RESEARCH

The two recommendations for future study will be focused on the use of CCTVs of high quality. The first is the drivers' use of mobile phones while driving must be monitored by the Image Sensing Cameras. Normally, Thai drivers prefer to call when driving due to tradition and the trend has increased substantially. If the road authorities especially Department of Rural Road (DRR) do not control traffic law strictly, the number traffic accidents will rise or increase dramatically. The second recommendation is to implement a new, innovative from transparent screen to warn drivers in order to alert and stop the illegal driving behaviour. The transparent screen is the application of a virtual water screen crossing the road, including the use of a laser or some appropriate wave at the sight line of drivers. The researcher hopes that the further study of new technology will be useful for the people who operate vehicles in Asia.

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APPENDIX

A. PSEUDO CODE

1. Classified Count

The classified traffic counting uses the trial and error method so as to adjust the accurate sizes of each vehicle as illustrated about the pseudo code in **Figure a.1**, **a.2**, and **a.3**. It takes more time to tune the angle of the camera and to focus the lens.

```
Function Extract Car Border In Frame(INPUT IMAGE FG Image)
{
        PARAMETER  P;
        INTEGER    Gap Column ← 0;
        INTEGER    Blank Column ← 0;
        STATE      Current State ← Road;
        LIST       Border List;
        Noise Reduction(FG Image);
        FOR(x = 1 TO P→Window Width) {V Histogram ← Count FG(x);IF(V Histogram >= P→FG  Threshold) {
IF(Current State = Road) {Gap Column ← 1;Start Car = x;}
    ELSE IF(Current State = Car) {Gap Column ← Gap Column + 1;}}
    ELSE {Gap Column ← 0;
IF(Current State = Car) {Blank Column ← Blank Column + 1;
IF(Blank Column > P→Min Gap) {Add Border To List (Border List , Start Car, x-Blank Column);
Blank Column ← 0;}}}}
    RETURN Border List;}
```

Figure a.1 the finding function of the boundary vehicles in one frame

```
Function Car Count(INPUT IMAGE FG Image)
{
    STATIC IMAGE Previous Image;
    IF(Previous Image = NULL) {Previous Image = FG Image; RETURN NULL;}
    LIST   BList = Extract Car Border In Frame(FG Image);
    LIST   AList = Extract Car Border In Frame(Previous Image);
    Car List = Detect Change(AList, BList);
    RETURN Car List;
}
```

Figure a.2 the finding function of the boundary – vehicles in normal case

```
Function Car Classify(INPUT LIST Car List)
{
    PARAMETER  P;
    Avg Car Width ← Find Average Car Width(Car List, P→Number Of Car Stat);
    SD Car ← Find SD Car(Car List, P→Number Of Car Stat);
    FOR EACH Car in Car List {Classify Car(Car→Count, Car→Width, Car→Height,
P→Threesholds,AvgCarWidth, SD Car);}}
```

Figure a.3 the function of classified count of vehicles

2. Traffic Synchronization

From **Figure a.4**, it can clearly be seen that the movements at the T intersection are in 6 directions, 2 movements of left turn directions are free flow. There are 2 sensors which detect vehicles when passing the Virtual Loops and send the signalized data to traffic controller. In case of the 4 Leg intersection, there are 10 directions and two of them are left turn-free flow or un-prohibited. Moreover, there are also two sensors so as to detect vehicles and send the data to another traffic controller. In addition, the Normal Phase Algorithm is presented in **Figure a.5** and pseudo code.

<u>Normal Phase Algorithm</u>

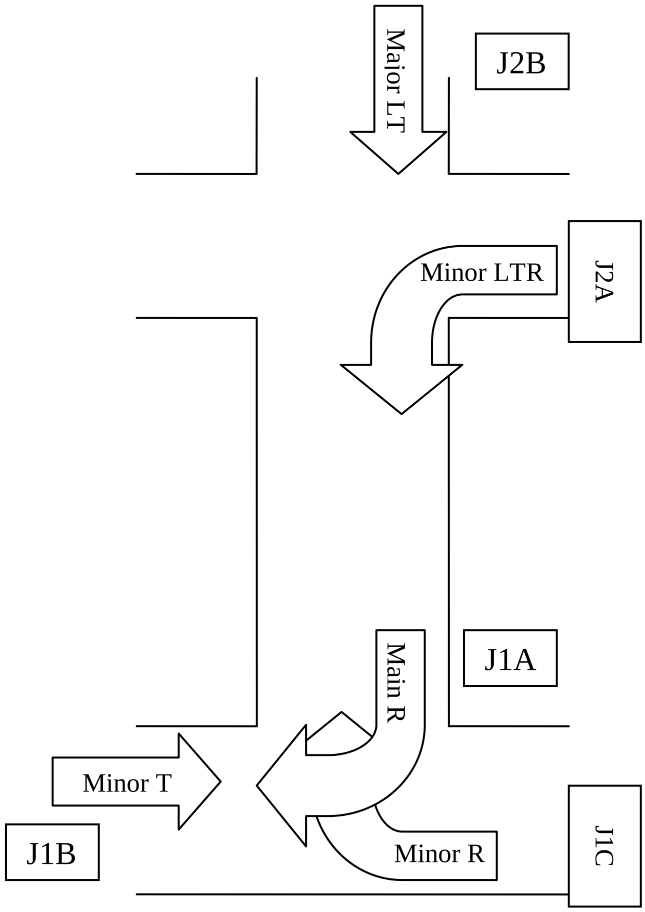

Figure a.4 Algorithm of Phases as based on sensors

```
Function TrafficPhaseJ1()
 Start All Red
Start Phase J1-A   For 67 Seconds (from SIDRA and Synchro)
 If No Car Detect At J1-A in 5 Seconds (headways) Then
        Stop Phase J1-A
 End If
 Continue Phase J1-B 20 - 50 Seconds (from SIDRA and Synchro)
 Continue Phase J1-C For varies 20 - 35 Seconds (from SIDRA and
Synchro)
 If No Car Detect At J1C in 5 Seconds (headways) then
        Restart Phase At J1
 End If

 Function TrafficPhaseJ2()
        Start All Red
 Start Phase J2-B   For 65 Seconds (from SIDRA and Synchro)
        If No Car Detect At J2-B in 5 Seconds (headways) Then
                Stop Phase J2-B
        End If
        Start Phase J2-A For 27 Seconds (from SIDRA and Synchro)
        If No Car Detect At J2-A in 5 Seconds (headways) Then
                Stop Phase J2-A
        End If
        Restart Phase At J2
```

Figure a.5 Algorithm of Phases as based on sensors

From the above Figure, there are 3 phases at T intersection and cycle times vary based on the traffic volumes at the period times. During peak hour, headways of vehicles pass through the Virtual Loop within 5 seconds and the characteristic of traffic flow is steady state/steady flow, therefore the cycle times will be extended up to maximum green times of J1-A,B, and C (from calculation of SIDRA and Synchro). In case of 4 Leg intersection, phases of J2-A and B are also the same as the J1A, B, and C's concepts.

Additional Algorithm (Offset or Green Wave Concept)

The offset times phase or Green Wave Phase will be proposed for the vehicles that pass 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 **Figure a.6** shows the algorithm of Green Wave Phase and Offset Times.

```
Function TriggerFromJ1C(Input: TriggeredTime)
        Stop MinorR and continue normal operation at J1
        If At TriggeredTime + 27 MajorLT is RED then
                Stop MinorLTR
                Release MajorLT
        End If
Function TriggerFromJ2A(Input: TriggeredTime)
        Stop MinorLTR
        Release MajorLT
        If At TriggeredTime+28 MinorR = GREEN Or MinorT = GREEN Then
                Restart phase at J1
        Else
        Increase time of MainR field calibration (0.5 -0.6 -0.8)*(Green Time of MajorLT) + 34
        End If
```

Figure a.6 Algorithm of Green Wave Phases as based on sensors

It is described from **Figure a.6** that the offset times as mentioned before are calculated based on the method of Australian Road Research Board (ARRB) (ARR123, 1989). In case of J2-B and J2-A to J1-A direction, 34 seconds of offset times will be taken into consideration and it will be minus with the amber and all red times (7 seconds). Therefore, 27 seconds of offset times will be proposed for the Green Wave Phase. In case of 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). Furthermore, the increment times of J1-A phase is during 0.5 to 0.8 times of green times of J2-B phase based on traffic volumes and calibration of filed data.

3. Lane Changing and Speeding

Normally, the application of tracking objects is used in the Blob Tracking Techniques as mention before. The separated objects are extracted from the background VDO. Moreover, the continuing objects must be checked and rechecked by only one piece of tracking in the same size. Otherwise, the object will be cut into another piece or another vehicle. **Figure a.7** shows the Pseudo Code of the tracking system.

```
Function Car Lane Changing (Input Frame From VDO)
 {
BG Model 🡐 Create Background Model;
While(Termination condition is not met)
{
Current Frame 🡐 Retrieve a frame from VDO;
Update Background Model(Current Frame, BG Model);
Foreground Image🡐 Retrieve Foreground Image(BG Model);
Object List 🡐 Object Segmentation(Foreground Image);
Car List 🡐 Detect Car List(Object List);
Lane Changing  Car(Car List);
}
}
```

Figure a.7 The system of tracking of each object

The Blob Tracking Techniques, the process of the Dynamic Time Warping, and K-Nearest Neighbors method are taken into consideration. The objects of the location in 2 dimensions (x and y axis) data are changed into the time series data by the chosen points of times. In addition, the parameter of lane width, speed limit, gap of vehicles, and the Virtual Loop or tracking block will be illustrated in **Figures a.8 –a.10**.

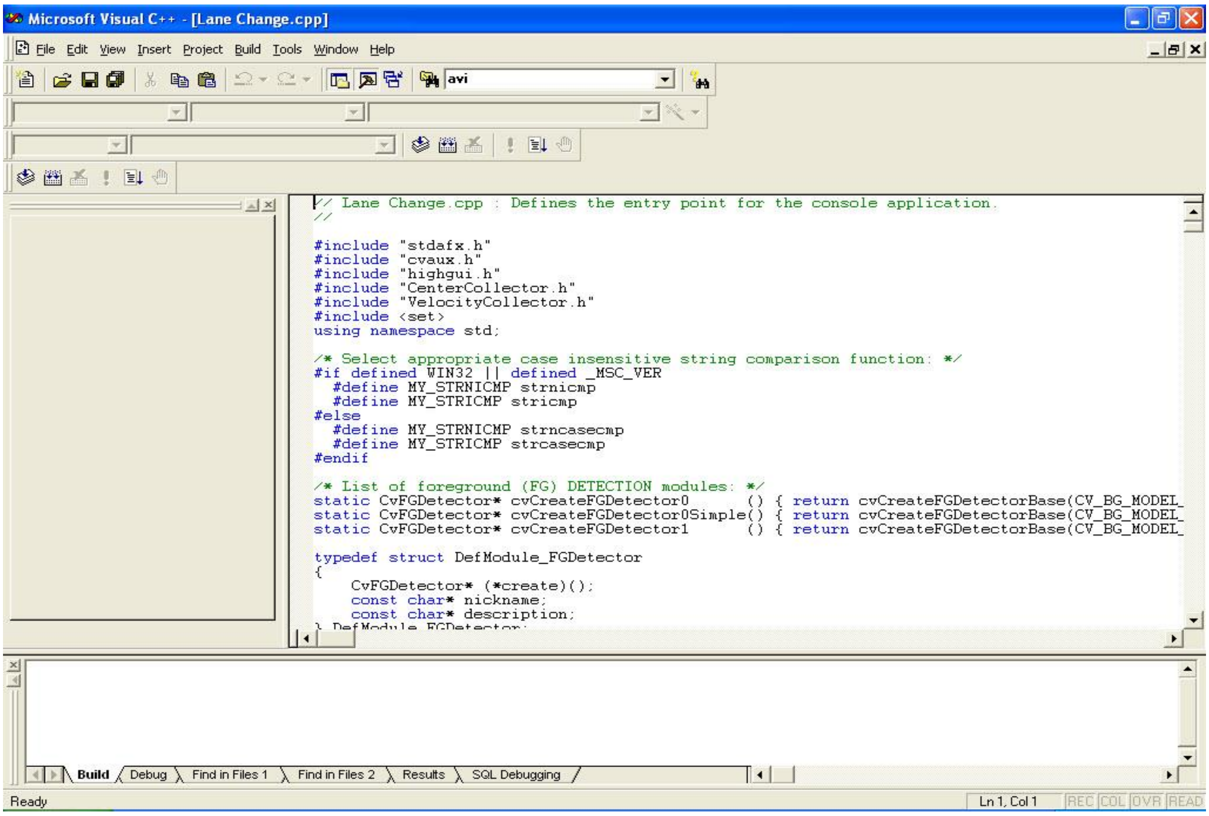

Figure a.8 the collected data in the parameters

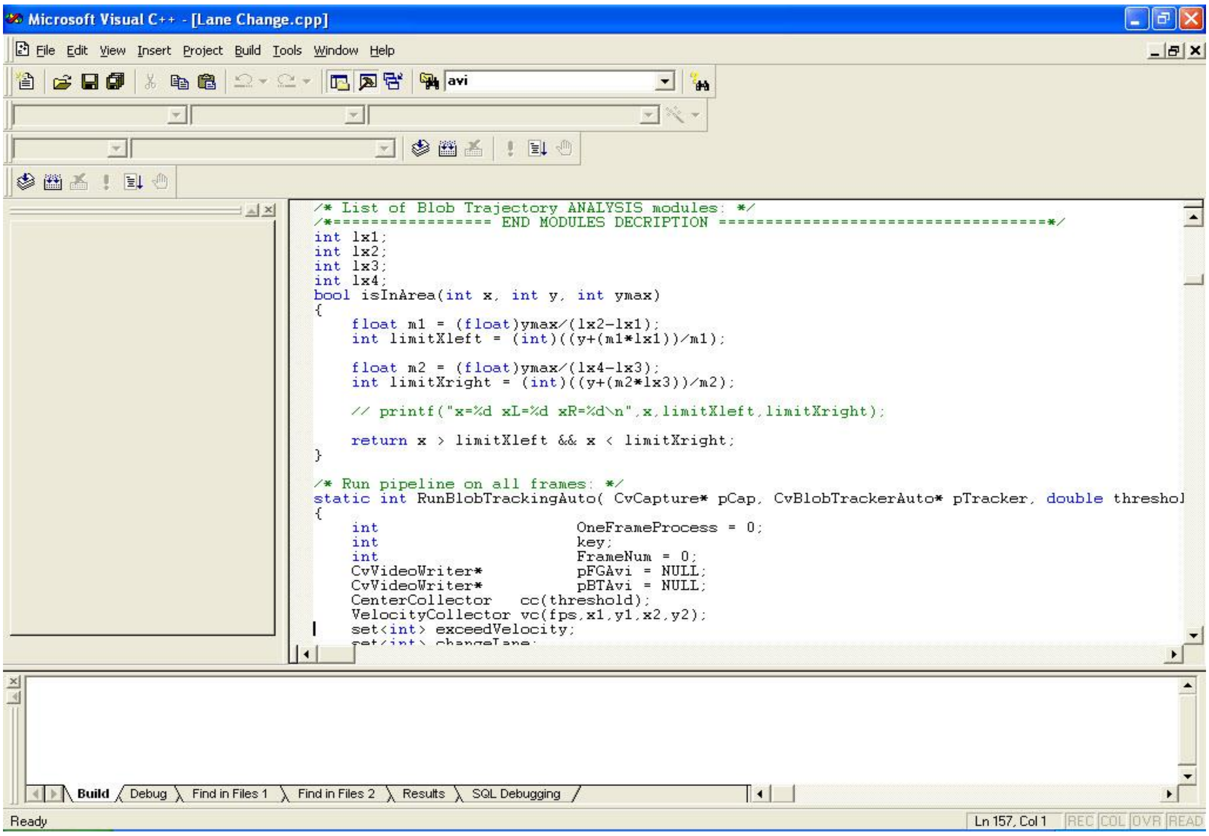

Figure a.9 the threshold of tracking block or virtual block

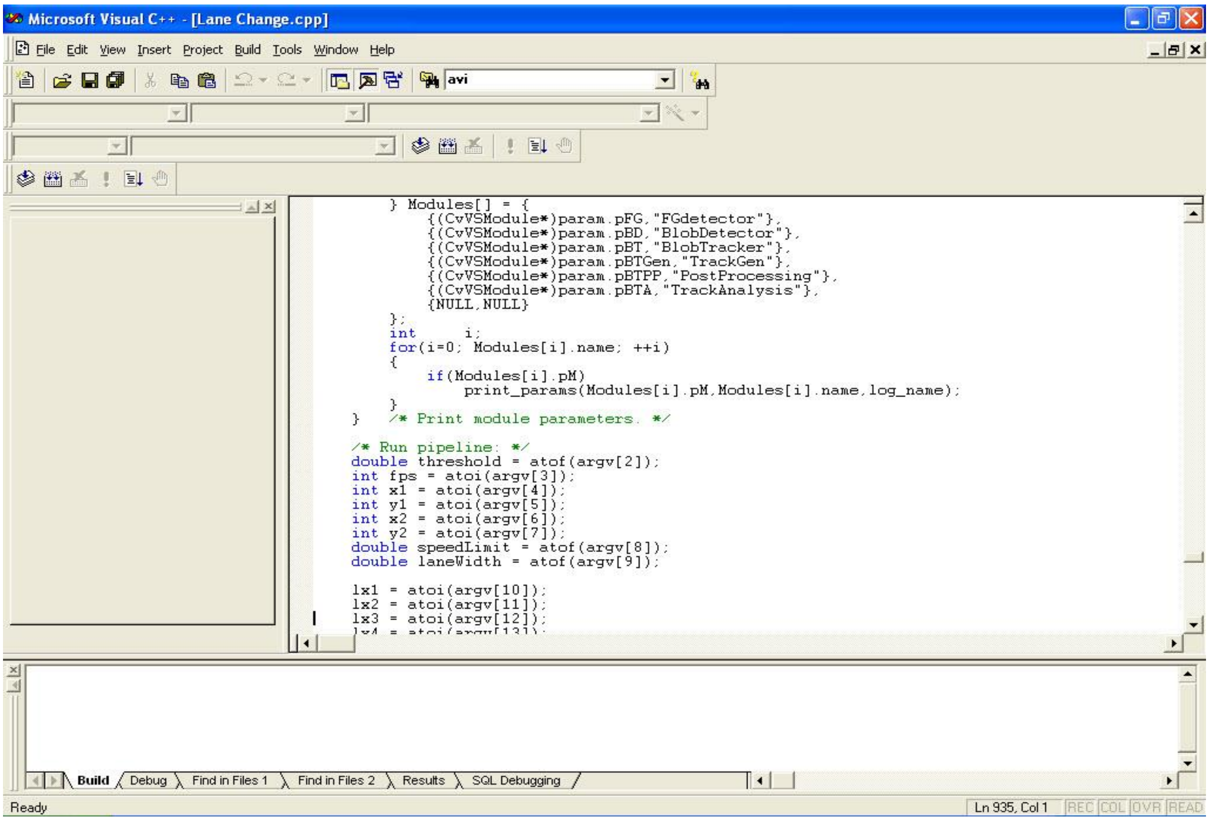

Figure a.10 the coding of lane width, speed limit, and gap of vehicles