TRAFFIC STATE ANALYSIS OF EXPRESSWAYS IN BANGKOK URBAN AREA USING WEB-BASED DATA

BY

CHHIVHOUT SOR

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

THAMMASAT UNIVERSITY

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A Thesis Presented

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Approved as to style and content by

Advisor and Chairperson of Thesis Committee ______________________

(Assoc. Prof. Mongkut Piantanakulchai, Ph.D.)

Committee Member and
Chairperson of Examination Committee ______________________

(Assoc. Prof. Chawalit Jeenanunta, Ph.D.)

Committee Member ______________________

(Dr. Sornthep Vannarat, Ph.D.)

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Abstract

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by

CHHIVHOUT SOR

Bachelor of Civil Engineering, Institute of Technology of Cambodia, 2014
Master of Science (Engineering and Technology), SIIT, Thammasat University, 2015

Traffic state is a key to measure and indicate traffic conditions on the road network. Traffic state plays an important function for Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS). In this thesis, traffic state data collection method is presented and online mapping services is the data source. The study aims to apply those traffic state data to define traffic patterns and congestion patterns and detect traffic anomaly and measure the degree of the abnormal traffic on the expressway system in Bangkok urban area in Thailand. A practice of severe traffic congestion detection is proposed. The concept of severe traffic congestion detection is used to verify that traffic anomaly really occurred and to neglect any small anomalous that is fluctuated on the road network. Results of the analysis show that normally the congestion patterns occur during peak hours from 7:00 am to 10:00 am and from 6:00 pm to 8:00 pm on normal working days. Based on Bayesian probability, the accuracy of the traffic state prediction is up to 86.36% and 80.34% for 24 hours and 15 hours (from 6:00 am to 9:00 pm) respectively. The rest of the incorrected predicted are assumed as the abnormal traffic. In conclusion, the proposed method to define traffic congestion patterns, predict traffic state, and to detect traffic anomaly can be applied to any area where the sufficient of traffic data are available.

Keywords: Traffic Congestion patterns, Traffic anomaly, Degree of traffic anomaly.

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Chapter 1

Introduction

1.1 General

Transportation is a major functional systems for providing a service to move things or people from one to another location. In developing countries, transportation system plays a very important role to the society for both economic and personal lives. Advances in transportation have changed the way people live and the way societies are organized. For these reasons, transportation is a major role in the field of developing the society and the quality of life. The main concept of transportation is to provide the efficient technique of moving people and goods from places to places rapidly, conveniently, comfortably, and economically. According to the history of transportation over the past 200 years have shown that the transportation modes have been developed including waterways, railways, highway, and even airway. Therefore, engineers who are knowledgeable in the concepts of transportation demand and management and also integrate land use and traffic management are needed for the society and economy in order to develop the new strategies of planning and management in the area of transportation. Obviously, highway engineers must take into account for the future traffic flow, intersections, structural design of pavement thickness, and pavement maintenance when they design road, traffic light, or manage any other public transportation.

Taking account on traffic management, traffic or highway engineers play the important role in the development of transportation system since their work is associated with the planning, monitoring, geometric design and traffic operation of roads. They must understand the interaction between driver's characteristics, vehicles and the roadway, so that people and goods be able to move safely and efficiently. However, still there are many problems in the field of transportation such as collision, parking difficulties, etc. Those problems result in traffic congestion. Furthermore, in these few decades, traffic demand of urban area is increasing dramatically that caused traffic congestion occur frequently. Nowadays, traffic congestion becomes a crucial topic study in the area of Intelligence Transportation System (ITS). Traffic congestion is a situation on road networks that vehicles move forward with a slower speed, or a longer travel time than it used to be, or an increasing of vehicular queuing. In general, traffic congestion begins within a single road segment, then it becomes larger along that road, finally, all the surrounding roads will become congested (Xu et al., 2013).

However, traffic congestion will release gradually after a period of time until free flow. The effective way to solve those problems is to have enough traffic information, so that engineers who are involved in the field of transportation such as traffic engineers, transportation engineers, highway engineers, etc. be able to determine which kind of problems that have a negative impact to the road network system. Normally, those information are obtained by conducting studies to collect and analyze the relevant data.

1.2 Motivation

According to the improvement in the area of ITS, wireless communications technology are equipped with vehicles and integrated with transportation infrastructure so as to help the traffic management for capturing and providing traffic information in real-time to websites or any other social media feeds or even mobile apps. So that road users are able to make a better choice for their traveling.

Within this few decades, advance information technology has developed very fast and standard living of people in urban areas also increase, so most of people have smart phone, tablet, etc. for using. Based on Bluetooth, Wi-Fi, or, Global Positioning System (GPS) in smartphone or tablet, locations of vehicles are determined, travel speed are calculated and finally, live traffic is generated in some mapping services such as Bing Maps, Google Maps, OpenStreetMap, etc. Traffic state which display by colors in those mapping services indicate the traffic condition and it is a main factor to describe the degree of traffic flow. Therefore, knowing traffic state or traffic information before hand it is helpful for travelers who are using the road network. For instance, road users are able to choose which road they should travel so as to improve their time management and reduce the traveling cost. According to “Urban Traffic Management Evaluation Index System” traffic state can be categorized into four different types, free flow, slight congested flow, congested flow, and heavy congested flow, mainly based on the averages speed of the vehicles travel on main road Huang et al. (2012).

So live-traffic in mapping service is a source in this study. The advantages of this kind of traffic data are:

- Be able to cover for large area
- Not to spend much of the money (cost effective)

1.3 Statement of Problem

Traffic congestion is always a serious and complex problem happened in the city. As mentioned in the introduction, traffic state is a performance measurement in evaluating the road network condition, so that traffic state analysis is an important content in Advance Traffic Management System (ATMS) and Advance Traveler Information System (ATIS). It must be a great advantage to the traffic management when the traffic patterns especially congestion patterns is accurately defined. Since the traffic management is well managed, traffic congestion will be reduced, traffic safety will be increased, and traffic forecasting will be improved.

In order to solve the traffic congestion problems, many roads are expanded, expressways and toll ways are built in some developping countries. Like other developed countries in South-East Asia, traffic in Bangkok of Thailand is very bad. According to Castrol Magnatic Start-Stop Index 2014, which use to measure traffic congestion by the number of starts and stops experienced by drivers, shows that Bangkok, Thailand is one of the congested city in Asia. Based on the demand and supply theory, traffic congestion can be reduced by either increasing road capacity such as expanding number of traffic lane or constructing more routes, expressways, etc., or by reducing vehicles on the road network. This is the reason why many expressways and toll ways are being built in Bangkok city. However, the National News Bureau of Thailand in 2013 state that the number of cars using expressways has increased nearly 2 million per day. So traffic congestion on expressways occurred frequently due to the multiple causes such as inadequate of mass transit or there are too many vehicles. To solve this problem, the studies and understanding of traffic behavior are necessary.

By investigating previous studies, the analysis of traffic condition on the expressways in Bangkok urban area has not been implemented. Therefore, the study and investigate the behavior of traffic on the expressways are very important for the improvement of traffic management in the city.

1.4 Objectives of the Study

Regarding to the open source of traffic state data from online mapping services, a script to retrieve these data is written. The main objective of this study is to use this kind of traffic state data to analyze and observe traffic behavior on expressways in Bangkok urban area in Thailand. Since we understand traffic behavior well, more traffic information such as traffic patterns, traffic anomaly, or traffic state prediction can be distributed to road users, government, and traffic engineers in order to help for the improvement in traffic management in the city.

In order to achieve this main goal, the study includes the method of collection traffic state data and methods of traffic state analysis such as:

- Identify traffic patterns and congestion patterns based on spatial and temporal analysis.
- Develop a model to predict traffic state based on historical data.
- Develop a system to detect abnormal traffic and measure the degree of traffic anomaly.

1.5 Significant of Study

This study will contribute to the field of transportation engineering and traffic engineering in order to develop the transportation system. The results of this study will provide the advantages to the government, researchers, and road users.

- To the government: They can develop or invest more infrastructure so as to improve the traffic congestion on the road network.
- To the researchers: The results will be useful and helpful in case to understand the traffic state behavior of the road network system. In addition, from image data, more analysis can be explored.
- To the road users: The studies will provide the information concerning road condition and traffic patterns to the users, so that they will have a good decision to improve their time management.

1.6 Scope of Study

In order to implement this study, the research will be conducted in Bangkok, the capital city of Thailand. This study will be focused on the traffic condition and traffic patterns on the expressways inside a metropolitan area of Bangkok.

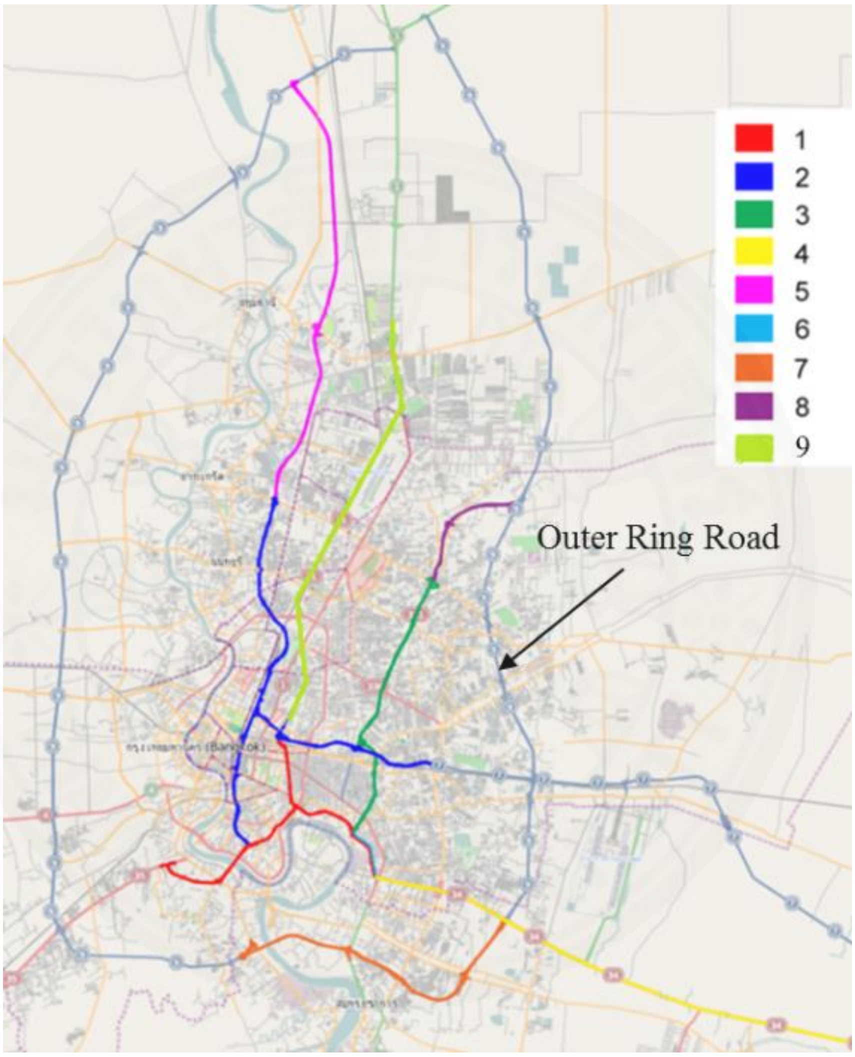


Figure 1.1 The expressway system in Bangkok, Thailand.
Image source: Thai expressway system.

The expressway system in Thailand comprises a high capacity controlled-access and connected to highways and provided the facility for the road users. The system is operated under the Expressway Authority of Thailand (EXAT), and is distinct from the Thai motorway network. In this study area, there are two major ring roads, inner and outer ring road and there are eight expressways inside the outer ring road as shown in Figure 1.1.

According to the EXAT website, the name of each expressway can be placed according to the date of completion.

1.6.1 Chalerm Mahanakhon Expressway

Chlerm Mahanakhon expressway is a main and the first expressway in Bangkok city in Thailand. The total length of this expressway is 26.7 km and it is divided into 3 links as follow:

- Link 1: Din Daeng to Khlong Toei (6.2 km)
- Link 2: Khlong Toei to Bang Na (8.9 km)
- Link 3: Khlong Toei to Dao Khanong (11.6 km)

On Chalerm Mahanakhon expressway, there are 17 toll plazas. Among them there are 3 toll plazas, Din Daeng toll plaza, Bang Na toll plaza, and Dao Khanong toll plaza, are on the elevated structure.

1.6.2 Sirat Expressway

It is a main and the second expressway in Bangkok City. The total length of the route is 37.7 km, and it divided into 3 links as follow:

- Link 1: Pak Kret to Ratchathewi (15.6 km)
- Link 2: Ratchathewi to Suan Luang (12.7 km)
- Link 3: Ratchathewi to Bang Khlo Laem (9.4 km)

On this expressway, there are 24 toll plazas in total. Among them there are 3 locations of the toll plaza on the elevated structure. The first location is Pracha Cheun toll plaza, the second location is A Soke toll plaza, and the last location is Si Nakarin toll plaza.

1.6.3 Ramindra Expressway

For this study, the expressway is combined by 3 corridors together (Third stage expressway system S1 section, Chalong Rat Expressway, and Ramindra-Outer Ring Road Expressway). This expressway begins from Bang Na to the North part, Bang Khen, and heading to Sai Mai. The total length of the route is 32.5 km. There are 15 toll plazas along the corridor, among them one toll plaza, Jatuchock toll plaza, is on the elevated road.

1.6.4 Bang Na Expressway

Bang Na expressway or Burapha Withi expressway, is connected with Chaloem Maha Nakhon Expressway in Khet Bang Na to Bang Pakong, Chonburi province. This toll road runs above National Highway route #34, (Bang Na – Bang Pakong Highway).

Bang Na Expressway is an elevated expressway with the total length of 55 km. However, in this study we are interested only in Bangkok urban area, so only 12.4 km are covered. Within this length, there are 4 locations of the toll plaza, but only one toll plaza, Bang Na km.6 loll plaza, is on the elevated structure of both in-bound and out-bound.

1.6.5 Udon Ratthaya Expressway

This expressway connected with Si Rat Expressway in Pak Kret to Bang Pa-In with the total length about 29.2 km. There are 5 locations of the toll plaza on each bound of the corridor, but only one location of the toll plaza, Bang Pa-In toll plaza, is on the elevated structure both in-bound and out-bound.

1.6.6 Bang Phli Suksawat Expressway

It is known as South Kanchanaphisek ring road; it is in Samut Prakan Province, begin from at the intersection between Bang Na Expressway and Outer Ring Road and end in Khet Thyng Khru, Phra Pradaeng with the total length of 21.2 km.

There are 5 locations of toll plaza of each bound corridor, but only one toll plaza, Bang Kaew toll plaza, is on the elevated structure of both in-bound and out-bound route.

1.6.7 Don Mueang Tollway

This tollway is not under to operation of EXAT, but it is under the operation of private company, Don Muang Tollway Public Company Limited. This company provided the tollway transport service for people to travel from Din Daeng to the Northeast region, Rangsit with the total length of 28.1km. This tollway begins from Din Daeng to Rangsit, run over Viphavadi (Road #31) and Phaholyothin Road. There are 11 locations of the toll plaza, but only 3 toll plazas, Don Mueang toll plaza, Din Daeng toll plaza, and Anusorn Satharn toll plaza, are one the elevated structure.

1.7 Organization of the thesis

Report in this study is divided into 5 chapters. The first chapter states the introduction which includes the general concepts of transportation, the motivations of the studies, statement of problem, objectives, significant, and scope and of the study. In chapter 2, the related study will be reviewed in order to see what the previous research has done and what parts need to be developed. Then, methodology and procedure of collecting and analyzing traffic state data will be mentioned in chapter 3. Chapter 4 will present results of analysis come along with the discussion. Finally, in chapter 5, we will make a conclusion and give some recommendations of this study. Furthermore, the future work of the research will be mentioned.

Chapter 2

Literature Review

2.1 Introduction

Since the traffic state analysis is an interesting research topic, many studies and modelling methods in this field have developed very fast. With the rapid development of technology, many experts and scholars has done thorough research with the difficult problem in the field of traffic flow theory, traffic information and traffic data collection. In this chapter, the related work will be reviewed to see what work has done and what work need to be improved.

2.2 Traffic data Collection Methods

The availability of traffic data provides the efficiency of the research study. Consequently, methods of collecting traffic data become an important aspect for the researchers. With the development of Intelligent Transportation Systems (ITS), the ways to collect traffic data is very convenient. Through the studied of Leduc (2008), the method to collect traffic data can be categorized into two groups: conventional traffic data collection method and the Floating Car Data method.

2.2.1 Conventional Traffic Data Collection Method

In general, the conventional traffic data collection method is the way that we use detectors located along the roadside to collect traffic data. According to Leduc (2008), the method can be divided into two types. One is the intrusive method which related to the use of sensors and data recorder implement of the road network. Another one is non-intrusive method which based on remote observation.

Intrusive method: Intrusive method is the method that sensors or data recorders placed on the road network. This method includes:

- Pneumatic road tubes
- Piezoelectric sensors
- Magnetic loops

Non-Intrusive method: Different from Intrusive method, Non-Intrusive method included:

- Manual counts
- Passive and active infra-red
- Passive magnetic
- Ultrasonic and passive acoustic
- Video image detection

2.2.2 Floating Car Data (FCD)

Unlike conventional methods, FCD is a method used for determining the speed of vehicles on the road network. FCD is a new method of collecting traffic data based on floating traffic sensors that collect localization data, speed, direction, and travel time. In this case, vehicles themselves play a role of sensors for the road network. The main source of FCD comes from a GPS device, smartphone phones and Bluetooth device (Nick and Hugo, 2012). Based on FCD, traffic congestion is identified, travel time is calculated, and traffic reports are quickly recorded.

There are some advantages and disadvantages of using FCD. The benefits of using FCD are:

- Providing a detailed data source
- Covering the whole network
- Containing large period of data
- Being able to convert to a large amount of application

However, the advantages of using this data are:

- No direct detail of traffic flow
- Depend on sample properties

2.2.3 Traffic State Data Collection

Due to the recent improvement of information technology, the ways to collect real time traffic data are more convenient. According to the widely used of GPS data, traffic flow is collected by using probe vehicles, the study of Asakura et al. (2015), locations of vehicles are determined and travel speed of vehicles are retrieved by using probe vehicles or smartphones as a probe device in the work of Kinoshita et al. (2014a), Yong-chuan et al. (2011), Bauza et al. (2010), Dhar and Garg (2014) and finally, traffic information are generated in some mapping services such as Google Maps, Bing Maps, etc. In the study of Tostes et al. (2013), the author developed an algorithm to collect the traffic flow image from online web based mapping service (Bing Maps). These image data show the colors green, yellow, and red which represented the traffic intensity on the road network. The colors which overlay road network in mapping services will be changed within green, yellow, red, and dark red, within fast to slow, according to a significant amount of road users on a particular segment by Matthews (2013). Similar work from LY et al. (2015), the author developed an algorithm to collect the traffic state data from online mapping services from Google Traffic, a feature of Google Maps, which displayed the traffic layer on the road network, to be the source of traffic state data.

2.3 Traffic Management

Traffic is related to the movement on the road network. The movement can run smoothly or not, it depends on the traffic management. However, one of the serious problems happens on the road network and many cities are facing is traffic congestion. Since that traffic management is well managed, traffic congestion can be reduced, traffic safety on the road is improved.

2.3.1 Traffic State Identification

The number of population in the city is increasing, traffic demand grows rapidly, and traffic flow of the road network is unstable. It changes from time to time in a day due to many factors such as traffic accident, social activities, the change of the weather, and some other unusual events. In order to deal with this unstable events, traffic state needs to be accurately identified. Therefore, traffic state identification is in challenging for urban road network. According to “Urban Traffic Management Evaluation Index System” (UTMEIS), traffic state can be divided into 4 different states, free flow, slight congested flow, congested flow, and heavy congested flow, according to the average speed of the vehicles travel on main road as shown in the table below.

Table 2.1 Classification of traffic state

Traffic State	Average Travel Speed (km/h)
Normal	Greater or equal 30
Mild Congestion	Between 20 and 30
Crowded	Between 10 and 20
Serious Crowded	Less than 10

On the other hand, the identification of the traffic state is based on Highway Capacity Manual of USA which traffic state can be identified by LOS (Level of Service). There are six levels which are denoted from letter A, the best conditions for traveling, to Letter F, the worst conditions for traveling according to the National Research and Transportation Research. Taking into account the fuzziness and the randomness of traffic state, Bo et al. (2010) and (Gao and Liu, 2010) proposed a cloud theory to identify the traffic state and aim at resolving the uncertainty transfiguration between the concept of quality and the value of quantity. Using travel speed, occupation and delay as a traffic data, the results of this research indicated that, the identification of the traffic state can be accurate until a large-sized of data are applied. However, Jinhui et al. (2011) presented the synthesized cloud so as to improve the accuracy of identifying the traffic state. Traffic flow data are collected by a variety of traffic detectors were used. This proposed method can identify traffic state and improve the state recognition's rate. A similar study proposed by Huang et al. (2011) by using Fuzzy C-Means clustering, traffic state can be identified. Traffic volume, speed, and traffic density which describes the characteristic of traffic flow, are used to be the traffic data. The results look similar to the results of actual measurement from traffic data by questionnaire survey through drivers.

In the study of Huang et al. (2012), proposed regional road network method to identify the accuracy of real time traffic condition by using travel time and delay as the traffic data. This method can be applied to online traffic condition and the occurrence of traffic congestion. Moreover, in order to effectively control and improve traffic system performance, a bottleneck is a significant point for consideration. The congestion at bottleneck have been studied, the algorithm has been developed to identify bottleneck locations (Chen et al., 2004). Gong and Yang (2009) used historical data to identify traffic state at the bottleneck based on the congestion indexes method.

The results proved that this method can display the traffic congestion more sensitively than speed and occupancy.

The traffic condition of the road network is changing every time with the unclear characteristics. Thus, clustering method can be used to identify the traffic state. However, if the traffic parameter thresholds are made only by human, these value will be subjectivity. If the massive FCD is used for neural network training directly, it may take too much time. So that result can not reflect the road traffic state in time (Wei and Li, 2012). In his study, k-means clustering and MLP neural network are combined together to calculate the threshold value of difference traffic state by using FCD. The results were consistent with the actual traffic condition. In order to improve the traffic management, real source of information is required. In the study of Ji et al. (2009) traffic state was identified by using velocity based on vague set theory.

2.3.2 Traffic Patterns and Congestion Patterns

The patterns of traffic are very important for traffic state analysis. Through those patterns, traffic state estimation or traffic state prediction can be effectively defined. Therefore, it is very necessary to identify the traffic pattern or congestion pattern in accuracy. Many various methods are proposed to deal with the traffic congestion. Zeng et al. (2009), studied the congestion patterns by using a dual graph to implement and simulate the model of traffic based on navigation and queuing of vehicles. However, this study needs more improvement. By analyzing the relationship of land use and traffic congestion, Tsekeris and Geroliminis (2013) proposed the Microscopic Fundamental Diagram (MFD) approach which deal with the traffic flow and traffic density to analyze the relationship between land use and traffic congestion. Another study on traffic congestion patterns in a large city was proposed by Wen et al. (2014), aim at analyzing the characteristics of traffic congestion under the influence of different conditions, such as different day of the week, weekend, and holiday. Based on Traffic Performance Index (TPI) data, typical congestion patterns are identified by using clustering method.

In the study of Wang et al. (2013b), an interactive system for visual analysis of urban traffic congestion based on GPS trajectories is mentioned. Through those trajectories, traffic congestion information can be extracted and derived. With the growth of Floating Car Data (FCD), collecting traffic information becomes more and more cost-effective. GPS floating car technology provides the accuracy of traffic information in a larger scale and in real-time (Yong-chuan et al., 2011). In his study, travel speed data collected from FCD are used to detect urban traffic congestion. Similar study, (Xu et al., 2013), a new FCD analysis method based on data cube was proposed to explore the congestion patterns. With FCD, travel speed can be defined. Using speed data, traffic congestion can identify based on spatial-temporal relationship. Then, traffic congestion patterns can be received by aggregated and explored with different spatial-temporal scale.

2.3.3 Traffic State Prediction

Traffic prediction or traffic congestion prediction is the effective method to improve traffic conditions and reduce travel delays in ATIS and ATMS. In the field of Intelligent Transport System (ITS), it is so important and necessary to predict or to provide the accurate traffic information for traffic management improvement. There are three problems regarding traffic congestions: Traffic volume prediction, traffic congestion prediction, and travel time prediction (Yang, 2013).

In the previous research work, speed, flow, and occupy are the main traffic parameters which needed to be solved. In the study of Dong et al. (2009), Maximum Entropy Method for traffic state prediction is proposed. Since the traffic state can be defined by LOS, thus, the traffic state prediction can be predicted based on LOS too. So in this study, the author used spatial features such as upstream and downstream of traffic conditions and upstream and downstream of traffic flow, and the temporal features such as, 5 minutes speed, flow, occupancy… merge into ME model and fuse to get LOS. The results are acceptable for short time prediction for 5minutes or 10 minutes and it will be quite different for the long prediction like one or two hours. To develop the previous study Dong et al. (2009), proposed a multimode Maximum Entropy model to predict the traffic state of urban expressways in Beijing, China. In this study, traffic state of the expressway is described by Micro-LOS (Micro-LOS is measured by speed, density, and volume). By using Micro-LOS apply to MME, we got a better result compare to the previous one because it can predict up to 30 minutes-ahead.

2.3.4 Traffic Incident Detection

Traffic incidents produce a lot of negative effects such as worsen the traffic safety, increasing travel time, making air pollution, and fuel consumption (Thomas and Dia, 2006). The main purpose of Traffic Incident Management System (TIMS) is to reduce these negative effects. In recent years, many and vary automatic incident detection methods have been explored, different techniques of data collection have been conducted, and different types of traffic data have been applied.

Since traffic incident detected in real time is crucial for traffic management, many methods for automatic incident detection (AID) have been developed. Automatic incident detection methods include pattern recognition method, statistical method, comparative method, time series method, smoothing or filtering method, traffic modeling method, artificial intelligence method, and image processing method (Ahmed and Hawas, 2012, Parkany and Xie, 2005). The general concept of AID is basically evaluated the change of traffic parameters (e.g. traffic volume, occupancy, speed) between upstream and downstream. In the study of (Yong-chuan et al., 2011), travel speed is divided into 5 categories and denoted within 5 state, serious congestion state, congestion state, normal state, smooth state, and fast state, based on the index system of traffic management evaluation of urban road. Then, traffic congestion is detected by analyzing the travel speed collected from floating car data. Normally, vehicles move slowly in the congestion area, and it should speed up to the limited speed of freeway. In the study of (Petty et al., 1997), acceleration and deceleration of vehicles are applied to probe-UCB algorithm. An incident is alerted whenever speed and acceleration of a single vehicle exceeds the threshold value. Another study (Asakura et al., 2015), shockwave theory is applied in order to examine an incident. The concept is based on 3 continuous vehicles which one is assumed not to pass the incident, while the other two are assumed to pass. Speed of those two vehicles must be reduced at the time of passing congested area. Similar study for (Kamran and Haas, 2007), one road is divided into segments and average speed of vehicles on each segment is calculated. The average speed on the behind and in the front are used for the verification whether an incident really occurred. By installing two adjacent detector station, speed at upstream and downstream are collected. Then, mean and standard deviation of speed at a specific time interval are calculated over a period of study. Using mean and standard deviation, some studies have been proposed a short-term forecasting or to predict the normal traffic condition or to find the expected traffic state in the next time interval (Wang et al., 2013a) & (Chin Long and Fan, 2007). The expected value depends on the threshold value which is obtained from calibration of incident data. An incident is alerted when there are unusual and significant changes in the traffic variable.

Traffic incident can be detected by comparing travel time (Li and McDonald, 2005, Kinoshita et al., 2014b). It can be compared the current travel time to the average one or compare to the past travel time. Basically, the current travel time is increasing, or travel speed is reduced if an incident occurred. Based on these concepts, link-based algorithms were developed to deal with traffic incident detection (Asakura et al., 2015). Travel time of two adjacent links are compared. The incident is detected when the travel time of upstream is greater than the travel time at downstream. Then, travel time different ratio and flow rate different ratio is calculated in order to compare with the threshold value.

Another general concept for traffic incident detection is to compare current traffic state (CTS) with the usual traffic state (UTS). The UTS is usually determined by historical data. In the study of (Kinoshita et al., 2015), speed data collected from probe car are used and converted into 3 states on traffic condition, good, moderate, and stop. The CTS is estimated from real time speed data and UTS is defined by archival data. Then the difference between CTS and UTS, divergence, is calculated in order to measure the degree of anomaly. Traffic incident is detected when the high-divergence is found. Another method to calculate degree of traffic anomaly is to calculate the congestion rate. Then, the threshold value is set to determine the normal traffic condition. The current traffic condition is said to be good when the velocity of the vehicle is upper than or equal to the threshold values. In this case degree of anomaly is equal to negative of congestion rate (Xing-wu et al., 2014). However, road condition is congested when velocity of vehicle is lower than threshold value. The degree of anomaly is equal 1- congestion rate.

Chapter 3

Methodology

3.1 Introduction

After having reviewed the existing studies related to traffic state analysis, the new proposed research and methodology are discussed in detail in this chapter. In this study, traffic state data collection from web-based, specifically from Google Maps and the improvemed algorithm to translate traffic state data will be presented in detail. Then, traffic state analysis method will be described.

3.2 Traffic Data in Google Traffic

In these couples decade, many kinds of traffic data were collected in different ways such as location based on GPS data, floating car data, CCTV traffic data, data from traffic sensors, etc. Thus, we can conclude that the more development of technology, the more convenience of traffic data to be collected. In recent years, in some online mapping services, applications of viewing traffic are provided for all road users to see the traffic condition. Those online mapping services generated traffic from GPS data, such as travel speed, flow, etc.

Figure 3.1 Real time traffic state in mapping services

Source: http://www.joshuastevents.net

Based on GPS data, locations of vehicles are determined, travel speeds are retrieved, and traffic information is generated. Traffic information is visualized in mapping services by colors. The colors will be changed within green, yellow, red, and dark red (within fast to slow) according to a significant amount of road users on a particular segment. Thus, real time traffic information from online mapping services becomes the source of traffic state data in this study. The advantages of using web based data are that it can cover a large area and it is cost-effective.

3.2.1 Data Acquisition Process (Web Crawler)

In order to collect traffic state data provided by online mapping services, a script to call for loading webpage without any illustration or obstacle, but only traffic layer is developed. The process of data acquisition is as the following steps:

- Send a request to open mapping services
- Set map to a specific location (longitude and latitude) to cover the whole area of study.
- Input an appropriate zoom level in order to see the traffic on the road network clearly.
- Turn off all the obstacle background to let only traffic state as colors display on the road network.
- Set time for the colors of traffic loading

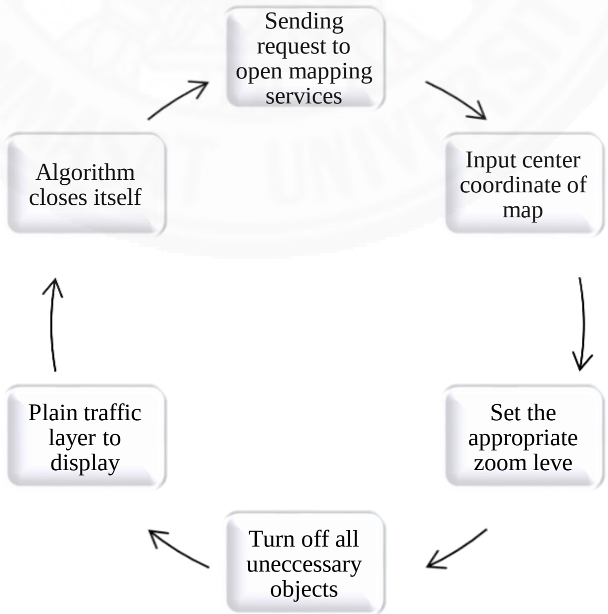


Figure 3.2 Web crawler algorithm

Source: Image adapted from (Ly, 2015).

To see traffic state clearly in mapping services, zoom level 16 is used in this study. Therefore, multi-screens of capture images are required. In order to cover all the areas of study, 19 screens of capturing image are needed.

3.2.2 Image Traffic Data Collection

After setting map to all screens and they display correctly, the size of an image need to be set, images are captured, the file name of every image is assigned as the date and time of capturing. Image data are stored in the database with the same folder but different screens folder. Traffic data in the form of images are collected every 10 minutes per day. So there are 144 images correspond to 144 time steps. The size of image data is 4000 pixel × 4000 pixels. Traffic state data in form of image looks like the figure below:

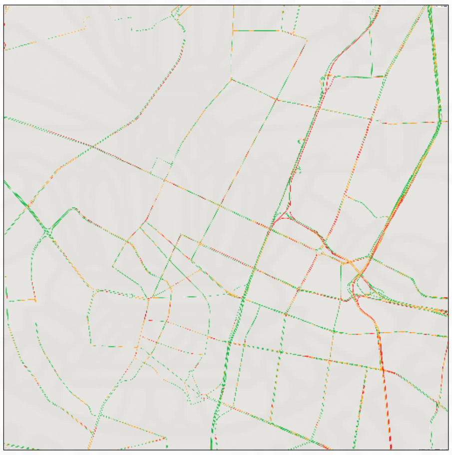


Figure 3.3 Image traffic state data collected on March 16, 2015 at 09:20 on screen 23

3.3 Image Processing

After obtained all the images from data collected in the area of study, a method to convert the colors in traffic state data into quantitative data is proposed.

3.3.1 Road Network Mask

The origin traffic state data from online mapping services shows only colors. Therefore, in order to get the traffic information from those colors, image processing is conducted. First, the images of each screen are selected and bound together to form a map in the study area with the same scale to the real location. Then, lines are traced manually on the colors of the expressways in the scope of study by using Auto CAD program. Figure 3.4 below presents a completed drawing of lines overlay all the expressways in the scope of study. The traced lines are called road network masks.

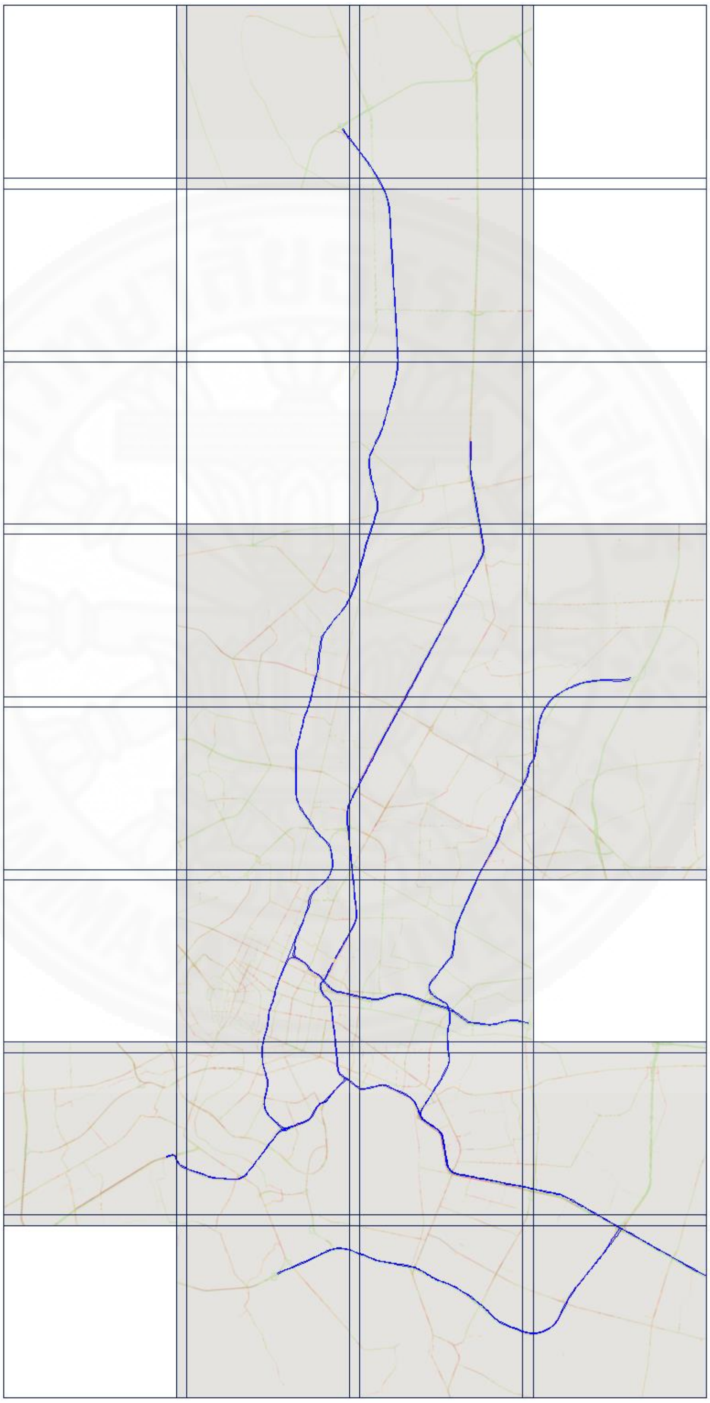


Figure 3.4 Road network mask

The purpose of tracing lines overlay the colors of expressways is to assign artificial traffic sensors as points to detect the colors that indicate traffic flow on the road network.

3.3.2 Artificial Traffic Sensors Assignment

Different from the previous study of Tostes et al. (2013), in order to get the information from the image traffic data, image processing software is used. Traffic information on the road is extracted based on percentage of different color pixels. Similar study to Ly (2015), in order to get traffic information from the images, the assignment of artificial traffic sensors all over road network is developed. In the concept of traffic sensor placement, the more traffic sensors are assigned, the more accuracy and reliability we get (Danczyk and Liu, 2011). However, the budget is a big constraint for those instruments. In practical application the traffic sensors such as Video Detection System (VDS), are installed about every 0.5km along the major highways. Another kind of traffic sensors, CCTV (Closed-Circuit Television), the cameras are placed in every 1 miles. However, in the study of Gong and Yang (2009), the traffic data detected by dual loop detectors with distances of 300 meters for each and by video monitor with distances of 1200 meters.

In this study, all the artificial traffic sensors (points) are assigned with the distance of 100 meters apart from each other along the expressways to detect the colors from images which indicated traffic flow on the road network. Points can be assigned by typing the “measure” command in AutoCAD program and input the distance 100. Thus, points will be generated as shown in the figure 3.5 below.

Figure 3.5 Assignment of traffic sensors with the distance 100 meters

Number of traffic sensors are placed on the expressway system in Bangkok urban area in total there are 3756 sensors. Number of sensors of each expressway according to the origin and destination are listed in the table below:

Table 3.1 Total number of traffic sensors of each expressway

No	Name of Expressway	Length (km)	Origin - Destination	Sensors	Total
1	Chaloem Maka Nakhon	6.2	Din Daeng - Khlong Toei	62	534
			Khlong Toei - Din Daeng	62	
		8.9	Khlong Toei - Bang Na	89	
			Bang Na - Khlong Toei	89	
		11.6	Bang Mot - Klong Toei	116	
			Klong Toei - Bang Mot	116	
2	Sirat	15.6	Pak Kret - Ratchathewi	156	754
			Ratchathewi - Pak Kret	156	
		12.7	Ratchathewi - Suan Luang	127	
			Suan Luang - Ratchathewi	127	
		9.4	Phaya Thai - Bang Khlo Laem	94	
			Bang Khlo Laem - Phaya Thai	94	
3	Ramindra	32.5	Sai Mai - Bang Na	325	650
			Bang Na - Sai Mai	325	
4	Bang Na	12.4	Bang Pakong - Bang Na	124	248
			Bang Na - Bang Pakong	124	
5	Udon Ratthaya	29.2	Bang Pa-In - Pak Kret	292	584
			Pak Kret - Bang Pa-In	292	
6	Bangphli Suksawat	21.2	Bang Phli - Phra Pradaeng	212	424
			Phra Pradaeng - Bang Phli	212	
8	Don Mueang Tollway	28.1	Rangsit - Din Daeng	281	562
			Din Daeng - Rangsit	281	

3.3.3 Coordinates of Traffic Sensors

After assigning all points to all expressways with the same scale to the real world, coordinates of the points can be extracted by using "DataExtraction" command in AutoCAD. After coordinates (longitude and latitude) of each sensor in the real world coordinate system are extracted, then they are sorted in order based on origin and destination of the corridor. Then, id of each point in each expressway is assigned. So that we can know traffic condition every point station.

The process still continues, road network mask need to be rescaled again by using Auto Cad program. Each image of the screen needs to scale to the same size of the image data collection (4000 pixel × 4000 pixels). The coordinates of the points within 4000 pixel × 4000 pixel need to be extracted. These coordinates are used to read the colors (GRB) in image data. The same work with the previous coordinate system in the real world, these coordinates are arranged in order along the expressways and assigned point id to be match with the real world coordinate system.

An example of those two kinds of point coordinates extracted from screen number 22 is shown in the table below. The screen column shows the screen number where the coordinates are extracted from. Id column indicated point id starting from the beginning of the road in the scope of study. Longitude and Latitude columns show the real coordinate in the coordinate system. Pixel X and Pixel Y columns are the coordinates use for reading color pixel in the image data.

Table 3.2 Coordinate of traffic sensor of Chalerm Mahanakhon Expressway

Screen	Id	Longitude	Latitude	X Pixel	Y Pixel
22	1	100.5505907	13.76740719	3393	2082
	2	100.5501702	13.76660591	3373	2120
	3	100.5497374	13.76581092	3354	2158
	4	100.5493268	13.76500438	3333	2197
	5	100.5489743	13.76417287	3316	2236
	6	100.548632	13.76333497	3299	2276
	7	100.5482661	13.76250792	3282	2316
	8	100.547833	13.76171373	3261	2354
	9	100.5473354	13.76096052	3238	2390
	10	100.5467266	13.76029078	3209	2421

3.3.4 Traffic Intensity Data

As known that traffic data from online mapping services display only colors, therefore those colors need to be interpreted into numerical indexes. The 4 colors, green, yellow, red, and dark red, are indexed by number 1, 2, 3, and 4 respectively. The process of conversion colors to the indices is presented in the Appendix A.

Table 3.3 Traffic intensity indexing

Traffic state	Color	Indices
Free flow	Green	1
Moderate flow	Yellow	2
Congested flow	Red	3
Heavy congested flow	Dark red	4
No data available	Gray/white	N/A

Source: Adapted from Ly, 2015.

3.4 Traffic State Analysis

Traffic state gives the information about traffic condition on a road network. The study of the traffic behavior is an important thing for the traffic management. Traffic condition on the network can be investigated based on time and space. There are a lot of output from traffic state data that give a good benefit to the traffic managers, researchers, and road users such as; from traffic data we can know:

- Traffic patterns on the road network
- Traffic congestion by time space
- Traffic anomaly or any incident
- Traffic state in the future
- Travel time from the origin to the destination of the road users, etc.

3.4.1 Traffic Patterns and Congestion Patterns Analysis

The condition of traffic varies from time to time with different days of the week. Traffic patterns or congestion patterns on the road network can be visualized based on spatial and temporal analysis (time and location).

There are many approaches to identify or define traffic patterns or congestion patterns. A simple concept to identify traffic patterns in this study is to calculate the average of traffic intensity.

The equation of calculating the average traffic intensity is as follow:

$$AI_{ij} = \frac{\sum_{k}^{N} I_{ijk}}{N} \qquad (1)$$

Where,

i : Index of point along the road

j : Index of time within a day

k : Index of day over a period of study

N : Total number of days in the analysis

I_{ijk} : Traffic intensity of point i at time j of day k

AI_{ij} : Average of traffic intensity of point i at time j

Since the traffic patterns on the road network of working day are different from the patterns of non-working day, thus the study will also investigate:

- Spatial-temporal of traffic patterns based on working day
- Spatial-temporal of traffic patterns based on weekend.
- Spatial-temporal of traffic patterns based on special holidays.

3.4.2 Severe Traffic Congestion Detection

Severe traffic congestion is a condition of a traffic network that travel demand exceeds road capacity for a period of time at the same location. Severe traffic congestion is conducted in order to show how long the congestion occurred and lasted which is different from online mapping services which show only the current traffic information.

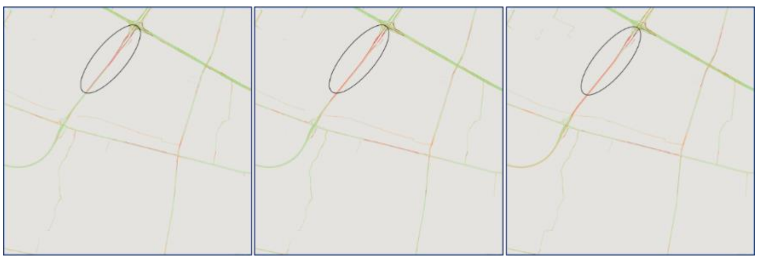


Figure 3.6 Severe traffic congestion at 3 adjacent time steps

Figure 3.6 above presents an example of severe traffic congestion investigated based on image data. By investigating traffic inside the circle, the congestion occurred on March 02, 2016 within 3 adjacent time steps (10:20, 10:30, and 10:40) in the morning on Bang Phli Suksawat Expressway. In the study, we will investigate this kind of congestion and will be detected and give the information to road users.

The severe traffic congestion detection model in this study is that whenever the conditions of traffic on the road network is congested or heavy congested within a specifically determinant time and space (it means that we need to set parameters of time and distance), then artificial traffic sensors which are placed on the corridors are detected. The severe traffic congestion is proposed in order to eliminate the scatter points detected that appeared for a short period of time (one time step) and occurred with a short distance. The severe congestion concept can be applied to real time traffic incident detection so as to verify if the incident really occurred. The general concept of the severe traffic congestion detection is explained in the table below:

Table 3.4 Example of severe traffic congestion detection

Space	Time		
	t-2	t-1	t
1	1	1	2
2	1	2	2
3	2	2	3
4	2	3	3
5	2	3	3
6	3	3	4
7	3	3	4
8	3	4	4
9	4	4	4
10	4	4	3
11	4	4	3
12	3	3	2
13	2	3	2
14	2	3	1
15	1	2	1

Space	Time		
	t-2	t-1	t
1	1	1	2
2	1	2	2
3	2	2	3
4	2	3	3
5	2	3	3
6	3	3	4
7	3	3	4
8	3	4	4
9	4	4	4
10	4	4	3
11	4	4	3
12	3	3	2
13	2	3	2
14	2	3	1
15	1	2	1

The table above shows an example of severe traffic congestion. Columns represent time steps and rows represent spaces (distance). Number 1, 2, 3, and

4, indicate traffic intensity which represents the traffic flow from free flow to heavy congested flow. For example; when traffic intensity is greater or equal 3 (congestion or heavy congestion) occurs 3 adjacent time steps and at least 5 adjacent points (point is artificial traffic sensor), then severe traffic congestion is detected. As shown in the example, point number 6, traffic congestion or heavy congestion occurred 3 adjacent time steps. Thus, point number 6 is detected. The same from point number 7 to 11. There are 6 adjacent points detected at the same time in this example, which is more than 5. Therefore, at that region the severe traffic congestion occurred at time t.

In this study, severe traffic congestion detection is detected in real time. Then, the attributes of points which are manually assigned will be used for providing the information to road users. The attributes of the point include:

- Date and time of congestion detection
- Name of expressway
- Destination
- Location of the congestion (between toll plaza)
- Length of congestion
- Duration of congestion
- Starting point of congestion

The concept of severe traffic congestion can be used to apply in traffic anomaly detection to verify if traffic incident really occurred. Furthermore, applying this concept, the scatter points of incident that do not effect much to the traffic condition on the road can be eliminated. Thus, it is detect only big anomaly that occurred for long time with long distance.

3.4.3 Traffic Anomaly Detection

Traffic anomaly is another analysis of finding any abnormal traffic on the road network. Traffic anomaly is defined as a deviation of current observation of traffic intensity from the usual traffic intensity (UTI). Thus, traffic anomaly will be detected whenever UTI is different from the current traffic intensity (CTI).

3.4.3.1 Probability Distribution of Traffic intensity

The probability of traffic intensity of the individual point at every time step is calculated by the formula:

$$P_{pt}(i) = \frac{N_{pt}(i)}{\sum_{i} N_{pt}(i)} \qquad (2)$$

Where,

i : Index of traffic intensity which range from 1 to 4

p : Index of point (artificial traffic sensor) on the corridor

t : Index of time-step

$P_{pt}(i)$: Probability of traffic intensity i occurred at point p of time t

$N_{pt}(i)$: Number of traffic intensity i occurred at at point p of time t

The probability must be updated whenever there are new information available, therefore, Bayes formula is applied to compute the conditional probability. Bayes formula is presented in equation (2) below:

$$P(I / E) = \frac{P(E / I) \times P(I)}{P(E / I) \times P(I) + P(E / I') \times P(I')} \qquad (3)$$

After having all the probability of every point at every time-step, the highest probability is observed and the traffic intensity that corresponds to the highest value is assumed as Usual traffic intensity (UTI).

3.4.3.2 Degree of Traffic Anomaly

The definition of traffic anomaly is a deviation from the usual traffic on the road network. Traffic anomaly may or may not cause traffic congestion. Thus, the degree of abnormal traffic is calculated in order to see how high or low of traffic condition compared to the normal condition. The degree of traffic anomaly is determined based on the probability of the individual point, and the formula of the calculation is followed the equation below:

$$DA_{pt} = \frac{UTI_{pt} - CTI_{pt}}{|UTI_{pt} - CTI_{pt}|} \times \frac{P(CTI)_{pt}}{P(UTI)_{pt}} \qquad (4)$$

Where,

p : Index of point (artificial traffic sensor) on the corridor

t : Index of time-step

DA_{pt}: Degree of traffic anomaly of point p at time t

UTI_{pt}: Usual traffic intensity of point p at time t

CTI_{pt}: Current traffic intensity of point p at time t

$P(UTI)_{pt}$: Probability of usual traffic intensity

$P(CTI)_{pt}$: Probability of current traffic intensity

3.5 Research Framework

In summary, the work in this study is divided into two main phases. Phase 1 is related to traffic data, which are collected from online mapping services and the methodology of acquisition traffic intensity data. Phase 2 is concerned about the methodology of analyzing traffic intensity. The whole framework of our methodology can be summarized as follows:

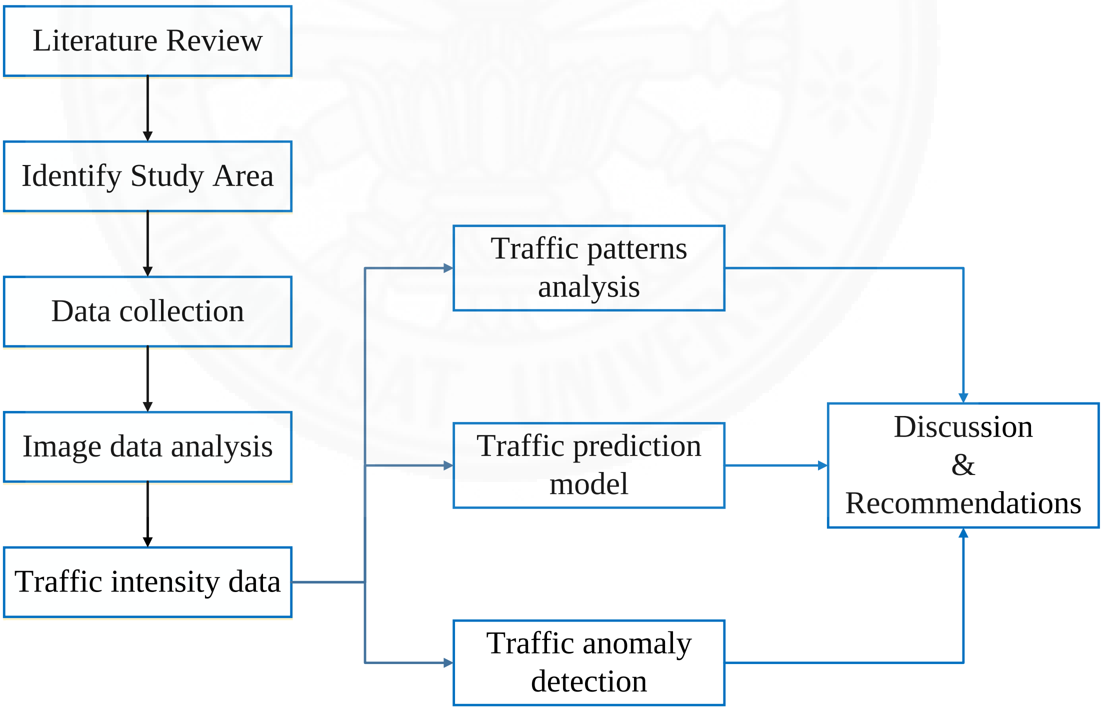


Figure 3.7 Research framework

Chapter 4

Results and Discussions

Traffic state data from online mapping services will be applied to the proposed methodology in this report. In this study, traffic data for one year collected from June 01, 2015 to May 31, 2016 will be used for analysis. However, due to some constrains caused by internet connection, the use of traffic data in this study is only 333 days over a whole year. In order to see the different patterns of traffic on the expressways, these data are divided into 4 groups, working day, Saturday, Sunday, and special holiday. The reason that these data are separated like this because on Saturday some people still go to work in some companies. For Sunday it is the day off, so people may prefer to stay at home. However, for special holiday that can be long holiday people may travel more. Hence, the usable data for these groups are:

Table 4.1 Categories of usable traffic data

No	Groups	Number of days
1	Working day	218
2	Saturday	46
3	Sunday	45
4	Special holiday	24

4.1 Traffic Patterns and Congestion Patterns

Traffic patterns and congestion patterns are visualized based on spatial and temporal of traffic intensity. Thus, the average traffic intensity of each group can be calculated by the following formula:

$$AI_{ij} = \frac{\sum_{k=1}^{n} I_{ijk}}{N} \qquad (5)$$

Where,

i: number of points on each expressway (see table 3.1)

j: number of time step (144 time-steps per day)

k: index of days

n: total number of days in each group (see table 4.1)

N: total number of traffic intensity at point i of time j exclude any days that have no data available.

4.1.1 Traffic Congestion Patterns on Chalerm Mahanakhon Expressway

Traffic patterns and congestion patterns on the Chalerm Mahanakhon expressway of working days, Saturdays, Sundays, and holiday will be discussed based on the links in the scope of study. In order to understand about traffic condition, traffic congestion on expressway, the map showing structure of the expressway and points of interest such as locations of the toll plaza, locations of entrance and exit is offered as follows:

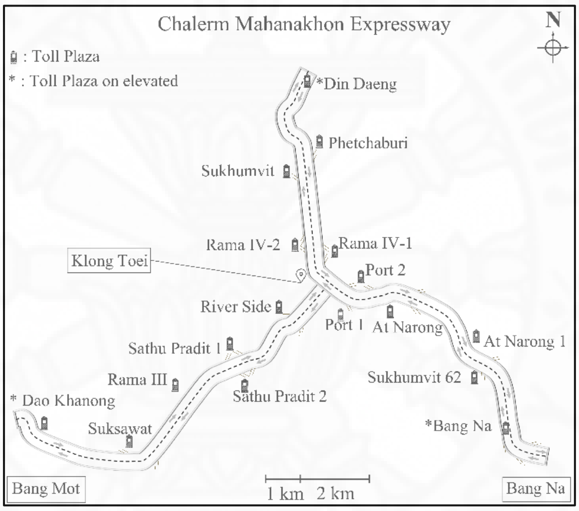


Figure 4.1 Map of Chalerm Mahanakhon expressway

Table 4.2 Points of interest on Chalerm Mahanakhon expressway

Expressway	Origin - Destination	Ramp / Toll plaza	Distance from beginning of route
Chalerm Mahanakhon (In-Bound)	Din Daeng - Khlong Toei	* Din Daeng toll plaza	400 m
		Off ramp	900 m
		Merge	1.6 km
		Phetchaburi toll plaza	2.3 km
		On ramp	2.5 km
		Off ramp	5.1 km
		Rama IV-1 toll plaza	5.5 km
		On ramp	5.8 km
	Dao Khanong - Khlong Toei	Merge	700 m
		* Dao Khanong toll plaza	1.2 km
		Suksawat toll plaza	4.1 km

		On ramp	4.2 km
		Rama III toll plaza	6.9 km
		Diverge	7.2 km
		Merge	8 km
		Sathu Pradit 1 toll plaza	8.6 km
		On ramp	8.9 km
		River Side toll plaza	10.5 km
		On ramp	10.9 km
	Bang Na - Khlong Toei	On ramp	1 km
		* Bang Na toll plaza	1.5 km
		On ramp	2.7 km
		Sukhumvit 62 toll plaza	3.2 km
		On ramp	3.4 km
		At Narong toll plaza	6.4 km
		On ramp	7 km
		Off ramp	7.4 km
		Port 1 toll plaza	7.9 km
		On ramp	8.3 km
		Diverge	8.7 km
Chalerm Mahanakhon (Out-Bound)	Khlong Toei - Din Daeng	Merge	100 m
		Merge	800 m
		Rama IV-2 toll plaza	1 km
		On ramp	1.1 km
		Sukhumvit toll plaza	3.1 km
		On ramp	3.3 km
		Diverge	4.7 km
		Merge	5.2 km
	Khlong Toei - Dao Khanong	Off ramp	1.4 km
		Off ramp	2.9 km
		Sathu Pradit 2 toll plaza	3.7 km
		On ramp	4.2 km
		Off ramp	7.2 km
	Khlong Toei - Bang Na	Off ramp	700 m
		Port 2 toll plaza	1.2 km
		On ramp	1.7 km
		Off ramp	2.4 km
		Diverge	4.2 km
		At Narong 1 toll plaza	4.7 km
		Merge	5.3 km

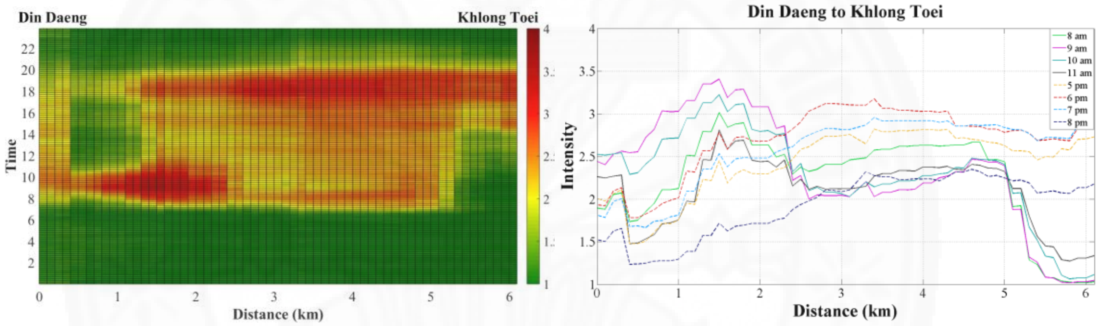
* Toll plaza on the elevated structure

4.1.1.1 Congestion Patterns on Working Days

Results of traffic congestion patterns of working day on the expressway from, Din Daeng to Khlong Toei, Dao Khanong to Khlong Toei, and Bang Na to Khlong Teoi are discussed first.

In figures of speed map, the horizontal axis represents the distance and the vertical axis represents time. Colors in the speed map show the traffic condition free flow, moderated flow, congested flow, and heavy congested flow. These colors are indexed by the traffic intensity from number 1 to 4. Results of traffic patterns in each section of the expressway can be described as follows:

- **Patterns from Din Daeng to Khlong Toei**



(A-1) (A-2)

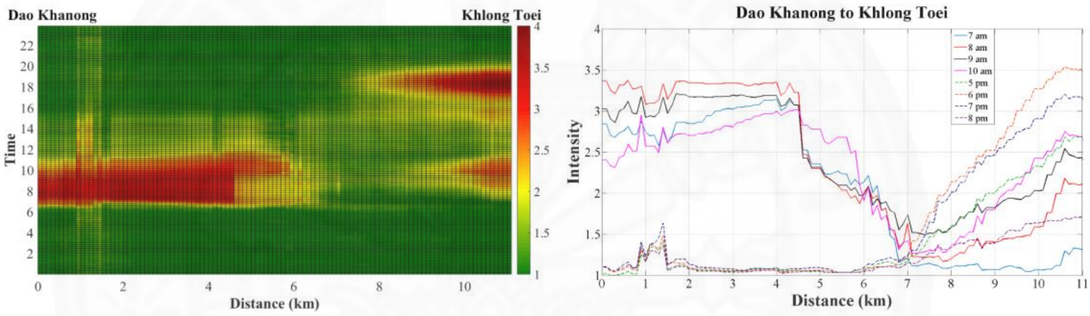
Figure 4.2 Traffic patterns on working days from Din Daeng to Khlong Toei

Traffic volume starts increasing around the beginning of the road. Normally, traffic congestions occur between 8 o’clock to 10 o’clock in the morning and 5 o’clock to 7 o’clock in the evening that is known as peak hour. Most of the daytime, traffic intensity is high on Din Daeng to Khlong Toei section. Traffic intensity of specific times is presented in the figure 4.2(A-2) above.

Based on points of interest of the expressway, traffic congestions occur from the beginning of the road to an on ramp at Phetchaburi toll plaza which located 2.5 km from Din Daeng (morning peak). For evening peak, starting from off ramp at 900 meters from Din Daeng to the end of the road, there is a big traffic congestion.

By investigating 4 specific times in the morning (8 am, 9 am, 10 am, and 11 am) we can see that the traffic condition at 9 am around a merging (1.6 km) before Phetchaburi toll plaza is very congested. The highest traffic intensity is 3.4. Then, it releases between 2 to 2.7 (within these 4 specific times) after Phetchaburi toll plaza to an off ramp before Rama IV-1 toll plaza (2.5 km to 5.2 km from Din Daeng). For the other 4 specific times in the evening (5 pm, 6 pm, 7 pm, and 8 pm), it is observed that after 1 km from Din Daeng, traffic volume is increasing during 5 pm to 7 pm. Severe traffic congestions occur at 6 pm from Petchaburi toll plaza to Rama IV-1 toll plaza. The highest traffic intensity at this time is about 3.2. Traffic intensity is decreased after 7 pm, however, at 8 pm from 3 km after Din Daeng to Khlong Toei, the condition of traffic still in a state between moderated flow and congested flow.

- **Patterns on Dao Khanong to Khlong Toei**



(A-3) (A-4)

Figure 4.3 Traffic patterns on working days from Dao Khanong to Khlong Toei

Dao Khanong to Khlong Toei (11.6 km) is the 2nd link of the expressway heading to the city. Normally, traffic intensity is high during peak period, morning peak and evening peak. A big traffic congestion start from 7 am to 10 am at the beginning of the road, Dao Khanong region, to an on ramp at Suksawat toll plaza region (4.2 km). At the end of this link around River Side toll plaza (10.5 km, Khlong Toei area), there is a small congestion occurring from 9 am to 10 am. During peak hour in the evening, traffic condition changes from free flow to congested flow at a merging (8 km from Dao Khanong) before Sathu Pradit 1 toll plaza to Khlong Toei region.

Figure 4.3(A-4) presents traffic congestion patterns from Dao Khanong to Khlong Toei in some specific times both in the morning and in the evening. Usually, at 8 am traffic state on Dao Khanong to Khlong Toei section is the most congested time in the morning, and traffic intensity varies from 3.1 to 3.4 between Dao Khanong and Suksawat toll plaza section. The congestion releases after 9 am and it peaks again at around the end of the section about 10 am.

By investigating traffic state in the evening peak, normally traffic condition is free from Dao Khanong to Rama III toll plaza (0 km to 6.9 km). Traffic intensity start increasing up to 3.5 at 6 pm around the River Side toll plaza. The intensity is decreasing at 7 pm and it becomes lower until free flow at 8 pm.

- **Patterns from Bang Na to Khlong Toei**

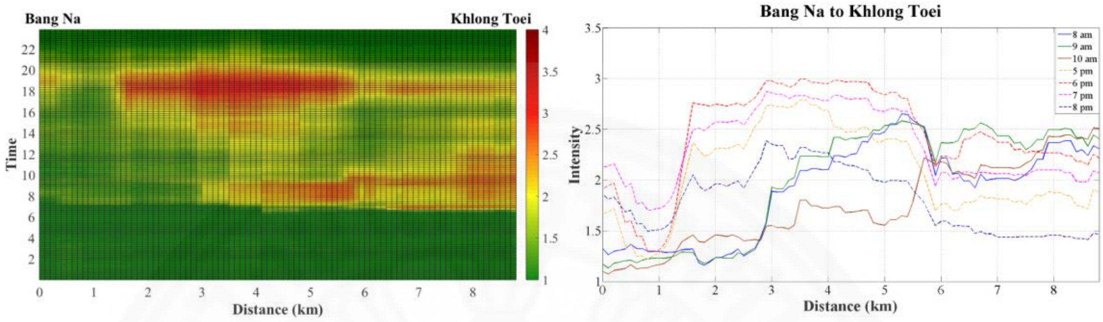


Figure 4.4 Traffic patterns on working days from Bang Na to Khlong Toei

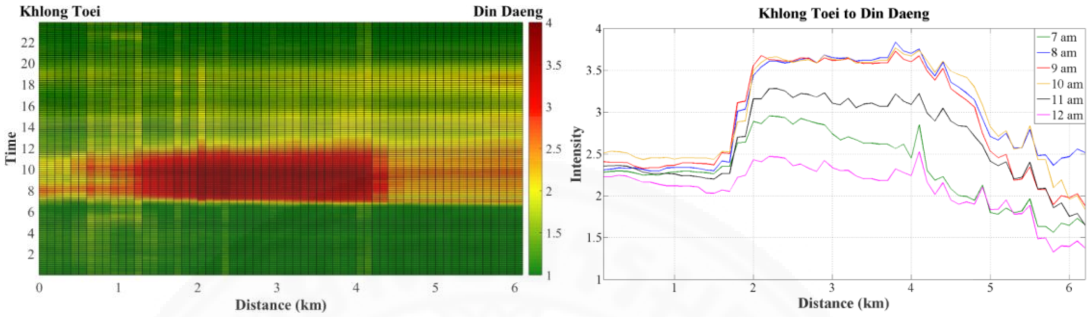
There are two locations that should be noticed on Bang Na to Khlong Toei section. The first location is starting from an on ramp at 3.4 km from Bang Na to Khlong Toei region where the traffic condition varies between moderated flows to congested flows in the morning period. The second location is between the Bang Na toll plaza and At Narong toll plaza (1.5 km to 6.4 km from Bang Na) where there is a long traffic congestion which take place during evening peak hours from 5 pm to 8 pm. Some specific times of traffic patterns on this section are presented in figure 4.4(A-6).

Normally, traffic intensity is increasing and vary from 2 to 2.6 from 8 o'clock to 9 o'clock in the morning near an on ramp (3.4 km from Bang Na) to Khlong Toei region. The intensity drop down at 10 am between 3 km and 6 km from Bang Na region, however, traffic condition still in the state between moderated flow and congested flow at Bang Na region (traffic intensity is 2 to 2.5).

For evening peak, traffic intensity starts increasing and it becomes congested at 6 pm at an on ramp of Sukhumvit 62 toll plaza which located at 3.2 km from Bang Na and the congestion last approximately 2.5 km, then it releases little by little. It is observed that between 6 pm to 8 pm traffic intensity is decreasing to free flow at Khlong Toei region.

Traffic congestion patterns on Chalerm Mahanakhon expressway in-bound from Din Daeng to kalongs Toei, Dao Khanong to Khlong Toei, and Bang Na to Khlong Toei have discussed already. Now traffic condition of out-bound, Khlong Toei to Din Daeng, Khlong Toei to Dao Khanong, and Khlong Toei to Bang Na are presented.

- **Patterns from Khlong Toei to Din Daeng**



(A-7) (A-8)

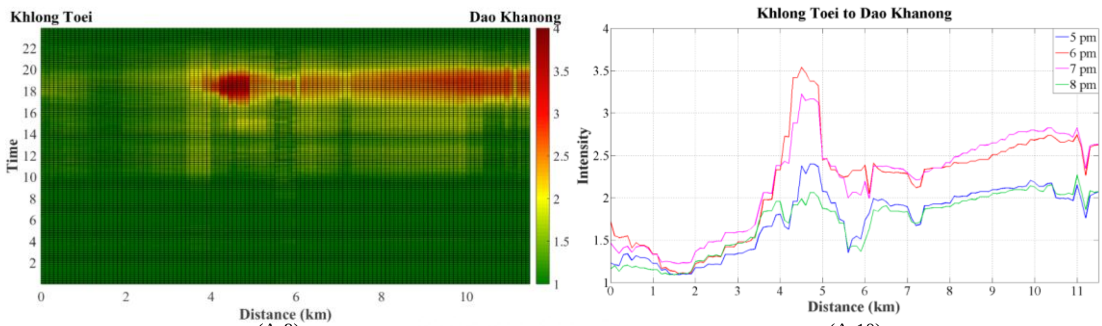
Figure 4.5 Traffic patterns on working days from Bang Na to Khlong Toei

Based on speed map showing in figure 4.5(A-7), there is a big traffic congestion happens in the morning around 7 am to 11 am. The congestion starts taking place from an on ramp after Rama IV-2 toll plaza (1.1 km from Khlong Toei) and it releases before a diverging, located at 4.7 km from Khlong Toei. It is observed that, traffic flow on Khlong Toei to Din Daeng section comes from Bang Na to Khlong Toei section and Dao Khanong to Khlong Toei section. That is one reason that cause the traffic condition on Khlong Toei to Din Daeng section becomes congested.

The patterns in some specific times in the morning on Khlong Toei to Din Daeng section is presented in the figure 4.5(A-8) above. Normally, traffic intensity is very high in the morning, especially from 8 am to 11 am between 1.7 km and 5 km from Khlong Toei. Within this period, traffic intensity on this section varies from 2.5 to 3.84 which indicates that it is in a congested flow and heavy congested flow. However, traffic condition on this section changes from congested flow to moderated flow and up to free flow after 12 am until midnight.

- **Patterns from Khlong Toei to Dao Khanong**

The speed map on Khlong Toei to Dao Khanong section shows in figure 4.6 that, most of the time traffic conditions on this section are free. However, there are two locations of the congestion occur in the evening. One is between 4 km and 5 km after Khlong Toei and the other one is about 8 km from Khlong Toei to Dao Khanong region.

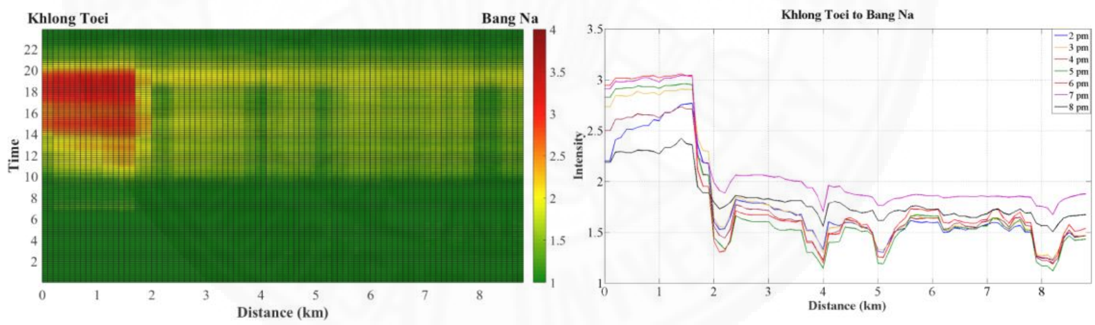


(A-9) (A-10)

Figure 4.6 Congestion patterns on working days from Khlong Toei to Dao Khanong

By investigating on points of interest on this section, the congestion occur around on ramp of Sathu Pradit 2 toll plaza (4.2 km to 5 km from Khlong Toei). According to the results in figure 4.6(A-10), around that location during 6 pm and to pm traffic intensity is high up to 3.51 which is considered as heavy congestion. After that the intensity dropped to 2.4, and it slightly increases up to 2.8 at the end of the section.

- **Patterns from Khlong Toei to Bang Na**



(A-11) (A-12)

Figure 4.7 Congestion patterns on working days from Khlong Toei to Bang Na

Traffic flow on Khlong Toei to Bang Na section comes from the flow from Din Daeng to Khlong Toei and Dao Khanong to Khlong Toei. Therefore, from Khlong Toei to Bang Na direction, traffic congestion occurs only in the evening around Khlong Toei region to an on ramp after Port 2 toll plaza (at the location of 1.7 km from Khlong Toei). Traffic intensity of some specific times is provided in figure 4.7(A-12). Based on traffic flow from Din Daeng to Khlong Toei and from Dao Khanong to Khlong Toei in the evening, it is observed that at 5 pm to 7 pm traffic intensity at the end of both sections are high between 2.7 to 3.5. Hence, traffic intensity is also high at the beginning of Khlong Toei to Bang Na section about 1.7 km from Khlong Toei. After that, traffic congestions release from congested flow to moderated flow from that location until Bang Na.

4.1.1.2 Congestion Patterns on Saturdays, Sundays & Holidays

Normally, traffic condition on Chalerm Mahanakhon expressway during Saturday, Sunday, and holiday looks better than the condition on general working days in term of traffic congestion. Results of traffic patterns and congestion patterns on Saturday, Sunday, and Holiday on this expressway are respectively presented by speed map showing in the figures below:

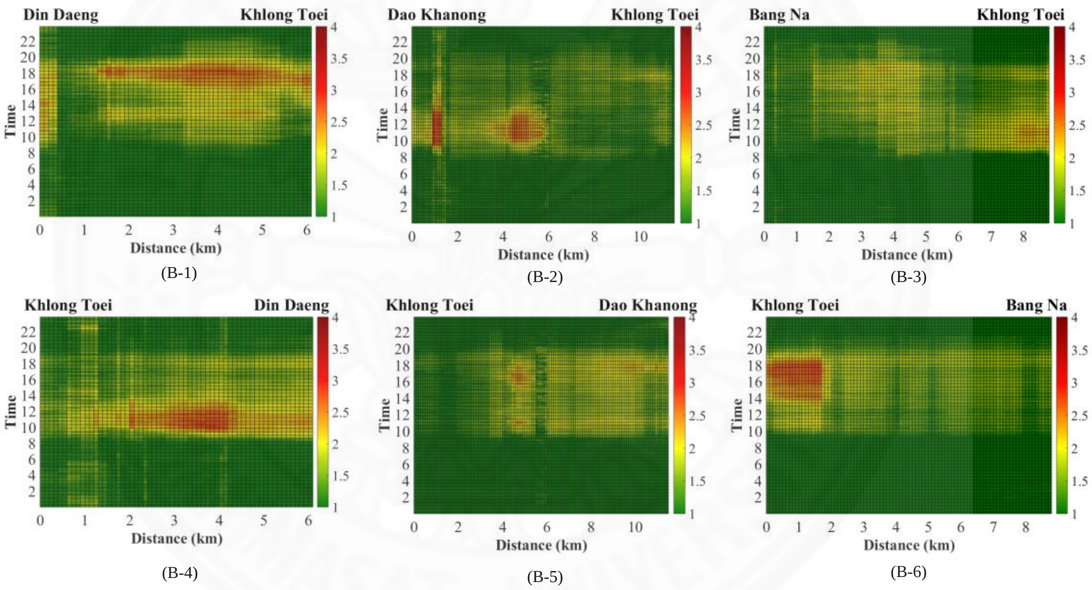
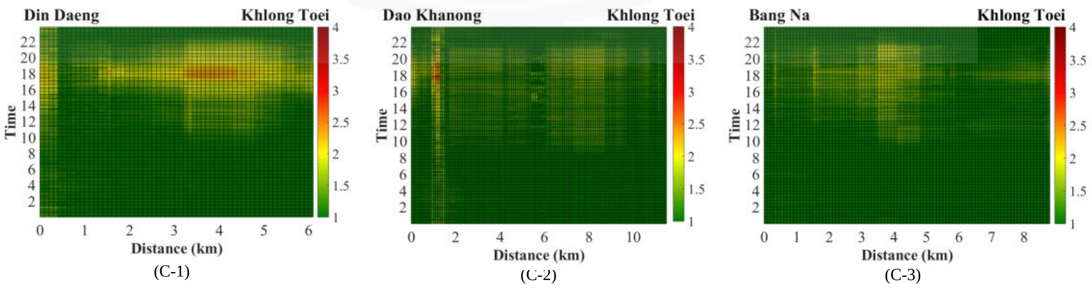


Figure 4.8 Traffic patterns on Saturdays



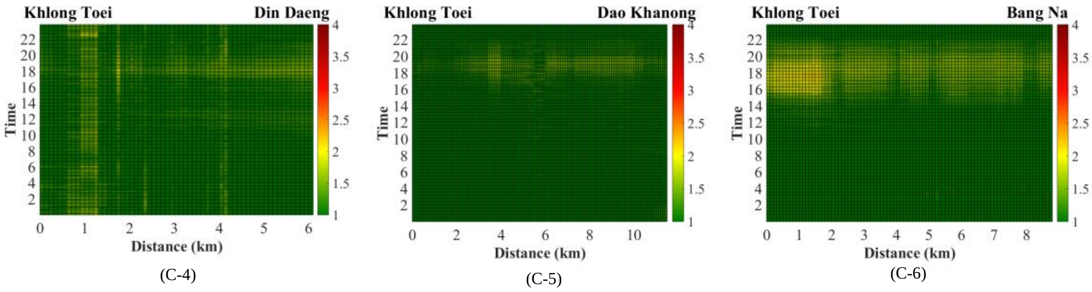


Figure 4.9 Traffic patterns on Sundays

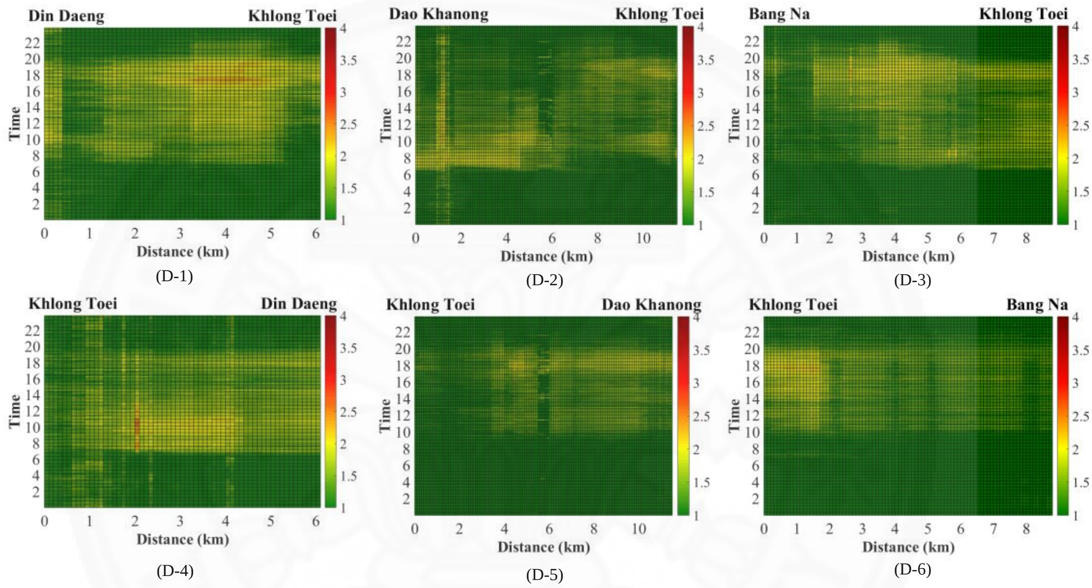


Figure 4.10 Traffic patterns on Holidays

According to these results from 3 categories of traffic state data (Saturdays, Sundays, and holidays), there is no serious traffic congestion on the Chalerm Mahanakhon expressway both in-bound and out-bound like normal working days. The patterns of traffic on Sundays show that most of the time traffic conditions on Chalerm Mahanakhon expressway is free in both direction, in-bound and out-bound. However, it is observed that, there is a fluctuation of traffic at Din Daeng toll plaza on Din Daeng to Khlong Toei section (400 meter from Din Daeng) and Dao Khanong toll plaza on Dao Khanong to Khlong Toei section (1.2 km from Dao Khanong). Besides, there is an amount of traffic occur on Din Daeng to Khlong Toei section which cause traffic condition becomes moderated flow in the evening around 6 pm to 7 pm. The change of traffic condition occurs near a merge before Phetchaburi toll plaza (1.6 km from Din Daeng) to the end of the section.

For traffic patterns during holidays, there are more traffic on this expressway compare to Sunday's patterns. Normally starting from 8 am to 8 pm, traffic state on Chalerm Mahanakhon expressway is moderated flow. According to the results we can know that people travel more on holiday compare to Sunday which is the only day off for them to rest at home after the whole week working. However, in overall there is no traffic congestion on the expressway during holidays.

Different from Sundays or holidays, on Saturdays some companies in Thailand still open, people still need to go to work, that's why there are some congestion areas on the expressway. By looking into in-bound direction, Din Daeng to Khlong Toei and Bang Na to Khlong Toei, there is a fluctuation of traffic occur at the toll plaza area as usual. In figure 4.8(B-2), it is observed that there is a short congestion occurs at Dao Khanong toll plaza, then there is a small congestion occurs around an on ramp after Suksawat toll plaza (4.2 km to 5 km from Dao Khanong). For Din Daeng to Khlong Toie section, there is a long congestion takes place near a merge before Phetchaburi toll plaza (1.6 km from Din Daeng) to the end of the section. Normally, the congestion of this section occurs in the evening around 6 pm and the highest traffic intensity is 2.8. For another section, Bang Na to Khlong Toei, usually traffic condition is moderated flow from 9 am to 7 pm along the road.

Looking to the opposite direction of these 3 links, Khlong Toei to Din Daeng, Khlong Toei to Bang Na, and Khlong Toei to Dao Khanong, we can see that traffic congestion occur at two locations. One is on the Khlong Toei to Din Daeng direction. The congestion start around 10 am to 12 am before Sukhumvit toll plaza which located at 3.1 km form Khlong Toei and it releases around a diverge at 4.7 km. The other location of traffic congestion is around Khlong Toei region where the flow comes from Din Daeng and Dao Khanong in the evening. The congestion occur from the beginning of the road until Port 2 toll plaza (1.2 km).

4.1.2 Traffic Congestion Patterns on Sirat Expressway

Traffic patterns and congestion patterns on Sirat expressway of working days, Saturdays, Sundays, and holiday will be discussed based on links in the scope of study. To understanding about traffic condition, traffic congestion on expressway, map showing structure of the expressway and points of interest such as locations of toll plaza, locations of entrance and exit are offered as follow:

Table 4.3 Points of interest on Sirat expressway

Expressway	Origin - Destination	Ramp / Toll plaza	Distance from beginning of route
Sirat (In-Bound)	Pak Kret - Ratchathewi	On ramp	700 m
		Off ramp	4.4 km
		Ngam Wong Wan toll plaza	4.7 km
		On ramp	5.1 km
		On ramp	5.8 km
		* Pracha Chuen toll plaza	7 km
		Ratchadaphisek toll plaza	8.3 km
		On ramp	8.6 km
		Bang Sue toll plaza	10.7 km
		On ramp	11.1 km
		Phahol Yothin toll plaza	12.6 km
		On ramp	12.8 km
		Diverge	14.3 km
		Klong Prapa toll plaza	14.4 km
		On ramp	14.5 km
		Diverge	15.1 km
		Merge	15.6 km
	Bang Khlo Laem - Ratchathewi	Off ramp	500 m
		Dan Chan toll plaza	1.3 km
		Off ramp	1.3 km
		On ramp	1.9 km
		Surawong	3.4 km
		On ramp	3.6 km
		Off ramp	4 km
		Hua Lamphong toll plaza	4.8 km
		On ramp	5 km
		Off ramp	5.7 km
		Yomarat toll plaza	6.9 km
		On ramp	7.1 km
		Off ramp	8.7 km
	Suan Luang - Ratchathewi	* Si Nakarin toll plaza	3.1 km
		Off ramp	4.6 km
		Rangkhamhaeng toll plaza	4.9 km
		On ramp	5 km

		On ramp	5.7 km
		Off ramp	6.4 km
		* A Soke toll plaza	8.5 km
		On ramp	8.7 km
		On ramp	9.2 km
		Off ramp	10 km
		On ramp	10.7 km
		Off ramp	11.6 km
		Phahol Yothin 2 toll plaza	12.2 km
		On ramp	12.5 km
Sirat (Out-Bound)	Ratchathewi - Pak Kret	Off ramp	100 m
		Off ramp	1.7 km
		Klong Prapa 1 toll plaza	1.8 km
		On ramp	1.8 km
		Off ramp	2.7 km
		Off ramp	4.7 km
		Off ramp	7.2 km
		* Pracha Chuen toll plaza	8.7 km
		Off ramp	9.9 km
		Off ramp	10.6 km
		Ngam Wong Wan toll plaza	11.2 km
		On ramp	11.6 km
		On ramp	15 km
	Ratchathewi - Bang Khlo Laem	Merge	400 m
		Off ramp	1.7 km
		Urupong toll plaza	1.9 km
		On ramp	2.3 km
		Off ramp	3.8 km
		Saphan Sawang toll plaza	4.6 km
		On ramp	4.8 km
		Off ramp	5.6 km
		Sathon toll plaza	6.6 km
		Off ramp	6.9 km
		On ramp	7.4 km
		Off ramp	9.1 km
	Ratchathewi - Suan Luang	Off ramp	300 m
		Phahol Yothin 1 toll plaza	800 m
		On ramp	1.1 km
		Diverge	2.1 km
		Merge	2.7 km

		Diverge	3.8 km
		* A Soke toll plaza	4.5 km
		Merge	4.8 km
		Rama IX toll plaza	6.1 km
		On ramp	6.4 km
		Diverge	7.1 km
		Rama IX-1 toll plaza	7.4 km
		Merge	7.6 km
		Off ramp	10.5 km

* Toll plaza on the elevated structure

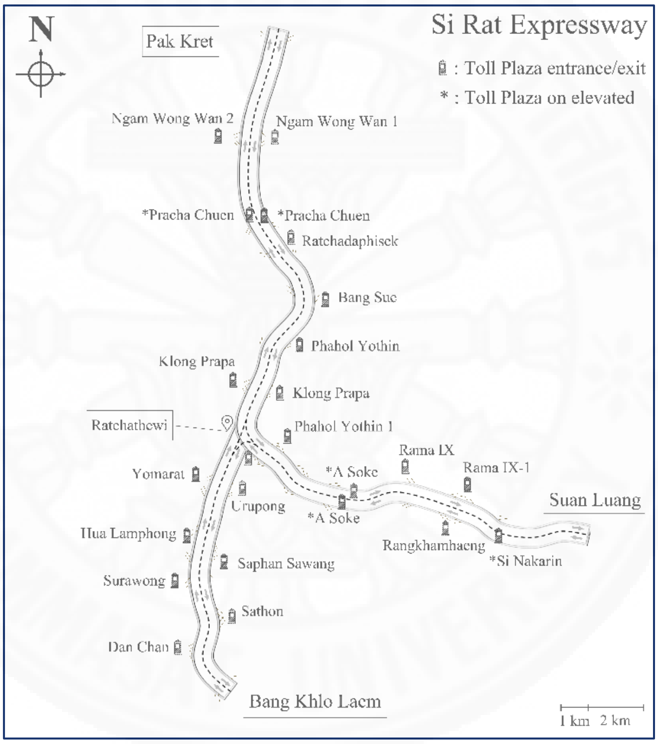
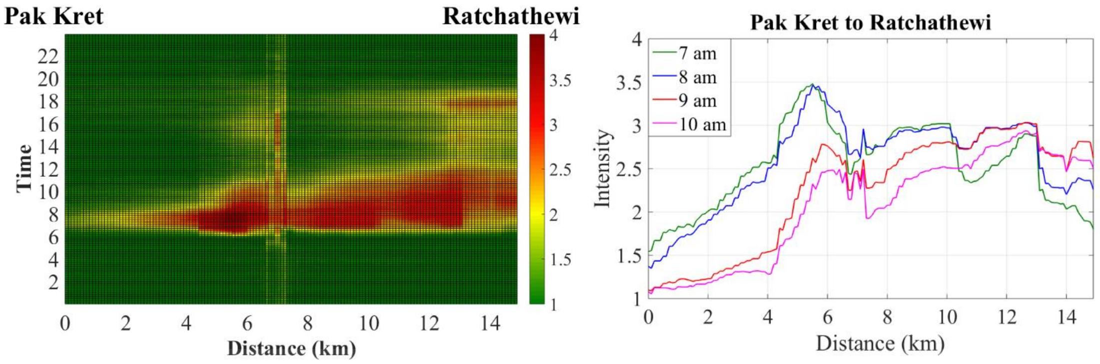


Figure 4.11 Map of Sirat expressway

4.1.2.1 Congestion Patterns on Working Days

Results of traffic patterns and congestion patterns on Sirat expressway in-bound of each link are presented in speed map and graph below.

- **Patterns on Pak Kret to Ratchathewi**



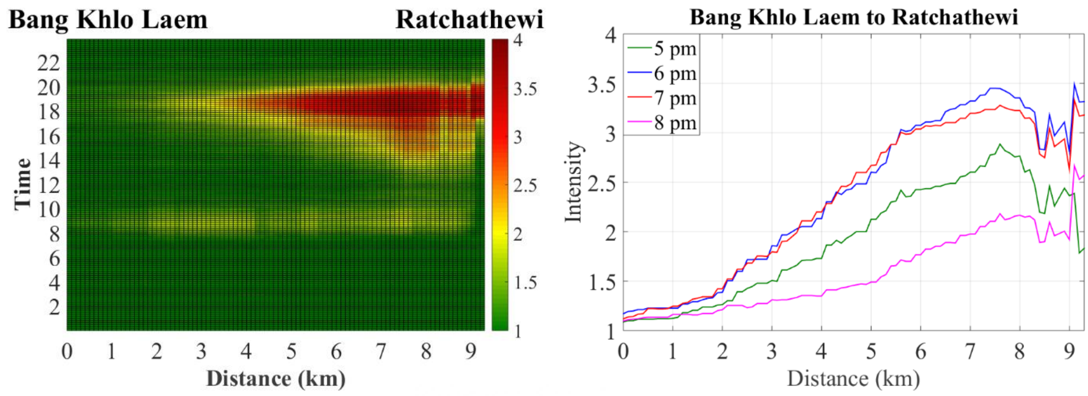
(E-1) (E-2)

Figure 4.12 Traffic patterns on working days from Pak Kret to Ratchathewi

According to results in speed map, figure 4.12(E-1), it is observed that there is a big traffic congestion occur in the morning from 7 am to about 10 am on Pak Kret to Ratchathewi section. Based on the points of interest on this section, the congestion takes place and becomes serious around Ngam Wong Wan toll plaza (4.7 km from Pak Kret) to the end of the section in Ratchathewi region. Figure 4.12(E-2) provides a visualization of traffic intensity in specific times of the morning peak. It is clear that normally traffic intensity is increasing and it has a peak during 7 am to 8 am around an on ramp at 5.7 km from Pak Kret. The highest traffic intensity is about 3.5, this index shows that there is a heavy congestion occur at that location. After passing the peak location, traffic intensity drops down and it remains between 2.8 and 3.1 which is still in the congestion state. Traffic congestion start releasing by time and traffic intensity is dropping down. However, traffic congestion until exist around an on ramp at Phahol Yothin toll plaza (12.8 km from Pak Kret) within those 4 hours. After that, the intensity start decreasing at the end of the section.

- **Patterns on Bang Khlo Laem to Ratchathewi**

Results of traffic congestion patterns on Bang Khlo Laem to Ratchathewi section (9.4 km) are presented in the figure 4.13 below. Based on results showing in speed map, figure 4.13(E-3), normally on working days there is a big traffic congestion occurs in the evening. This congestion happens around 5 km from Bang Khlo Laem heading to Ratchathewi region. Traffic intensity during peak period are presented in figure 4.13(E-4). This figure shows that, traffic intensity during evening peak are significantly increasing especially from 6 pm to 7 pm.

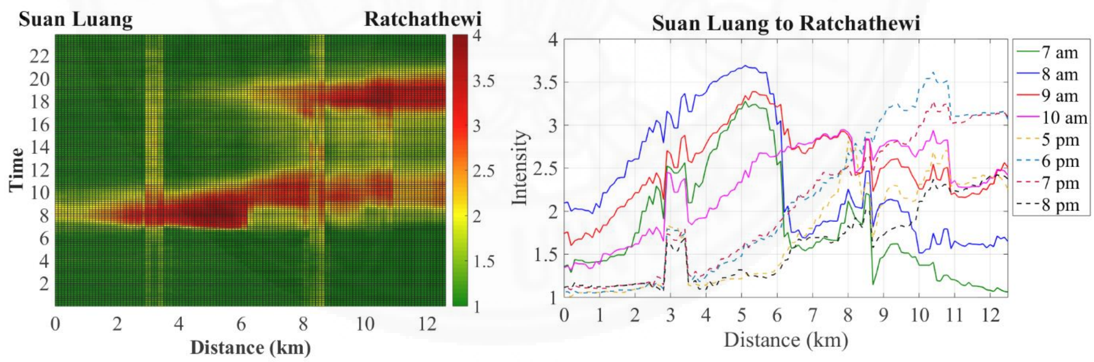


(E-3) (E-4)

Figure 4.13 Traffic patterns on working days from Bang Khlo Laem to Ratchathewi

It is observed that traffic intensity start increasing at a location of 2 km from Bang Khlo Laen until it peaks around an on ramp at Yomarat toll plaza area (7.1 km from Bang Khlo Laem) which the highest traffic intensity is 3.5. Traffic intensity drops down after an off ramp at 8.7 km, then it quickly go up again at the end of the section.

- **Patterns on Suan Luang to Ratchathewi**



(E-5) (E-6)

Figure 4.14 Traffic patterns on working days from Suan Luang to Ratchathewi

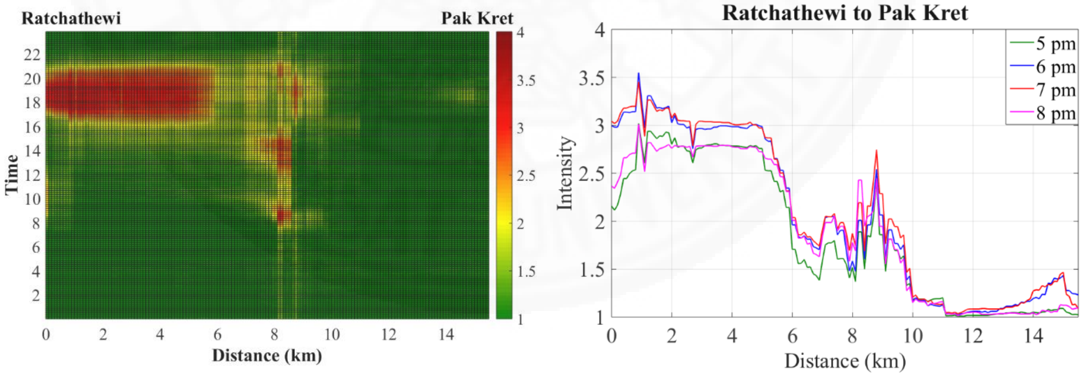
Results of traffic congestion patterns on Suan Luang to Ratchathewi section are presented in the figure 4.14 above. Based on results showing in speed map in figure 4.14(E-5), normally there are two big congestion locations on working days. First location, traffic congestion occurs at Si Nakarin toll plaza (3.1 km from Suan Luang) up to an off ramp (11.6 km) in the morning 7 am to 10 am. Second location, traffic congestion occurs in the evening and begin from A Soke toll plaza (8.5 km) to the end of the section (Ratchathewi region). Some specific times of the congestion are visualized by traffic intensity in figure E-6. It is observed that, traffic is peak at 8 am which the intensity is 3.7 (heavy congested) at an on ramp of Rangkhamhaeng toll plaza. Then, it drops down to moderated flow after an off ramp at 6.4 km. After a peak at Rangkhamhaeng region, traffic intensity is still high during 9 am to 10 am between 6 km to 11 km on this section.

For the evening, we can see that there is a peak at 6 pm (intensity is 3.6) at an on ramp location (about 2 km before Ratchathewi) and it continues congested until Ratchathewi area at 7 pm. However, at 8 pm we can see traffic flow is significantly dropping down.

These are results of congestion patterns on Sirat expressway in-bound direction, from Pak Kret, Bang Khlo Laem, Ratchathewi, and Suan Luang going to Ratchathewi. Now, results of out-bound direction, from Ratchathewi go to Pak Kret, Suan Luang, and Bang Khlo Laem will be discussed in the following.

• Patterns on Ratchathewi to Pak Kret

According to the results in the figure 4.15, it is observed that there is a big congestion area occurs in the evening about 5 pm to 8 pm around Ratchathewi region.



(E-7) (E-8)

Figure 4.15 Traffic patterns on working days from Ratchathewi to Pak Kret

It is notice that, flow in Ratchathewi region come from flow of Suan Luang and Bang Khlo Laem. As having discussed in the congestion patterns from Suan Luang to Ratchathewi and Bang Khlo Laem to Ratchathewi above, the congestion normally occurs at Ratchathewi region during evening. This is one of the reason why there is a big congestion around Ratchathewi area on Ratchathewi to Pak Kret section. By investigate the traffic intensity in the figure 4.15(E-8), traffic intensity during evening time (5 pm to 8 pm) is high at Ratchathewi region to an off ramp at 4.7 km. Within this length traffic intensity is vary from 3 to 3.5 that is in the condition of congested flow.

- **Patterns from Ratchathewi to Suan Luang**

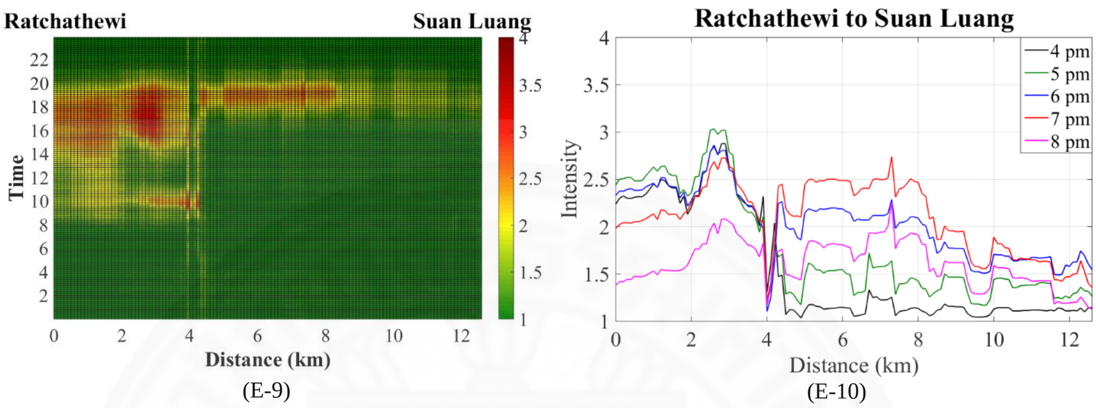


Figure 4.16 Traffic patterns on working days from Ratchathewi to Suan Luang

As we have known, traffic flow at Ratchathewi comes from Pak Kret and Bang Khlo Laem. According to the congestion patterns discussed in the previous section, there is a big congestions occur in the evening at Ratchathewi region on Bang Khlo Laem to Ratchathewi link. Thus, there are also the congestion patterns at Ratchathewi area on Ratchathewi to Suan Luang section. Normally, the congestion starts about 4 pm to 8 pm around Ratchathewi region to A Soke toll plaza (4.5 km from Ratchathewi). Based graph shown in figure 4.16(E-10), there is a peak from 4 pm to 7 pm at a merge about 2.7 km from the beginning of the road. However during evening, traffic intensity on this link is vary from 2 to 2.5 that revealed that the condition on the road is moderated flow except the merge location at 2.7 km.

- **Patterns on Ratchathewi to Bang Khlo Laem**

For Ratchathewi to Bang Khlo Laem section, it is observed that normally there is a congestion patterns occur during morning from 8 am to 12 pm. The congestion may cause by the flow from Pak Kret and Suan Luang. However, this congestion takes place about 1 km round Ratchathewi region. The congestion patterns are presented in the figure below:

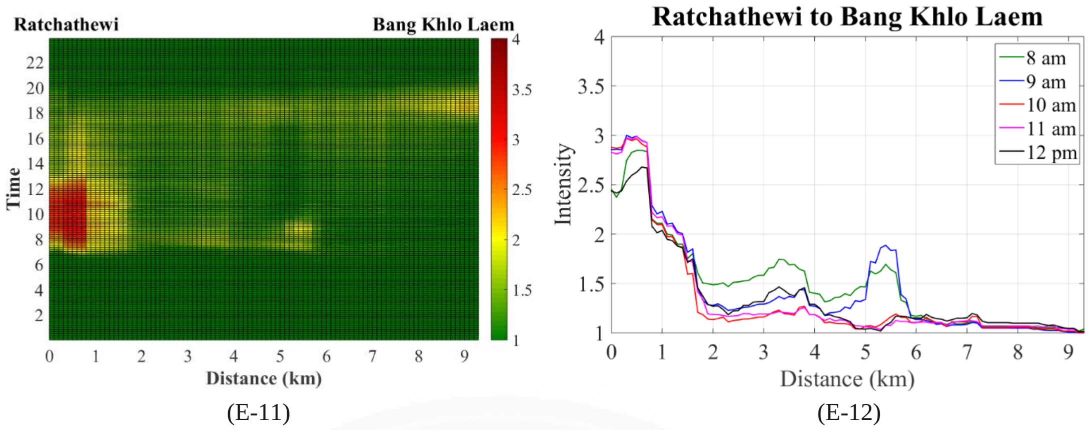


Figure 4.17 Traffic patterns on working days from Ratchathewi to Bang Khlo Laem

Normally, traffic condition on Ratchathewi to Bangkhlo Laem is free. Based on the results show in figure 4.17 above, there is a short length congestion patterns occur about 4 hours in the morning at a merge 400 meter from the Ratchathewi go to Bang Khlo laem. The highest traffic intensity is about 3 at that region, after that the intensity drop to the free flow.

4.1.2.2 Congestion Patterns on Saturdays, Sundays, & Holiday

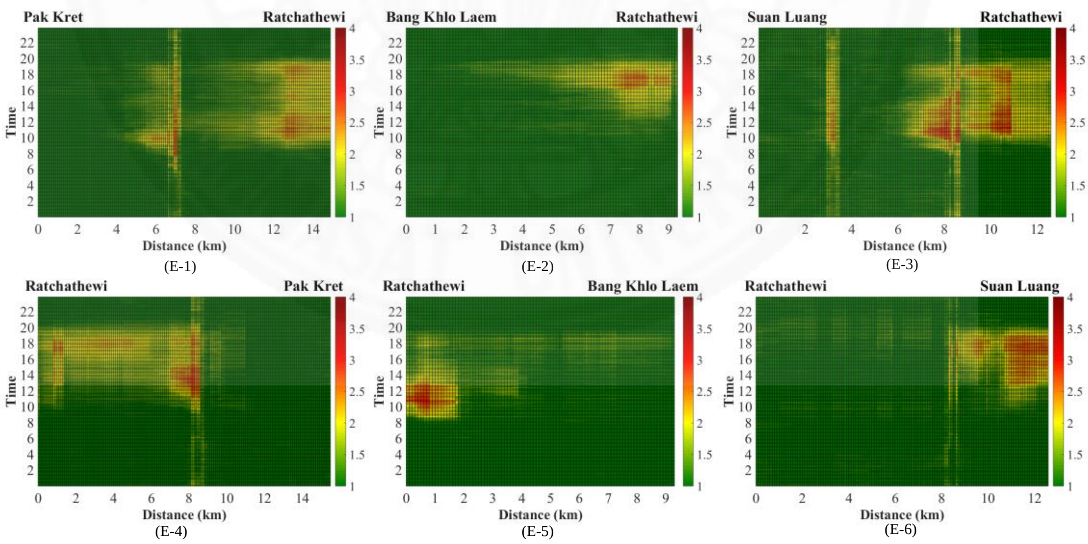


Figure 4.18 Traffic patterns on Saturdays on Sirat expressway

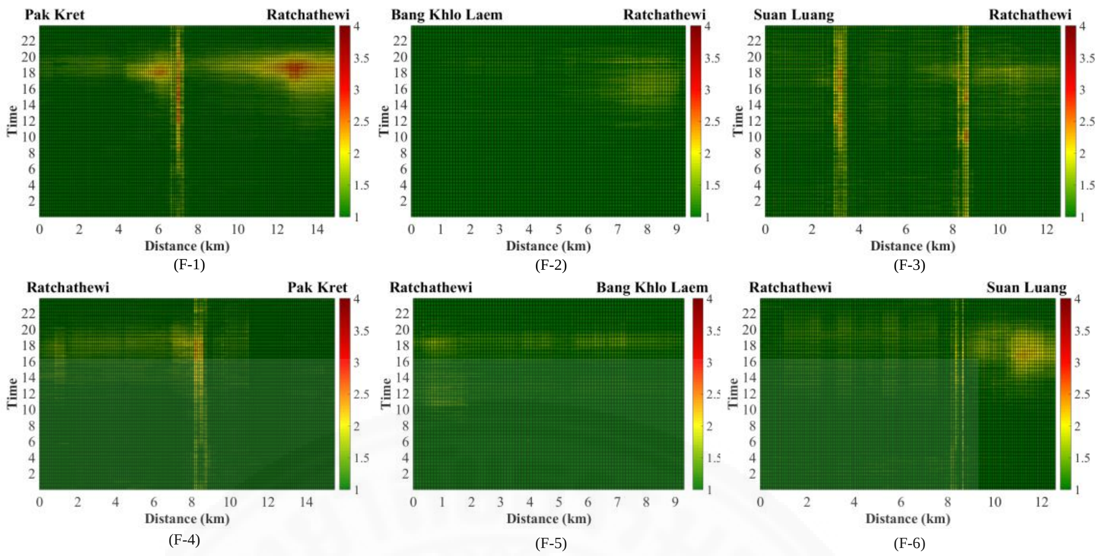


Figure 4.19 Traffic patterns on Sundays on Sirat expressway

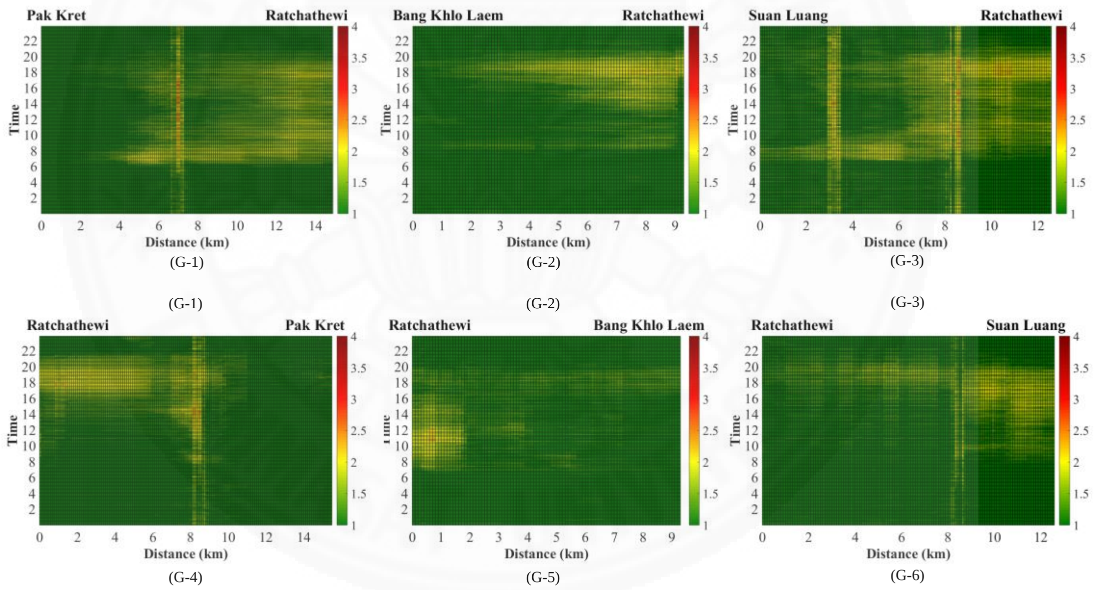


Figure 4.20 Traffic patterns on holidays on Sirat expressway

Different from general working days, traffic congestion on weekends or on holidays look better since there are less congestion than it usual. According to results of traffic congestion patterns on Saturday showing in figure 4.18 above, usually there are more traffic at toll plaza locations and around Ratchathewi region compare to the patterns on Sunday and holiday. Normally, start from afternoon until evening there are more traffic around Ratchathewi. However, there is no any serious congestion is noticed as it usual have on working days. Figure 4.19 and 4.20

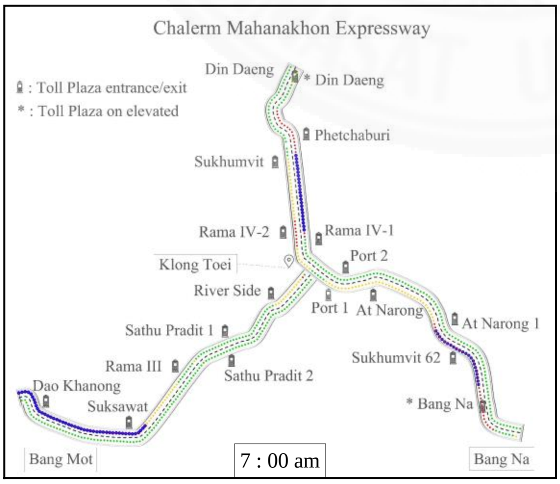
indicate that, most of the time on Sunday or holiday traffic conditions on Sirat expressway is free.

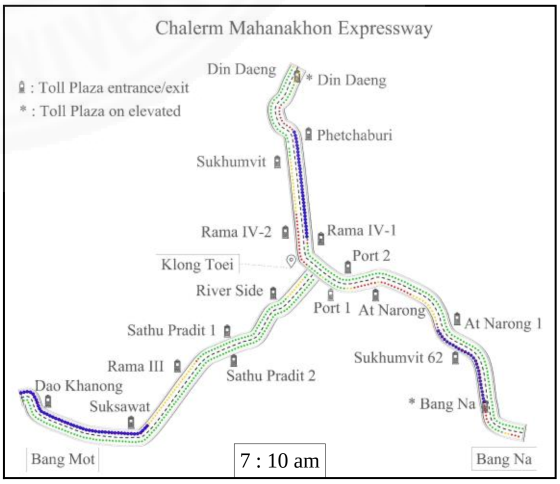
4.2 Severe Traffic Congestion on Expressways

The two important of variables determination for severe traffic congestion are duration and length of traffic congestion. When these two parameters are set to be small value, traffic congestion will be alerted a lot that can be disturb to the road users and traffic controllers. On the other hand, when these two parameters are set to be high or big value, the alerting of the severe congestion will be less and sometimes small severe congestion will be neglected.

However, in this study the duration of 3 time-steps, 30 min, and 10 points, length of congestion 1 km, are set for the severe congestion. Results of severe traffic congestion are presented in figures as below. Colors on the expressways indicate real time traffic state on expressway. There are 5 displayed colors which are used for indicating traffic condition. Green color indicates free flow, yellow color indicates moderated flow, red color indicates congested flow, dark red color indicates heavy congested flow, and blue color indicates severe congestion that corresponds to the condition of the parameters that have been set.

1.2.1 Severe Traffic Congestion on Chalerm Mahanakhon Expressway





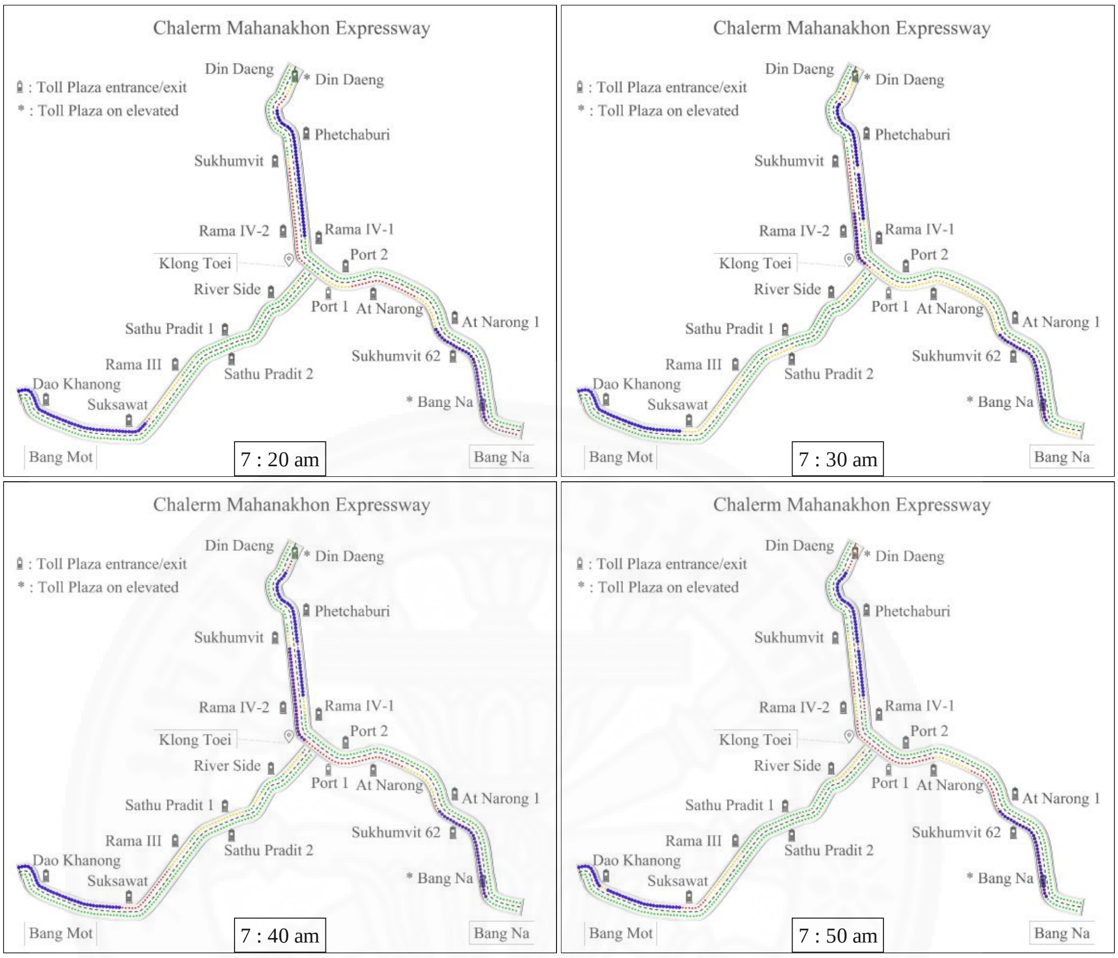
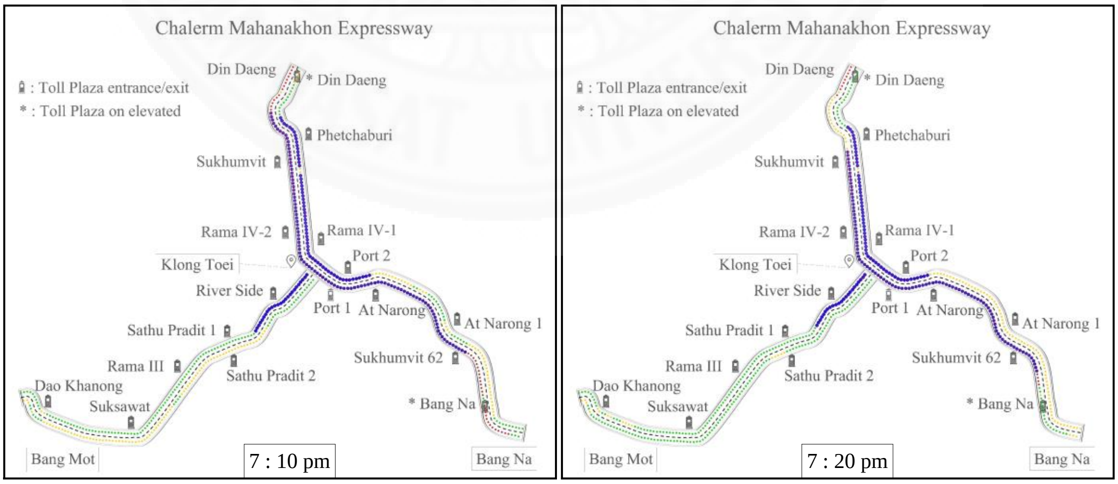


Figure 4.21 Severe traffic congestion detected on May 17, 2016 (Morning)



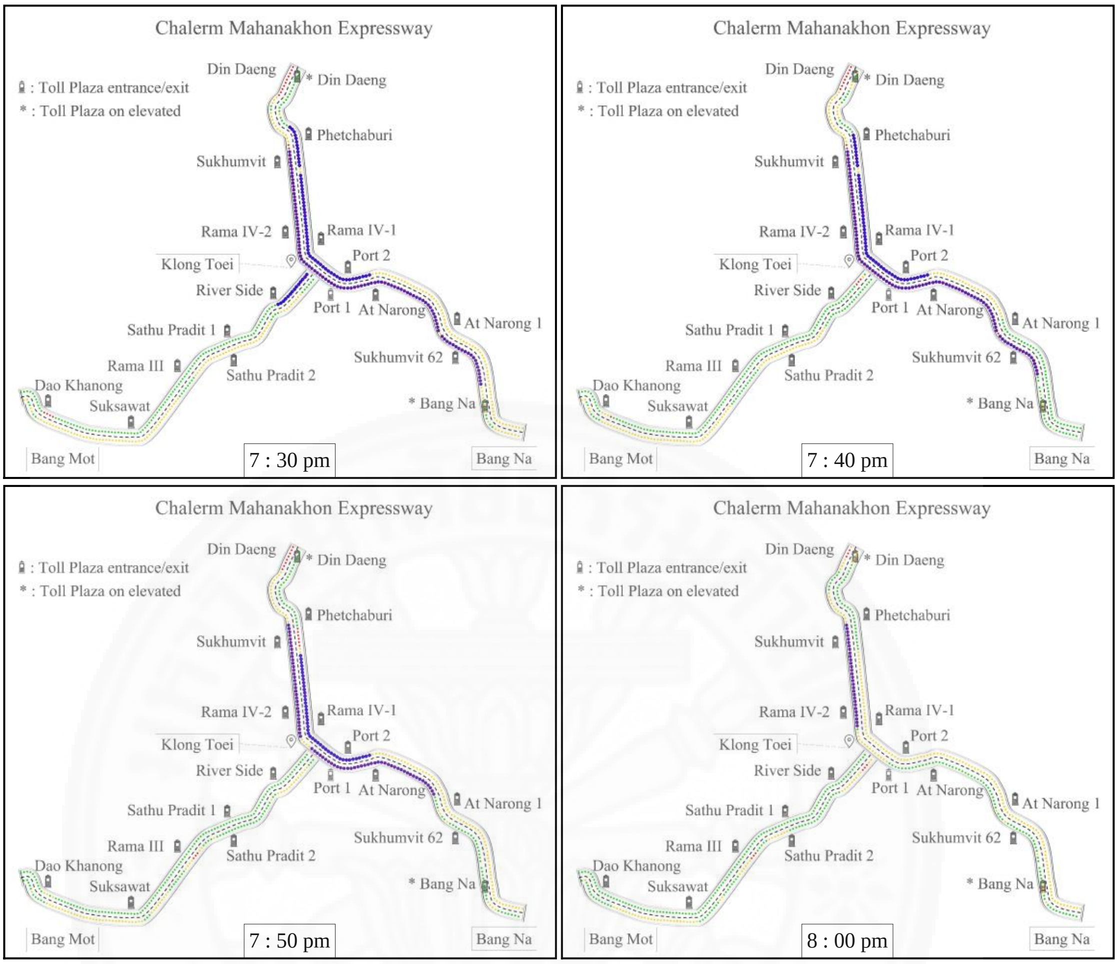


Figure 4.22 Severe traffic congestion detected on May 17, 2016 (Evenning)

Results above present the severe traffic congestion on Chalerm Mahanakhon expressway which are detected on May 17, 2016 during morning from 7 am to 8 am and evening from 7 pm to 8 pm.

- **Severe traffic congestion in the morning**

For in-bound direction, on the first link of this expressway, Din Daeng to Khlong Toei, there is a severe congestion occurred between Phetchaburi and Rama IV-1 toll plaza at 7:00 am. The congestion point started near Rama IV-1 toll plaza, then it caused queuing of vehicles until Din Daeng toll plaza after one hour later (at 7:50 am). On the second link of in-bound corridor, Bang Na to Khlong Toei, the severe congestion point started at about 1 km after Sukhumvit 62 toll plaza and ended at 1.2 km before that toll plaza. The queue of the congestion continued until about 500 m before Bang Na toll plaza at 7:50 am. On the third link of in-bound corridor, Dao Khanong to Khlong Toei, there is a severe congestion took place between the beginning of the section and Suksawat toll plaza. The head of the congestion occurred around Suksawat toll plaza region. After about one hour, it is observed that the congestion is release a little bit and the head of the congestion point changed from about 300 meter after Suksawat toll plaza to about 500 meter before that toll plaza.

For out-bound corridor, it is observed that severe congestion started occurring at 7:30 am and it released at 7:50 am on Khlong Toei to Din Daeng direction, first link of the expressway. According to this one hour results, severe traffic congestion took place at Sukhumvit toll plaza until Khlong Toei.

- **Severe traffic congestion in the evening**

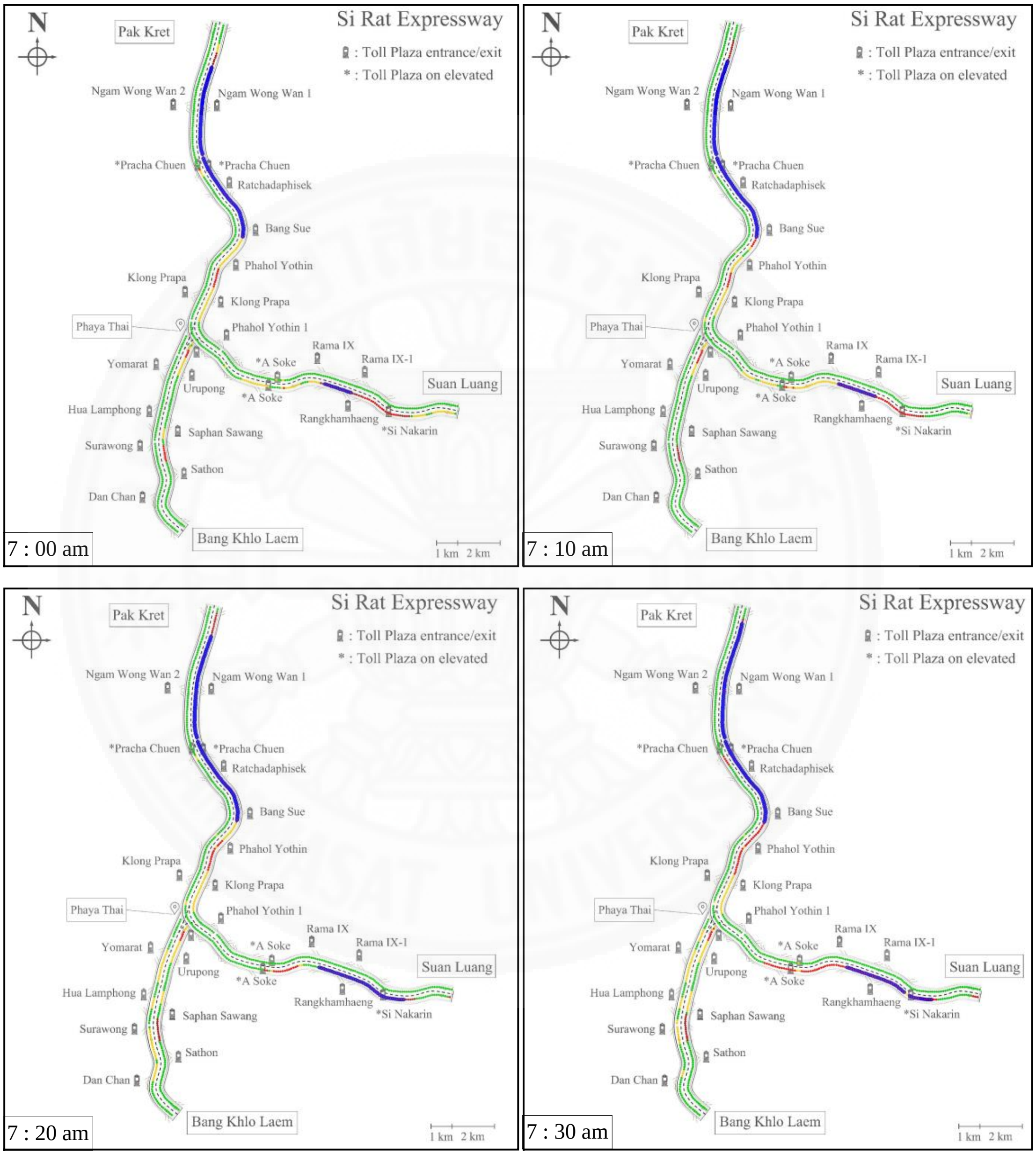
During evening, it is observed that severe congestion occurred many locations on Chalerm Mahanakhon expressway. From Din Daeng to Khlong Toei direction, the severe congestion took place in Khlong Toei region. Based on these results, the severe congestion point is observed at 7:10 around 500 m after port 2 toll plaza and it queued until about 800 m before Phetchaburi toll plaza. This severe congestion was releasing and at 8:00 pm traffic condition on this section is moderated flow. For location of the severe congestion is occurred from Bang Na to Din Daeng corridor, it is a long severe traffic congestion. The congestion point occurred at Sukhumvit toll plaza and it caused queue until about 1 km after Bang Na toll plaza. The severe congestion on this corridor released at 8:00 pm and only between Sukhumvit toll plaza and Rama IV-2 toll plaza, the severe congestion still last. However, by looking into the results of traffic patterns and congestion patterns on Chalerm Mahanakhon expressway, normally the congestion takes place around the detected region.

4.2.2 Severe Traffic Congestion on Sirat Expressway

The results below present the severe traffic congestion on Sirat expressway which are detected on July 06, 2016.

- **Severe traffic congestion in the morning**

According to these results, the congestion point occurred on the first link of Sirat expressway at Bang Sue toll plaza at 7 o'clock in the morning on in-bound corridor, Pak Kret to Phaya Thai, and it caused queue of vehicles until Pak Kret region. One hour later, the congestion point moves up to Klong Yothin toll plaza. Furthermore, there is another severe congestion occurred on the second link of this expressway, Suan Luang to Phaya Thai direction. The severe congestion point took place only after Rangkhamhaeng toll plaza at 7 o’clock. Finally, one hour later the tail of the congestion is prolong to Si Nakharin toll plaza. Thus, it is really a severe congestion that occurs more than one hour.



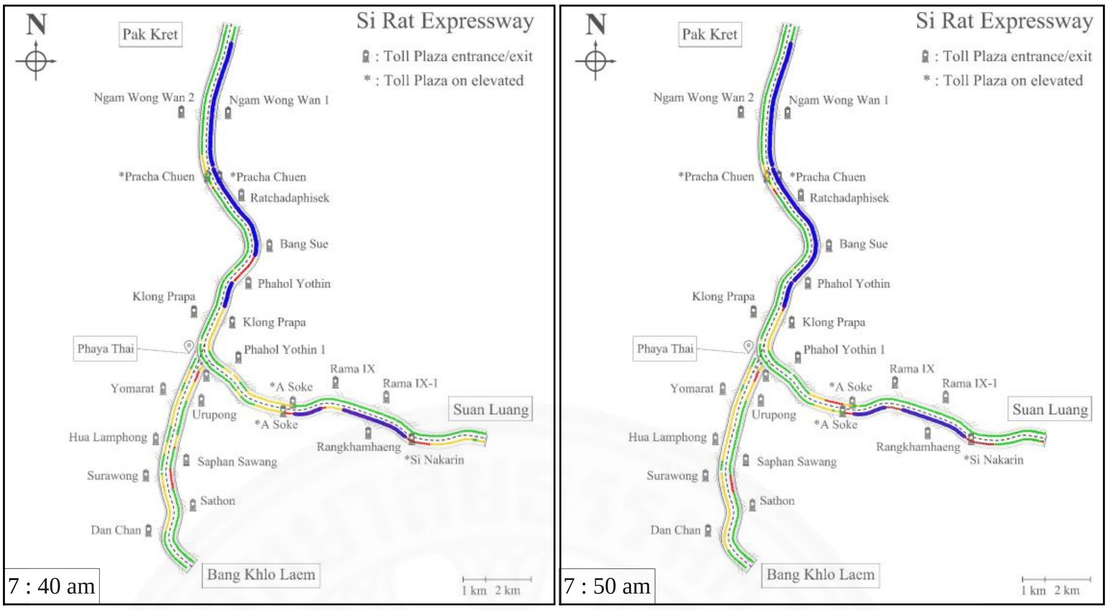
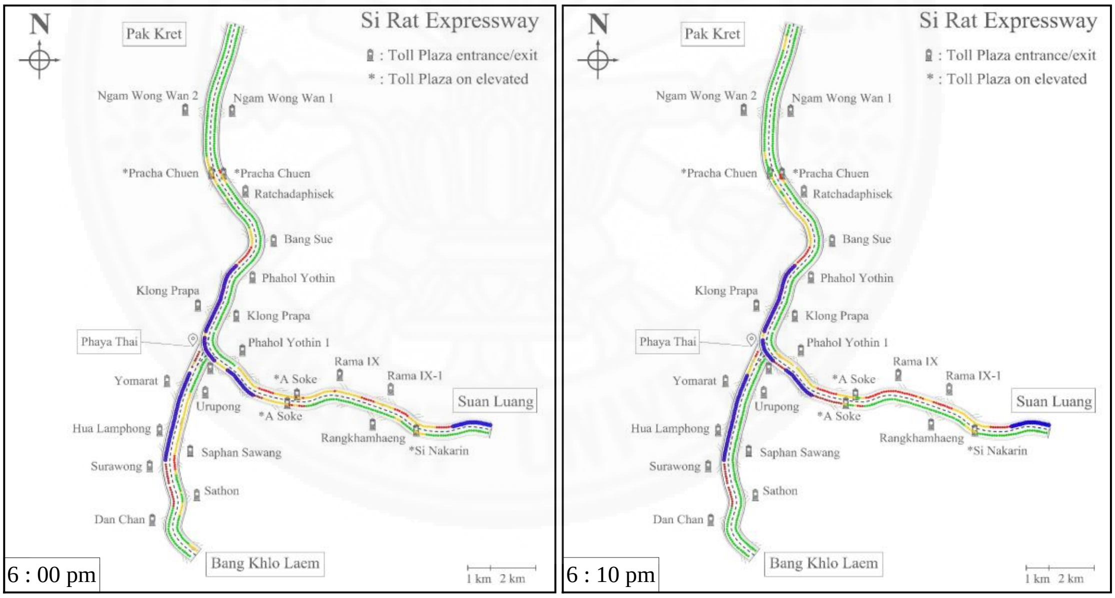


Figure 4.23 Severe traffic congestion detected on July 06, 2016 (Morning)

- **Severe traffic congestion in the evening**



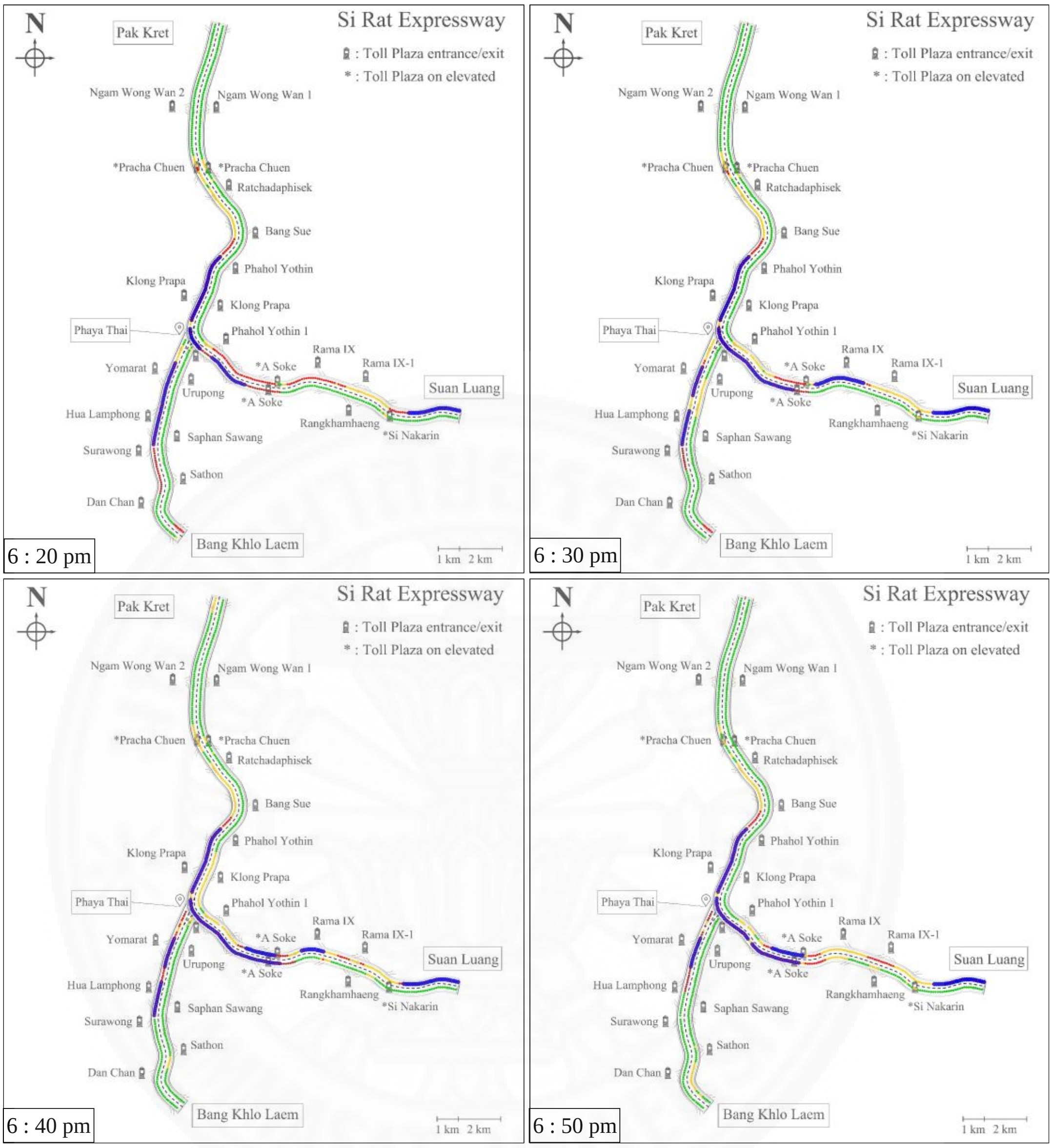


Figure 4.24 Severe traffic congestion detected on July 06, 2016 (Evening)

During evening, the severe congestion occurred around Phaya Thai region. On Suan Luang to Pak Kret direction, there is a long traffic congestion occurred around 2.5 km after Klong Prapa toll plaza. From 6:00 pm to 6:50 pm, it is observed that queue of vehicles increases until A Soke toll plaza. For another link from Bang Khlo Laem to Phaya Thai, within this one hour severe traffic congestion, which occurred near an on ramp of Yomarat toll plaza to an on ramp of Surawong toll plaza, is released. From Phaya Thai to Suan Luang, the severe traffic congestion is observed around Rama IX toll plaza at 6:30 pm, around A Soke toll plaza at 6:40 to 6:50 pm, and one hour last around Suan Luang region.

4.3 Traffic Anomaly Detection

The expected value is defined by the highest probability of traffic state and it is a function of days of the week, date of the month, month of the year, holiday or not, time, and space. Conditional probability based on Bayes' theorem is applied to compute the probability of each point in every time step.

$$P_{pt}(I_c / E_1E_2E_3E_4) = \frac{P_{pt}(E_1E_2E_3E_4 / I_c) \times P_{pt}(I_c)}{P_{pt}(E_1E_2E_3E_4 / I_c) \times P_{pt}(I_c) + P_{pt}(E_1E_2E_3E_4 / I_c') \times P_{pt}(I_c')} \quad (6)$$

The denotations in this equation are described as follows:

p : Points along the expressway.

t : Time-step, there are 144 time-steps per day.

c : Colors of traffic state, green, yellow, red, and dark red.

$P(I_c)$: Probability of traffic intensity which is corresponds to traffic state.

$P(I'_c)$: Probability of traffic intensity of the complement of an event I_c.

E_1 : Day of week.

E_2 : Date of month

E_3 : Month of year

E_4 : Holiday or not-holiday

After having all the probability of every point at every time-step, the highest probability is observed and the traffic intensity that corresponds to the highest value is assumed as Usual traffic intensity (UTI).

4.3.1 Traffic Anomaly on Chalerm Mahanakhon expressway

Results of actual traffic intensity, expected traffic intensity correspond to the highest probability, and degree of traffic anomaly are presented in figures below.

Free flow   Moderated flow   Congested flow   Heavy congested flow

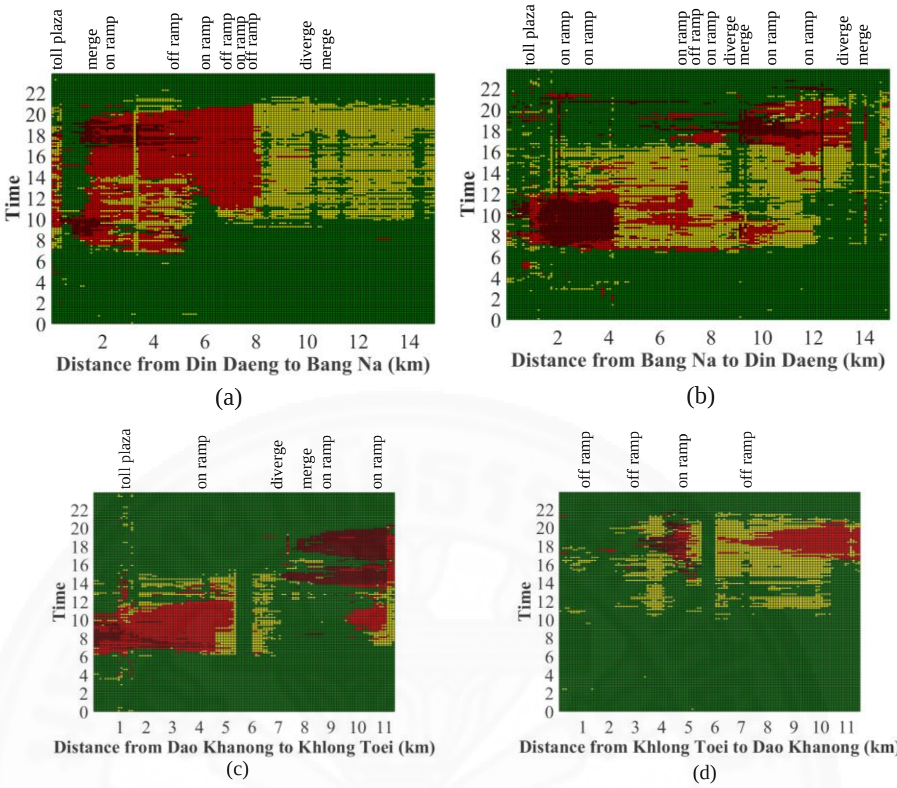


Figure 4.25 Traffic state expectation on Chalerm Mahanakhon expressway on May 04, 2016

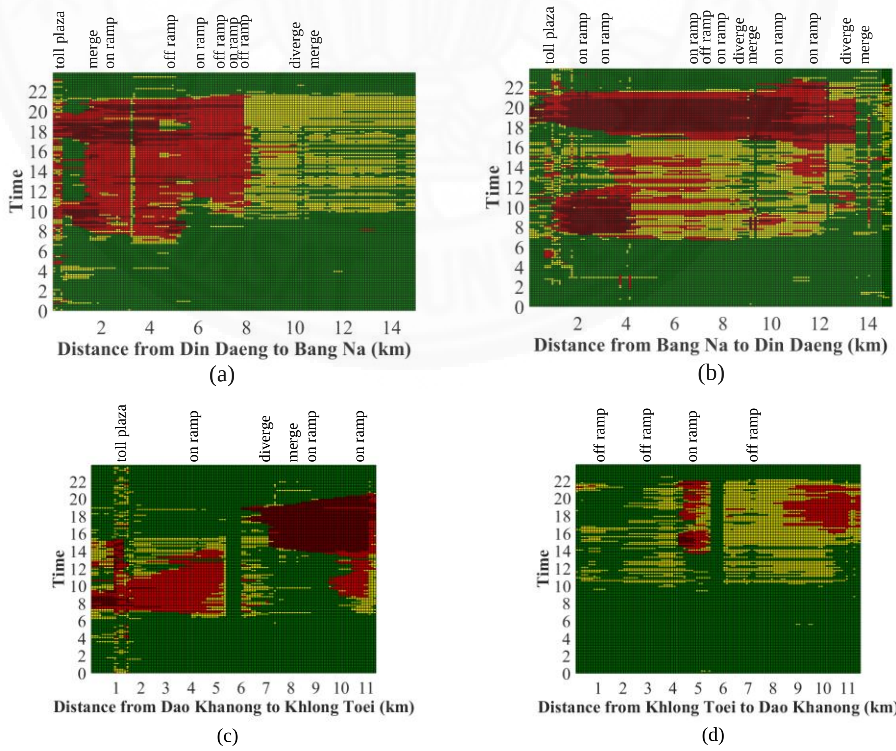


Figure 4.26 Actual traffic state on Chalerm Mahanakhon expressway on May 04, 2016

Figure 4.25 presents the expected traffic intensity on May 04, 2016 of each link both in-bound and out-bound corridor which correspond to the maximum probability calculated from Bayes' theorem. Figure 4.26 shows the actual traffic intensity occurred on Chalerm Mahanakhon expressway on the same day. Normally, the daily traffic conditions on the road network change from time to time depend on travel demand of road users. However, traffic patterns on every section of the road should be similar according to types of days. The results above reveal that, the actual traffic intensity looks similar to the expected condition. The different of traffic intensity from the expected value will be considered as an anomaly.

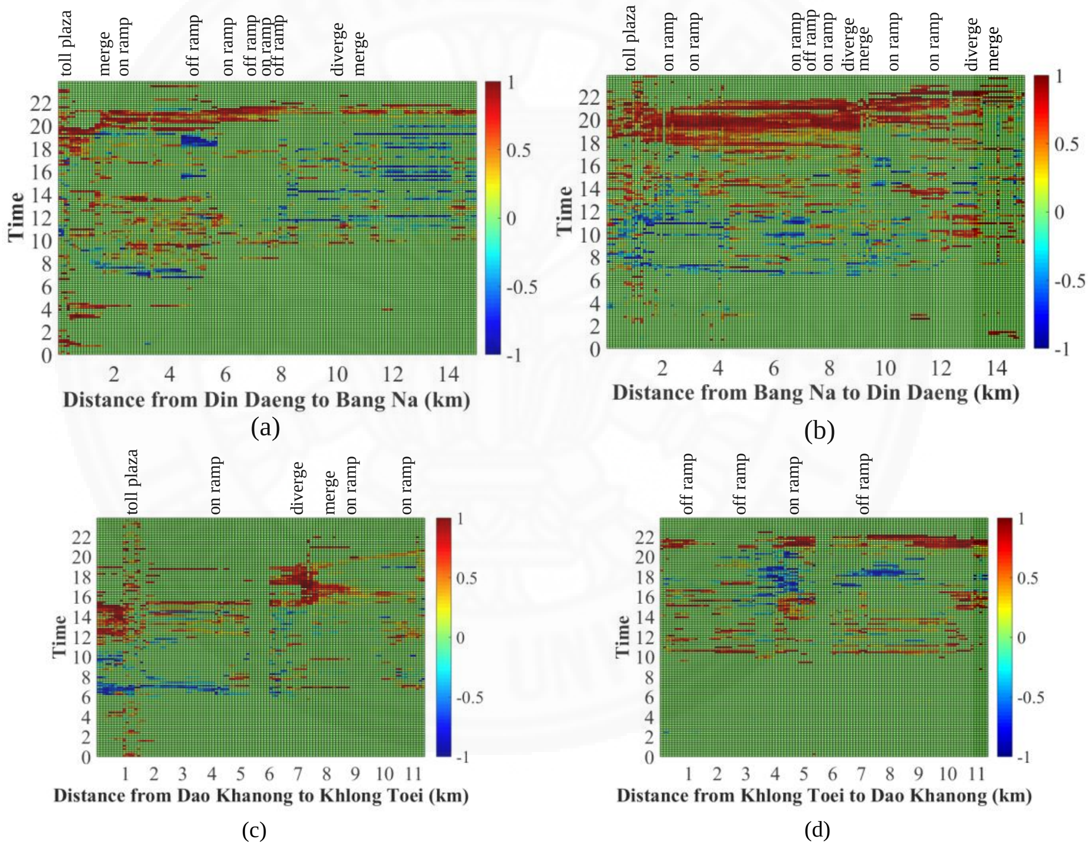


Figure 4.27 Traffic anomaly and its degree detected on May 04, 2016.

Figure 4.27 above presents the degree of traffic anomaly on each bound of corridor. Colors in these figures show the degree of traffic anomaly which is ranged from -1 to 1 and the normal condition of the traffic is represented by number 0.

The negative sign shows the lower traffic intensity while the positive sign indicates the higher traffic intensity compared to the normal condition. Whenever the current observation of traffic intensity is lower than the expected, it will give the negative sign. On the other hand, the sign will be positive whenever the current traffic intensity it higher than the expectation. The degree of traffic anomaly in absolute value is high or low depends on how the frequency of the intensity occurred. If any of intensity values rarely happen and they suddenly happen, so the degree of the anomaly is high.

According to the results of traffic anomaly in figure 4.27, traffic anomaly occurred and scattered along the road. By looking into points of interest from Din Daeng to Bang Na in table 3 above, a big of traffic anomaly is observed in the evening around Din Daeng toll plaza location and between a merge of 1.6 km and an on ramp at 7.9 km (figure 4.27a). On the opposite link of the corridor, from Bang Na to Din Daeng (figure 4.27b), a very big of traffic anomaly which cause a serious congestion is observed in the evening around 6 pm to 9 pm. Traffic anomaly took place from Bang Na toll plaza, km.1.5, to Din Daeng region. For the other link, from Dao Khanong to Khlong Toei (figure 4.27c), there are 2 remarkable locations of the traffic anomaly. The first location, traffic anomaly occurred in the morning about 7 am before Dao Khanong toll plaza and the degree of the anomaly is negative that reveals that there is less traffic compared to the usual traffic condition. However, at the same location from 1 pm to about 3 pm, traffic anomaly is observed and the degree of abnormal traffic is positive which indicates that there are more traffic than the normal condition. The last location, traffic anomaly occurred in the evening around 4 pm to 6 pm at km. 6 to an on ramp at 8.9 km from Dao Khanong. For the last corridor, from Khlong Toei to Dao Khanong (figure 4.27d), traffic anomaly is observed around 2 pm to 9 pm between km. 4 and km. 5 from Khlong Toei. Another location of the traffic anomaly is after an off ramp, 7.2 km from Khlong Toei, traffic is less at 6 pm and traffic volume is high around 9 pm.

By applying the severe traffic congestion concepts, the scatter points of traffic anomaly can be eliminated and considered as a fluctuation of the traffic that is not effected much to the normal traffic condition. The two important in the variables determination for severe traffic congestion are duration and length of traffic congestion. When these two parameters are set to be small value, traffic congestion will be alerted a lot that can disturb to the road users and traffic controllers. On the other hand, when these two parameters are set to be high or big value, the alerting of the severe congestion will be less and sometimes small severe congestion will be neglected. In this study, the duration of 30 minutes (3 time steps) and the abnormal length of 1 km (10 points) are set.

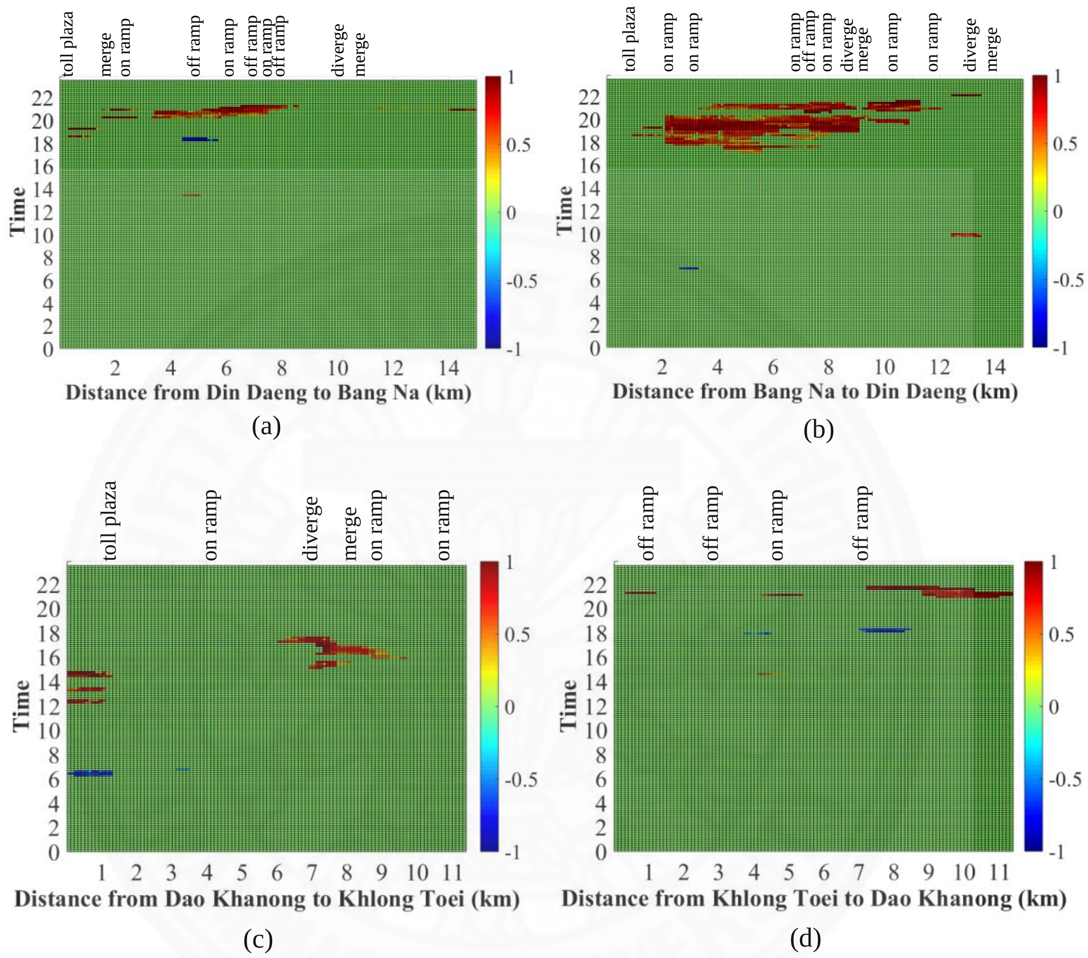


Figure 4.28 Severe traffic anomaly and its degree detected on May 04, 2016.

Results of severe traffic anomaly and its degree are presented in figure 7 above. After applying severe traffic congestion concepts, only some locations of big traffic anomaly which are discussed in the previous section are remaining. Therefore, it is concluded that abnormal traffic or traffic incident must occur at those regions.

Within a whole year of the study, the degree of severe traffic anomaly on each link of the expressway are summed together according to the positive and negative sign of the degree of traffic anomaly in order to see the frequency of locations where traffic anomaly occurred.

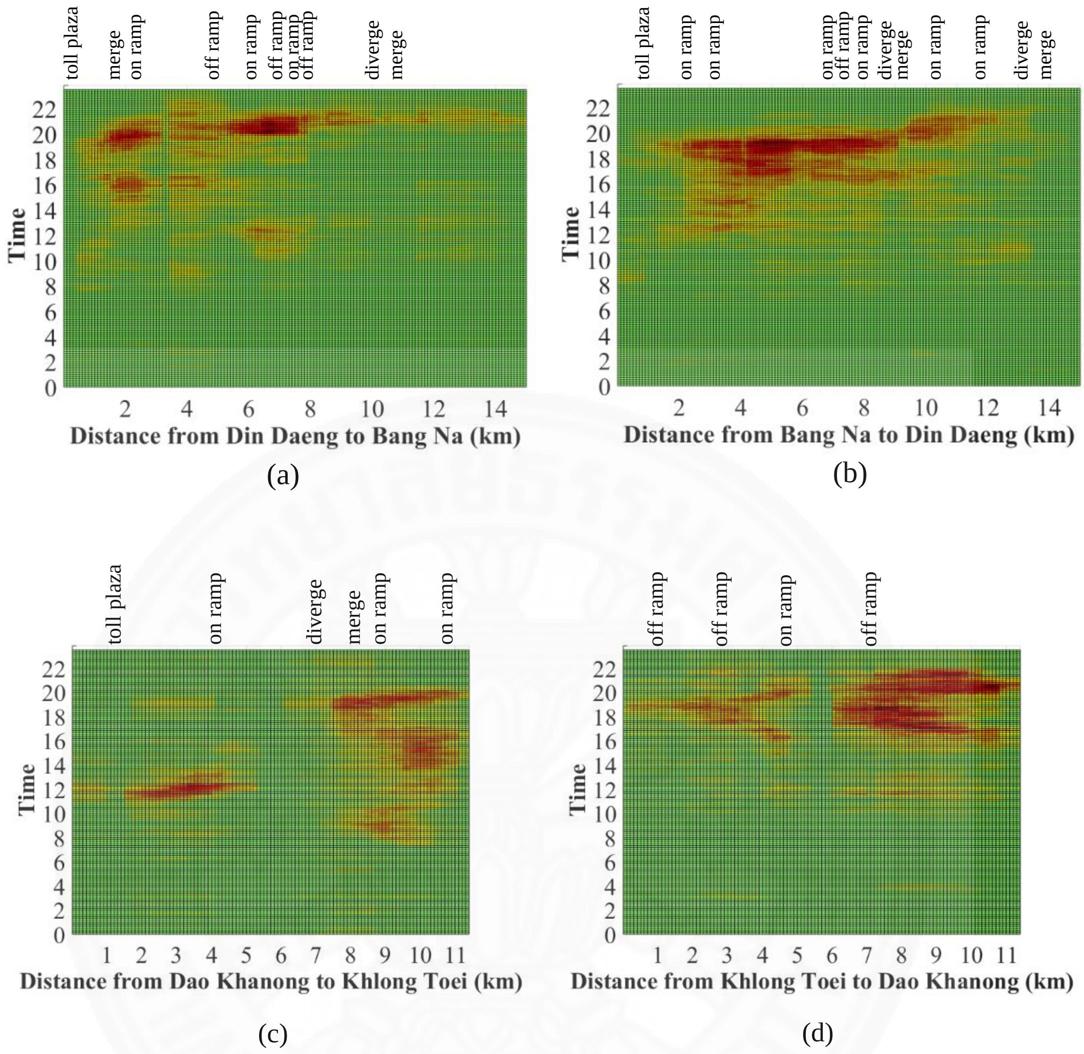


Figure 4.29 Frequency of traffic anomaly causing traffic congestion over a year

Results of frequent traffic anomaly occurred and causing traffic congestion are presented in figure 4.29. Colors, green, yellow, and red, in figure 4.29 indicate the degree of traffic anomaly from low to high. From the results of the aggregation of severe traffic anomaly, in many instances traffic anomaly is observed in the evening. It is observed that, from Din Daeng to Bang Na (figure 4.29a), most of the time traffic anomaly occurred at two regions. The first region, traffic anomaly that cause traffic congestion took place from a merge at km.1.6 to an on ramp at km.2.5 around 8 pm. The second region, traffic anomaly that cause traffic congestion occurred from 8pm to 9 pm between an on ramp at km.5.8 and an on ramp at km.7.9. For the opposite direction, Bang Na to Din Daeng (figure 4.29b), frequently, traffic anomaly causing traffic congestion occurred between an on ramp at km.2.7 and a merge at km.9 during rush hours from 6 pm to 7 pm.

For another link from Dao Khanong to Khlong Toei (figure 4.29c), traffic anomaly occurred at two regions. One is at noon after Dao Khanong toll plaza to an on ramp at km.4.2 and the other one is between a merge at km.8 and an on ramp at Khlong Toei region. Most of the time the anomaly occurred around 9 am, from 2 pm to 5pm, and from 7 pm to 8 pm. For the last corridor, from Khlong Toei to Dao Khanong (figure 4.29d), the abnormal traffic occurred in the evening at two regions at an off ramp at km.1.4 to an on ramp at km.4.7 and after an off ramp at k.7.2 to Dao Khanong region.

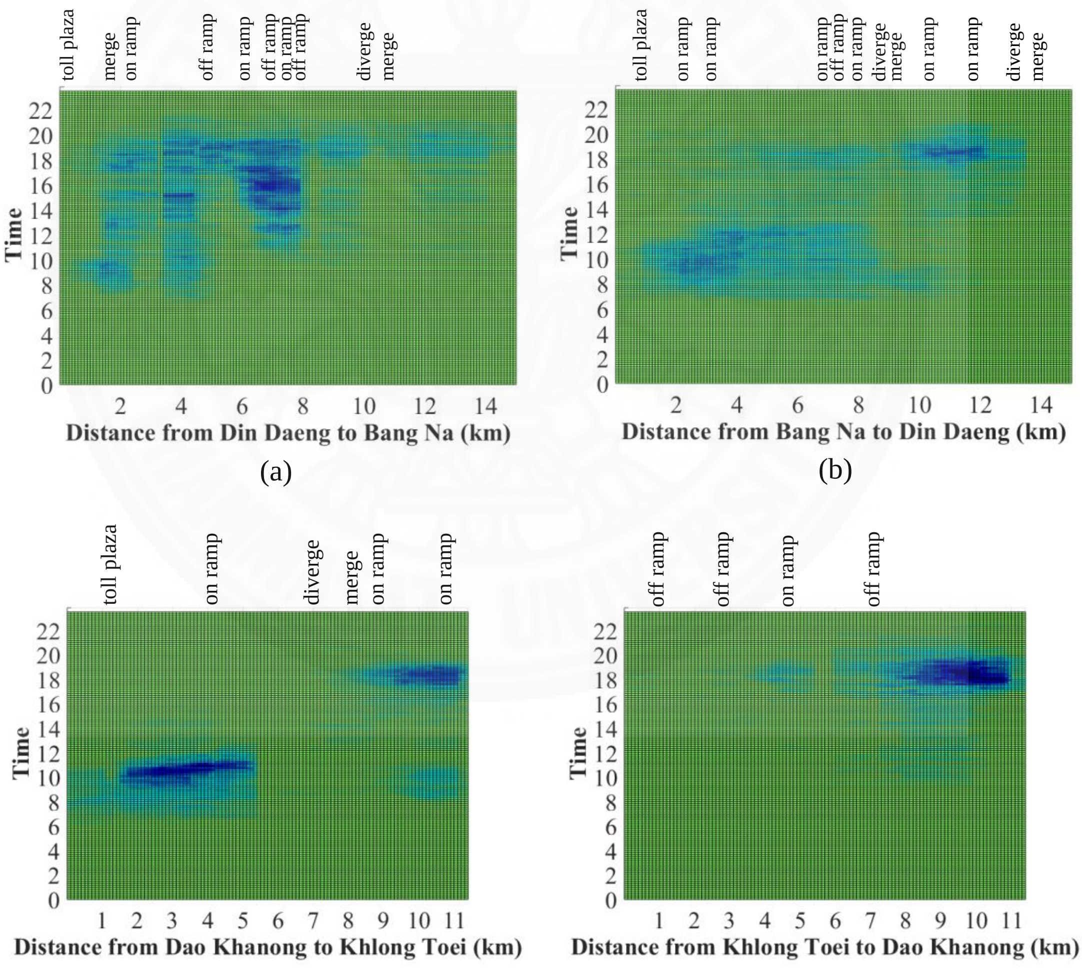


Figure 4.30 Frequency of traffic anomaly not causing traffic congestion over a year

Results of abnormal traffic that does not cause traffic congestion are presented in figure 4.30 above. On Din Daeng to Bang Na section, most of the time the anomaly took place at a merge to an on ramp around km number 2, km number 4, and another location the anomaly occurred at an on ramp (km.6) to an off ramp at km.7.9 from 2 pm to 7 pm. For the opposite direction, Bang Na to Din Daeng, normally there are two location of the abnormal traffic. First location, the abnormal traffic occurred between an on ramp at km.2 and km.4 in the morning from 9 am to 11 am. For the second location, traffic anomaly took place between an on ramp at km.10 and km.12.2 in the evening. For Dao Khanong to Khlong Toei corridor, mostly traffic anomaly occurred at two regions. One is after Dao Khanong toll plaza to km.5 around 10 am to 11 am, and the other one is after an on ramp at km.9 to an on ramp at Khlong Toei region around 6 pm. For the last corridor, from Khlong Toei to Dao Khanong, normally abnormal traffic took place at Dao Khanong region in the evening around 6pm.

Number of traffic anomaly over a whole year are divided into 4 classes from the low degree to the high degree of traffic anomaly as shown in table 4. Class 1 (0%), it is normal condition, class 2 (0.0 to 50%), it is a fluctuation of the traffic on the expressway, class 3 (50% to 75%), it is abnormal condition, and class 4 (>75%), it is a highly abnormal of traffic. Percentage of events detected are presented in table 4 below. The percentage of traffic anomaly detected are categorized into two types. The first type, degree of traffic anomaly are include a whole day, 24 hours and the second type, only 15 hours from 6 am to 9 pm are included.

Table 4.4 Percentage of degree of traffic anomaly detected

Class	Degree (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0	86.36%	80.34%
Class 2	0.0 – 50	7.07%	10.39%
Class 3	50 – 75	3.99%	5.71%
Class 4	> 75	2.58%	3.55%

According to the percentage detected in table 4, within this whole year there are 86.36% of all the events are the normal condition, 7.07% are considered as a fluctuation of the traffic, 3.99% are abnormal traffic, and 2.58% are highly abnormal, in case a whole day of traffic on the expressway is considered. However, if traffic on the expressway from 6 am to 9 pm are considered, traffic anomaly occurred more than a whole day consideration. It can be seen that, for class 1, the normal condition occurred

80.34%, the fluctuation occurred 10.39%, abnormal occurred 5.71%, and highly abnormal occurred 3.55% of all the events.

Chapter 5

Conclusions and Recommendations

In the field of traffic analysis, traffic information such as speed, flow, occupancy etc. are very important to define traffic state. According to the discussion in the introduction part, traffic state is a key to measure and indicates traffic condition on the road network. Traffic state data are very useful and they play an important role in the Advance Traffic Management System and Advance Traveler Information System.

Therefore, in this study traffic state data which are collected from web-based mapping services are used for analysis in order to determine traffic patterns and congestion patterns, detect severe traffic congestion that last for a long period and a long distance, detect traffic anomaly that may or may not cause traffic congestion that they occurred different from their frequency happen, and last by not least the degree of traffic anomaly are calculated so as to measure the level of abnormal traffic and see how high or low of traffic intensity compared to the normal condition. All the analysis are conducted on the expressway system in Bangkok urban area in Thailand.

In the last part of this chapter, we will present the contributions and give some recommendations along with future work that can be further extended from this study.

5.1 Contributions

By applying traffic state data that are collected from online mapping services into the proposed method in this study, we obtained results and found that they will be useful for both researchers and the practitioners.

- To the researchers: The new way of collecting traffic state data will help them to reduce the expense compare to the use of traffic sensor, video camera, etc. In addition, this new data collection concept may give them more idea to improve and develop the new algorithm or use another program to capture the traffic state in form of image.
- To the road users: The results of this study will provide the accuracy of traffic condition on the road network. Based on the results of traffic patterns and congestion patterns, severe traffic congestion, and traffic anomaly detection,

the users will see which location and what time the congestion normally occurs, and traffic anomaly on the expressway system. So that they can make their decision to select a good way for their traveling to improving their time management in traveling and reduce their stress.

- To the traffic management: results of the study are useful for traffic manager to manage traffic in the city. The results of traffic congestion patterns show locations and time that traffic congestion normally occurs that we cannot avoid. However, the congestion can be reduced by constructing a new road. Moreover, for results of traffic anomaly, traffic manager can investigate the abnormal traffic that may cause by traffic accident. So that they can send some traffic police to clear that accident as soon as possible.

5.2 Recommendations for future work

Although the new traffic state data provided some good results in the analysis, there are still some limitations in this study. The following recommendations are given in order to improve and consider for the future work.

- We do not need any financial support to collect traffic state data from online, what necessary for data collection is internet connection. Over the period of collecting this kind of data (one year), we found that 10% of traffic state are missing due to the internet connection. So, it is recommended to use the stable of the internet to collect this kind of data.
- By the investigation of image traffic data with zoom level 16, sometimes the pixel of the color on the big road covers the pixel of some small roads that make some points extract wrong color. So for the better detection of the color, zoom level should be smaller than 16 based on road network of the study.
- Normally, traffic patterns on working days are similar and traffic on non-working days are less on the road network. Therefore, it is recommended for any special events such as holidays should be detected.

- Traffic state prediction of each day should be aggregated to find the average traffic prediction patterns and compared with the traffic patterns calculated by all actual traffic data.

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Appendices

Appendix A

Algorithm 1: Traffic State Data Web Crawler

```
<!DOCTYPE html>
<html>
  <head>
    <title>Traffic Layer</title>
    <meta http-equiv="refresh" content="600" />
    <style>
      html, body, #map-canvas {
        height: 100%;
        margin: 0px;
        padding: 0px
      }
    </style>
    <script src="https://maps.googleapis.com/maps/api/js?v=3.exp&sensor=false"></script>
    <script>
var map;
var rangsit = new google.maps.LatLng(14.16200,100.682300);

var MY_MAPTYPE_ID = 'custom_style';


function initialize() {

  var featureOpts = [
    {
      stylers: [
        { hue: '#000000' },
        { visibility: 'off' },
      ]
    },
    {
      elementType: 'labels',
      stylers: [
        { visibility: 'off' }
      ]
    },
    {
      featureType: 'water',
      stylers: [
        { color: '#FFFFFF' }
      ]
    }
  ];

```

```
    var mapOptions = {
      zoom: 16,
      center: rangsit,
      panControl: false,
      zoomControl: false,
      scaleControl: true,
      mapTypeControlOptions: {
        mapTypeIds: [google.maps.MapTypeId.ROADMAP, MY_MAPTYPE_ID]
      },
      mapTypeId: MY_MAPTYPE_ID
    };

    map = new google.maps.Map(document.getElementById('map-canvas'),
        mapOptions);

    var styledMapOptions = {
      name: 'Custom Style'
    };

    var customMapType = new google.maps.StyledMapType(featureOpts, styledMapOptions);

    map.mapTypes.set(MY_MAPTYPE_ID, customMapType);
    var trafficLayer = new google.maps.TrafficLayer();
    trafficLayer.setMap(map);


  }

  google.maps.event.addDomListener(window, 'load', initialize);

      </script>
    </head>
    <body>
      <div id="map-canvas"></div>
    </body>
  </html>
```

Appendix B

Algorithm 2: Color Indexes Conversion Algorithm

```
function Result = Code_22(x,y,Folder)
Answer = zeros (length(x) ,8);
load('idCM22.mat')
Concat = [];
color = zeros (length(x),1);
Imgs = dir([Folder '/' '*.png']);
NumImgs = size(Imgs,1);
%% Sorting the picture files
Imgsfields = fieldnames(Imgs);
Imgscell = struct2cell(Imgs);
sz = size(Imgscell);
% Convert to a matrix
Imgscell = reshape(Imgscell, sz(1), []);
% Make each field a column
Imgscell = Imgscell';
% Sort by first field "name"
Imgscell = sortrows(Imgscell, 2);
% extract date
Imgscell = reshape(Imgscell', sz);
% Convert to Struct
Imgssorted = cell2struct(Imgscell, Imgsfields, 1);
%% Read idividual files
tic
for k=1:NumImgs
    Ans =double(imread([Folder '/' Imgssorted(k).name]));
    pixel=impixel(Ans,x,y);
    Answer (:,6:8,k) = pixel;
    %Read color into code
    for i=1:length(pixel);
        if (pixel(i,1)<220)&&(pixel(i,2)>200)&&(pixel(i,3)<200)
            color(i)=1;
        elseif (pixel(i,1)>230)&&(pixel(i,2)>120)&&(pixel(i,3)<220);
            color(i)=2;
        elseif (pixel(i,1)>220)&&(pixel(i,2)<120)&&(pixel(i,3)<200);
            color(i)=3;
        elseif (pixel(i,1)<220)&&(pixel(i,1)>100)&&(pixel(i,2)<100)
&&(pixel(i,3)<100);
            color(i)=4;
        else color(i)=0;
        end
    end
    %write to matrix
    Answer (:,1:3,k) = idCM22;
    Answer (:,4,k) = x;
    Answer (:,5,k) = y;
    Answer (:,6,k) = color;
    clear pixel
    clear Ans
    Concat = horzcat(Concat, Answer(:,6,k));
end
Result = horzcat(Answer(:,1:5), Concat);
toc
end
```

Appendix C

Results from the analysis

1. Results of traffic patterns and congestion patterns

A. Traffic patterns and congestion patterns on Ramindra expressway

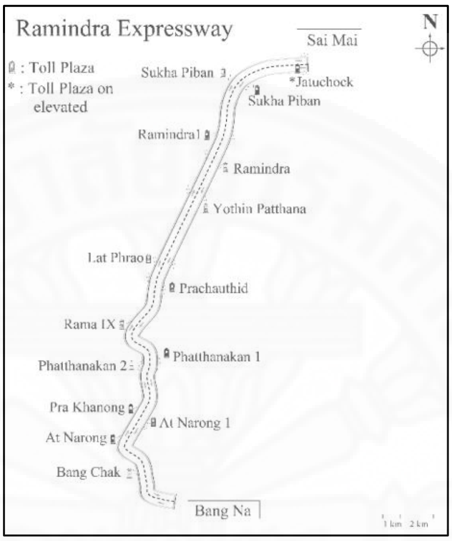


Figure 1 Map of Ramindra expressway

Table 1 Points of interest on Ramindra expressway

Expressway	Origin - DestinatiOn	Ramp / Toll plaza	Distance from beginning of route
Ramindra (In_Bound)	Sai Mai - Bang Na	On ramp	100 m
		*Jatuchock toll plaza	500 m
		Off ramp	3.7 km
		Su Kha Piban toll plaza	4.7 km
		On ramp	5 km
		Off ramp	8 km
		Ramindra toll plaza	10 km
		On ramp	10.5 km
		Yothin Phatthana toll plaza	12.7 km
		On ramp	13.1 km
		Off ramp	15.2 km
		Prachauthid toll plaza	18.1 km
		On ramp	18.2 km
		Off ramp	19.5 km
		Off ramp	20.1 km
		Off ramp	22.2 km
		Pantthanakan 1 toll plaza	22.9 km
		On ramp	23.2 km
		Off ramp	26 km
		Off ramp	26.8 km

		At Narong toll plaza	27.2 km
		On ramp	28.1 km
Ramindra (Out_Bound)	Bang Na - Sai Mai	Bang Na toll plaza	3.1 km
		On ramp	4.5 km
		Off ramp	5 km
		At NarOng 2 toll plaza	5.4 km
		Pra KhanOng toll plaza	7.3 km
		On ramp	7.7 km
		Off ramp	9.8 km
		Ptthanakan 2 toll plaza	10.1 km
		Rama IX toll plaza	12.7 km
		Off ramp	13.1 km
		On ramp	15.2 km
		Lat Phrao toll plaza	16.8 km
		Off ramp	18.3 km
		On ramp	19.8 km
		On ramp	20.2 km
		Off ramp	21 km
		On ramp	22.2 km
		Off ramp	23.1 km
		Ramindra 1 toll plaza	24.6 km
		On ramp	25 km
		On ramp	26.8 km
		Su Kha Piban toll plaza	28.1 km
		Off ramp	29.4 km

* Toll plaza on the elevated structure

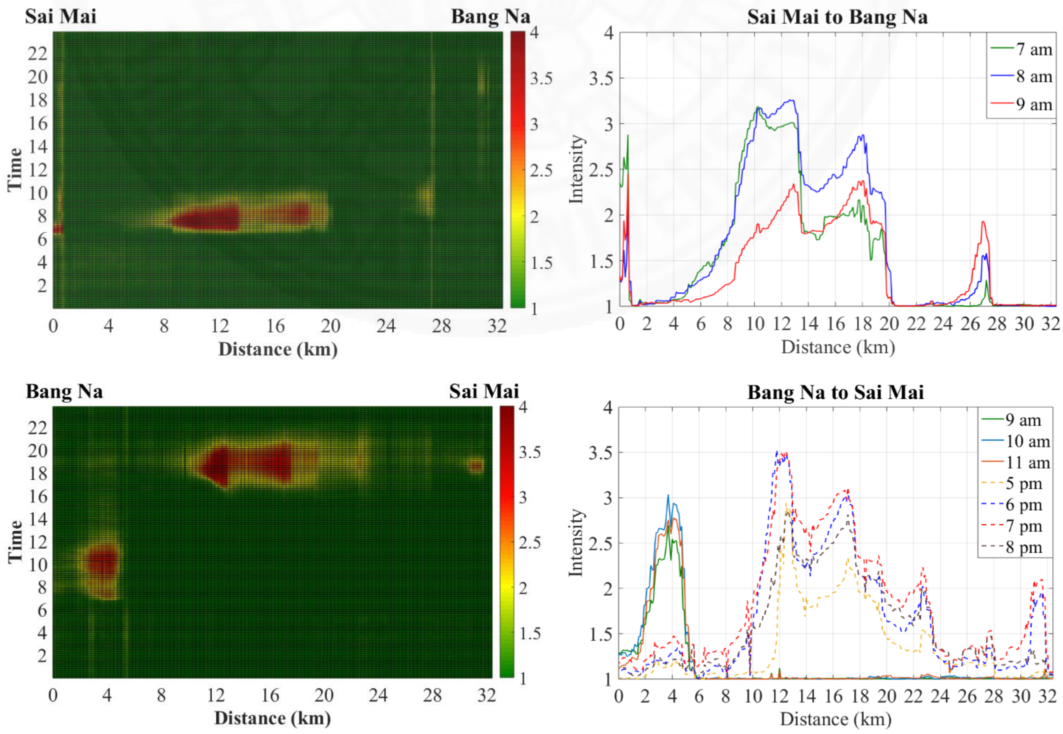


Figure 2 Congestion patterns of working days

B. Traffic patterns and congestion patterns on Bang Na expressway

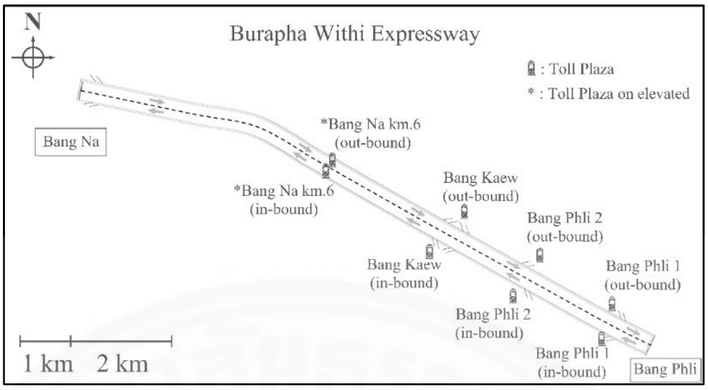


Figure 3 Map of Bang Na expressway

Table 2 Points of interest on Bang Na expressway

Expressway	Origin - Destination	Ramp / Toll plaza	Distance from beginning of route
Bang Na (In_Bound)	Bang Phli – Bang Na	Off ramp	300 m
		Bang Phli 1 toll plaza	700 m
		Bang Phli 2 toll plaza	3.1 km
		On ramp	3.4 km
		Off ramp	4.3 km
		Bang Kaew 1 toll plaza	4.6 km
		Merge	5.3 km
		On ramp	7.2 km
		*Bang Na km.6 toll plaza	7.4 km
Bang Na (Out_Bound)	Bang Na – Bang Phli	On ramp	1.6 km
		*Bang Na km.6 toll plaza	4.8 km
		Off ramp	5.3 km
		Diverge	7.2 km
		Bang Kaew 2 toll plaza	7.9 km
		Merge	8.3 km
		Off ramp	9.1 km
		Bang Phli 2 toll plaza	9.5 km
		Bang Phli 1 toll plaza	11.8 km
		On ramp	12.2 km

* Toll plaza on the elevated structure

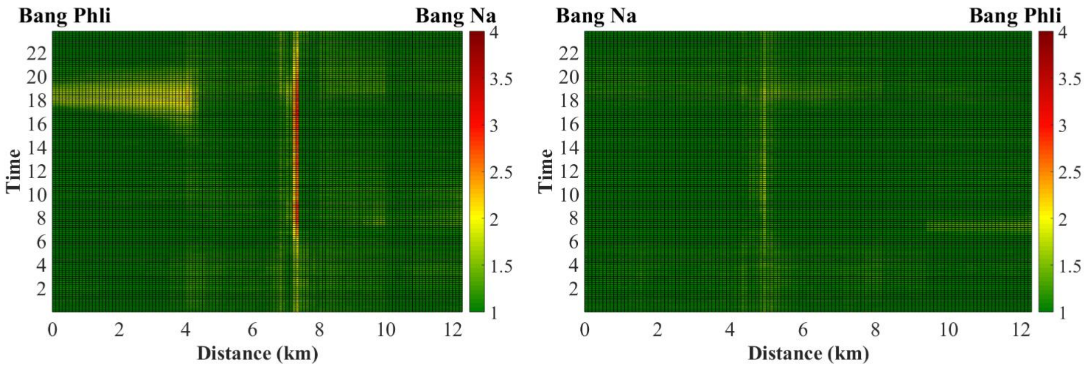


Figure 4 Traffic patterns on working days

C. Traffic patterns and congestion patterns on Udon Ratthaya expressway

Table 3 Points of interest on Udon Ratthaya expressway

Expressway	Origin – Destination	Ramp / toll plaza	Distance from beginning of route
Udon Ratthaya (In_Bound)	Bang Pa_in – Pak Kret	* Bang Pa-In toll plaza	400 m
		Chiang Rak toll plaza	10.2 km
		On ramp	10.4 km
		Off ramp	16 km
		Off ramp	16.8 km
		Bang Phun toll plaza	17.7 km
		On ramp	18.2 km
		Off ramp	24 km
		* Si Samarn toll plaza	25.2 km
		On ramp	25.4 km
		Off ramp	27.2 km
		Mueang Thong Thani toll plaza	27.5 km
		On ramp	27.8 km
Udon Ratthaya (Out_Bound)	Pak Kret – Bang Pa_in	Off ramp	1.5 km
		Mueang Thong Thani toll plaza	1.8 km
		Off ramp	4 km
		Si Samarn toll plaza	4.4 km
		On ramp	5.2 km
		Off ramp	11.4 km
		Bang Phun toll plaza	11.9 km
		On ramp	12.5 km
		Off ramp	18.9 km
		Chiang Rak toll plaza	19.1 km
		* Bang Pa-In toll plaza	28.9 km

* Toll plaza on the elevated structure

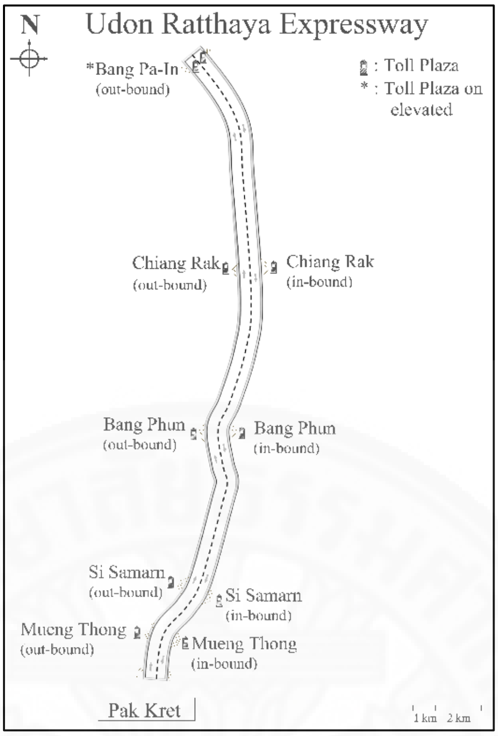


Figure 5 Maps of Udon Ratthaya expressway

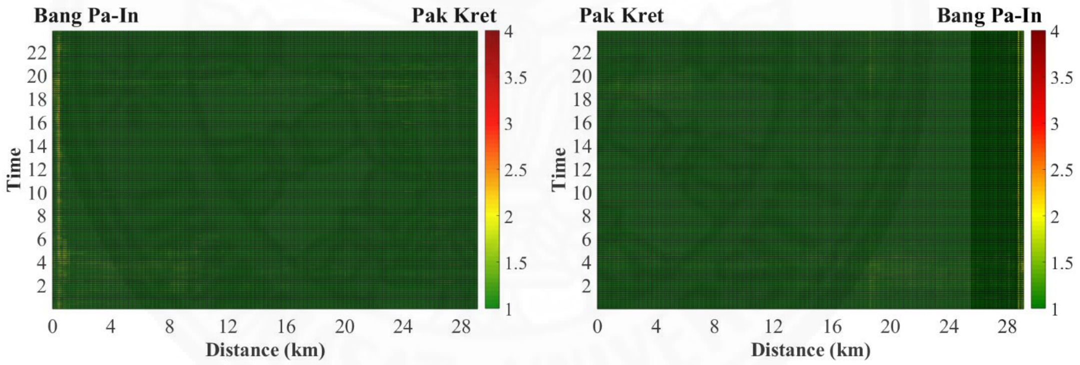


Figure 6 Traffic patterns on working days

D. Traffic patterns and congestion patterns on Bangphli Suksawat expressway

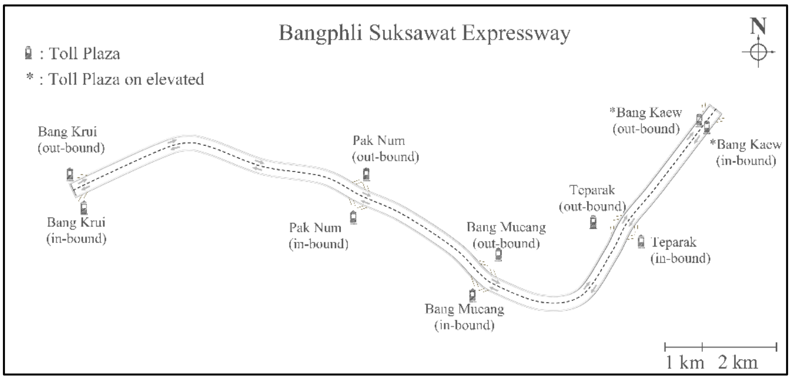


Figure 7 Map of Bangphli Suksawat expressway

Table 4 Points of interest on Bangphli Suksawat expressway

Expressway	Origin - Destination	Ramp / Toll plaza	Distance from beginning of route
Bangphli Suksawat (In_Bound)	Bang Phli – Phra Pra Daeng	On ramp	300 m
		* Bang Kaew toll plaza	600 m
		Off ramp	4.1 km
		Teparak toll plaza	4.2 km
		On ramp	4.3 km
		Off ramp	9 km
		Bang Mueang toll plaza	9.1 km
		On ramp	11 km
		Off ramp	13.1 km
		Pak Num toll plaza	13.2 km
		On ramp	14.7 km
		Off ramp	17.8 km
		On ramp	18.7 km
		Off ramp	21 km
		Bang Krui toll plaza	21.2 km
Bangphli Suksawat (Out_Bound)	Phra Pra Daeng – Bang Phli	On ramp	300 m
		Off ramp	2.6 km
		On ramp	3.5 km
		Off ramp	6.6 km
		On ramp	8.2 km
		Pak Num toll plaza	8.3 km
		Off ramp	10.3 km
		Bang Mueang toll plaza	12.3 km
		On ramp	12.4 km
		Off ramp	17 km
		Teparak toll plaza	17.1 km
		On ramp	17.2 km
		* Bang Kaew toll plaza	20.7 km
		Off ramp	21 km

* Toll plaza on the elevated structure

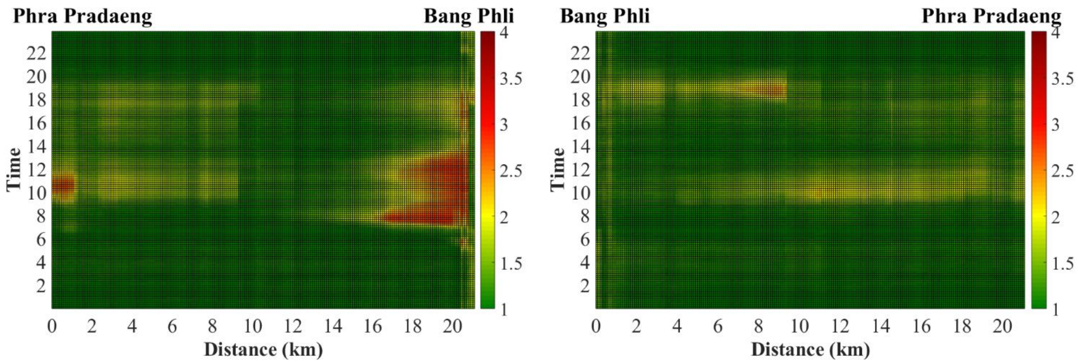


Figure 8 Traffic patterns on working days

E. Traffic patterns and congestion patterns on Don Mueang tollway

Figure 9 Map of Don Mueang tollway

Table 5 Points of interest on Don Mueang tollway

Expressway	Origin - Destination	Ramp / Toll plaza	Distance from beginning of route
Don Muang Tollway (In_Bound)	Rangsit – Din Daeng	On ramp	600 m
		Merge	3.2 km
		Off ramp	6.1 km
		On ramp	7.4 km
		* Don Mueang toll plaza	12.8 km
		On ramp	14.1 km
		Lak Si toll plaza	14.2 km
		Chaeng Watthana toll plaza	15.1 km
		On ramp	15.7 km
		Off ramp	18.5 km
		Off ramp	20 km
		Off ramp	21.7 km
		On ramp	23.1 km
		Ladprao toll plaza	23.3 km
		Off ramp	24.1 km
		Off ramp	27.5 km
Don Muang Tollway (Out_Bound)	Din Daeng – Rangsit	* Din Daeng toll plaza	1.1 km
		On ramp	1.4 km
		Sutthisan toll plaza	3.8 km
		On ramp	4.1 km
		Off ramp	5.3 km
		Ladprao toll plaza	5.9 km
		On ramp	6.1 km
		Ratchadaphisek toll plaza	7.6 km

		On ramp	7.8 km
		Off ramp	8.7 km
		Bang Khen toll plaza	9.5 km
		On ramp	9.7 km
		Off ramp	12.7 km
		Off ramp	13.4 km
		Off ramp	13.9 km
		Lak Si toll plaza	14.2 km
		On ramp	14.4 km
		On ramp	15.8 km
		Off ramp	18.7 km
		* Anusorn Satharn toll plaza	20.5 km
		Off ramp	20.8 km
		On ramp	22.1 km
		Off ramp	26.2 km
		Off ramp	27.6 km

* Toll plaza on the elevated structure

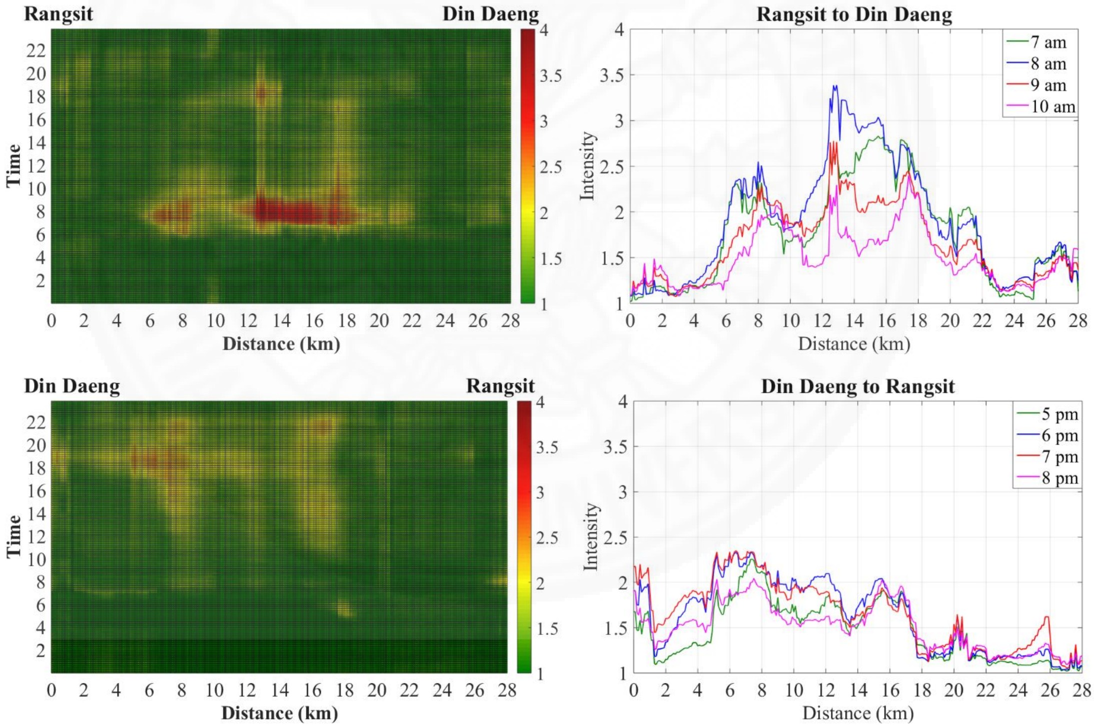
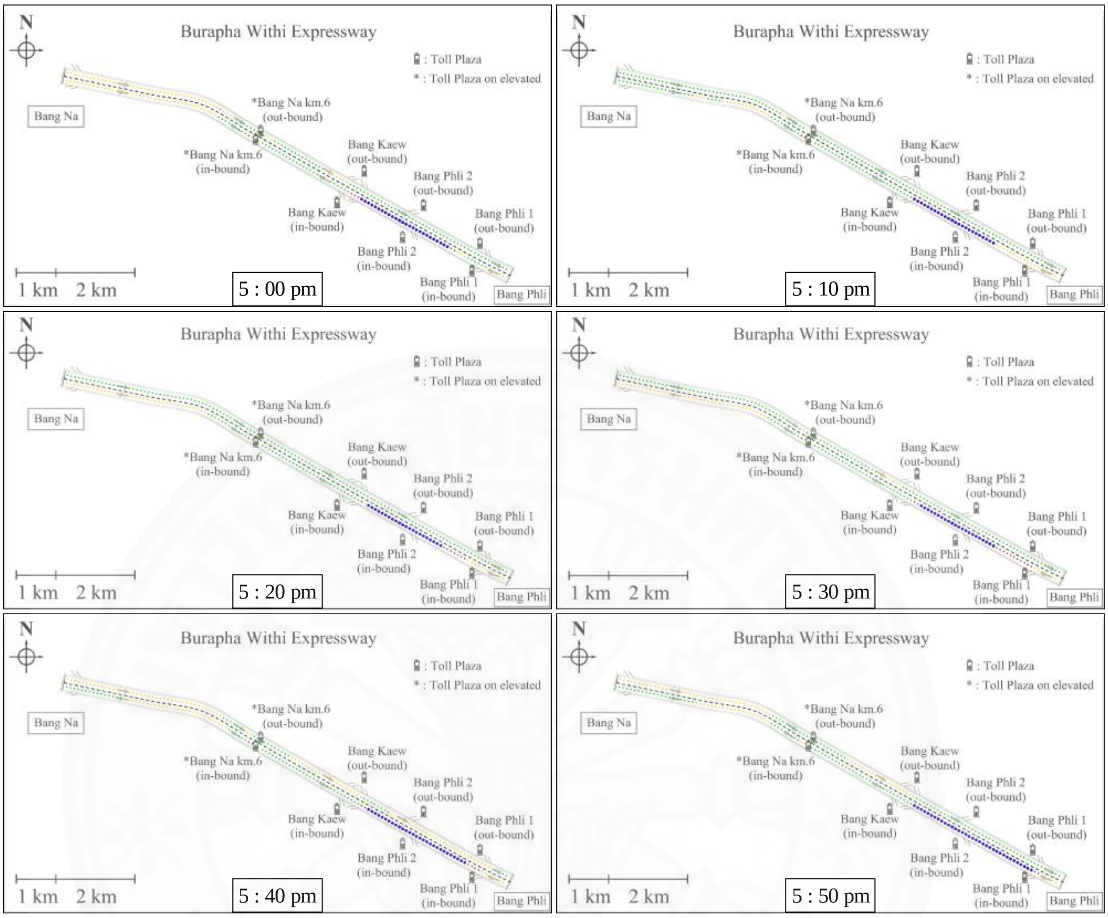


Figure 10 Traffic patterns on working days

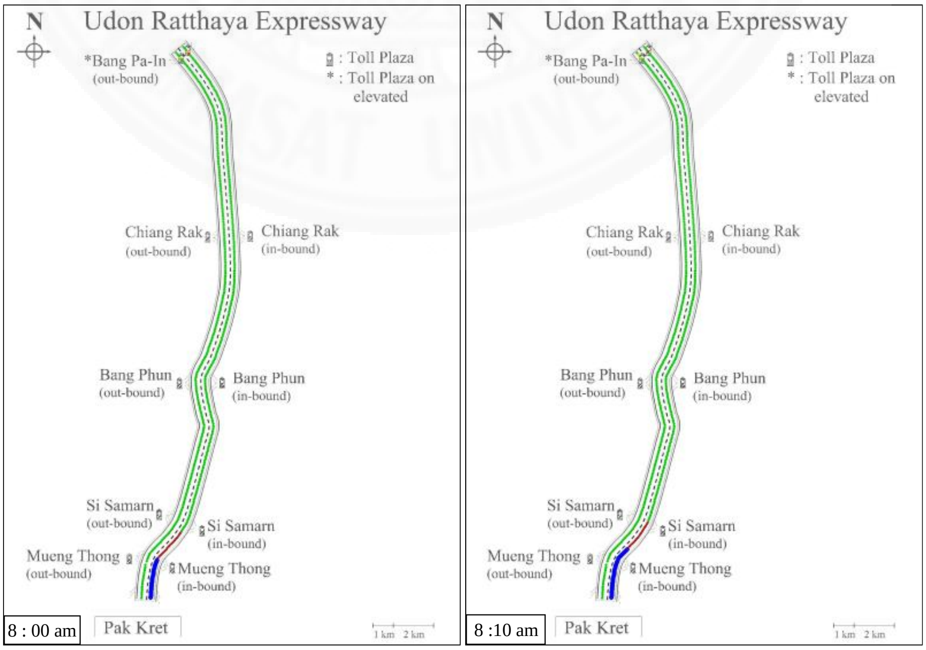
2. Results of severe traffic congestion

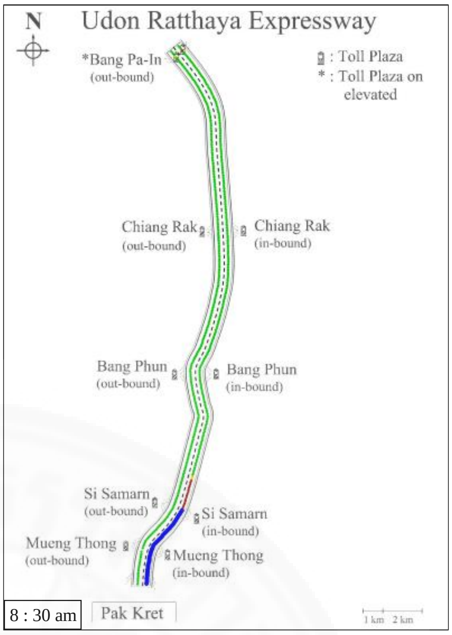
A. Severe traffic congestion on Ramindra expressway

B. Severe traffic congestion on Bang Na expressway

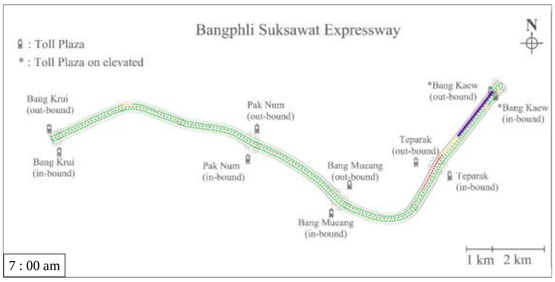


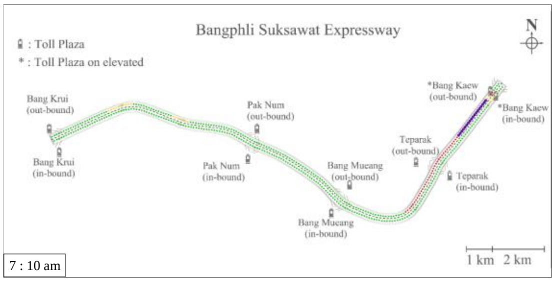
C. Severe traffic congestion on Udon Ratthaya expressway



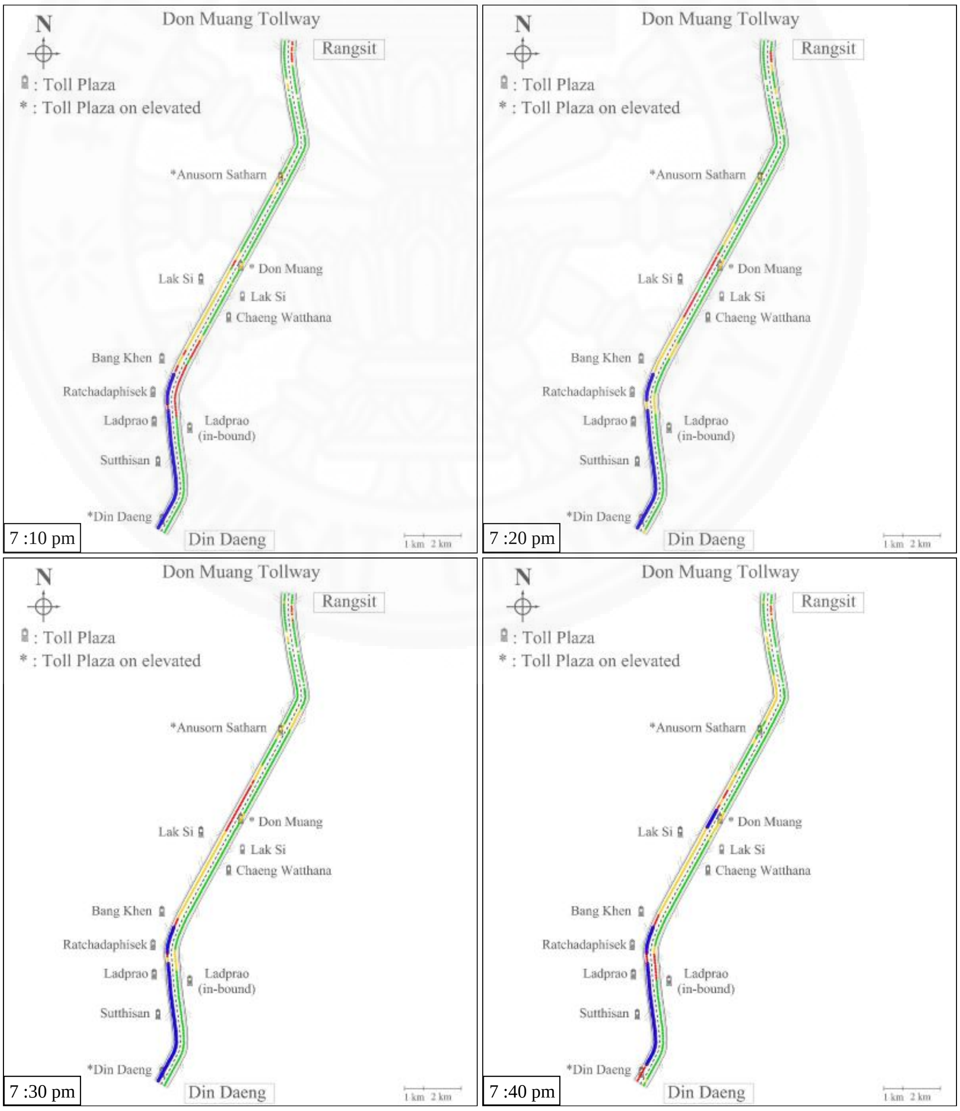


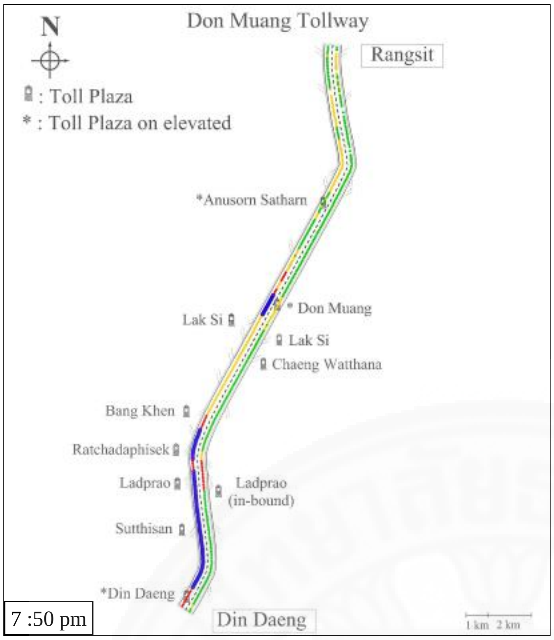
D. Severe traffic congestion on Bangphli Suksawat expressway

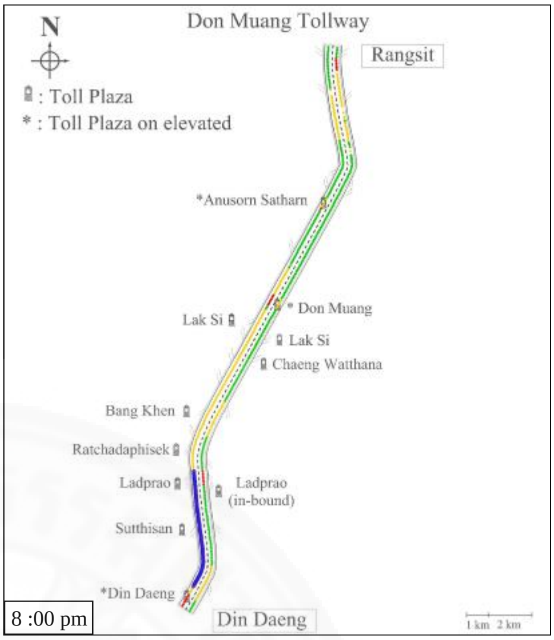




E. Severe traffic congestion on Don Mueang tollway







3. Results traffic anomaly detection

Table 1 Percentage of degree of traffic anomaly detected on Sirat expressway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	90.01%	85.80%
Class 2	0.0 - 50%	4.86%	7.02%
Class 3	50 - 75%	2.99%	4.23%
Class 4	> 75%	2.14%	2.95%

Table 2 Percentage of degree of traffic anomaly detected on Ramindra expressway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	95.61%	94.98%
Class 2	0.0 - 50%	2.11%	2.52%
Class 3	50 - 75%	1.33%	1.50%
Class 4	> 75%	0.95%	1.00%

Table 3 Percentage of degree of traffic anomaly detected on Bang Na expressway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	95.43%	95.68%
Class 2	0.0 - 50%	1.82%	1.84%
Class 3	50 - 75%	1.42%	1.32%
Class 4	> 75%	1.34%	1.16%

Table 4 Percentage of degree of traffic anomaly detected on Udon Ratthaya expressway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	98.70%	99.05%
Class 2	0.0 - 50%	0.60%	0.45%
Class 3	50 - 75%	0.41%	0.28%
Class 4	> 75%	0.29%	0.22%

Table 5 Percentage of degree of traffic anomaly detected on Bangphli Suksawat expressway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	90.53%	87.32%
Class 2	0.0 - 50%	4.56%	6.29%
Class 3	50 - 75%	2.85%	3.78%
Class 4	> 75%	2.05%	2.62%

Table 6 Percentage of degree of traffic anomaly detected on Don Mueang tollway

Classification	Degree of abnormal (%)	Percentage of events detected	
		From 00:00 to 23:50	From 6:00 to 20:50
Class 1	0%	85.44%	81.36%
Class 2	0.0 - 50%	7.09%	9.18%
Class 3	50 - 75%	4.35%	5.57%
Class 4	> 75%	3.13%	3.90%