A Study on Traffic State Patterns in Urban Area: A Case Study of Bangkok, Thailand

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Abstract: This study attempted to investigate traffic state patterns in an urban area by using the data from web-based mapping services. One month traffic state data of the road network in Bangkok were collected. In order to perform the area-based analysis, the data was organized into grid of cells with uniform size. Statistical features of each cell were calculated to find patterns of traffic states. As the result, the traffic patterns of the whole urban area were presented. Diurnal traffic state patterns by different days and different locations of the urban area were also discussed. Finally, the concentric patterns of traffic state in Bangkok was revealed and found to be consistent with previous studies.

Keywords: Area based analysis, Traffic state patterns, Urban traffic

1. INTRODUCTION

With the rapid growth of urban areas, traffic becomes one the most challenging issues in the society. Increasing traffic problems in the city such as traffic congestion, traffic safety, equality of access and environmental issues grow into big obstacles for developing the economy and dramatically impact the people quality of life. Alternative approaches to solve and alleviate the problems exist, but in recent years, implementation of the advanced traffic management system (ATMS) has been considered as a preferable approach. By integrating new technologies, the system can improve traffic flow and safety. With sufficient information of traffic states of urban road network, the government, road authorities and policy makers can have a better way to understand the traffic. This includes traffic mobility observation, evaluation of overall performance of the traffic in urban road network, and investigation of traffic problems; for instance, detection of bottleneck in the road network. Moreover, for road users, especially commuters, this information serves as a tool for their decision making. By choosing better route at the right time, both travel time and cost of travel can be reduced which provide benefit to individual and the economy of the country as a whole. Therefore, the traffic state becomes basic and valuable information for understanding and increasing overall performance of road network, and has substantial benefit to policy makers, traffic authorities and the general public.

Traffic state patterns provide a thorough representation of the spatial-temporal road network conditions. It also represents the traffic congestion information of the road network which is very important in traffic management (Lozano *et al.*, 2009; Yong-chuan *et al.*, 2011). Likewise, the study of Wang *et al.* (2013) demonstrated the necessity of having a visual system to detect and investigate patterns of traffic jams and their propagation. Furthermore, patterns of traffic condition of the whole city over times give a good representation of land use change, economic growth and how the city (Liu *et al.*, 2012). There is a wide spectrum of literature focused on methods to estimate traffic state patterns. Some researchers studied about the traffic condition pattern recognition by using various techniques such as clustering method (Montazeri-Gh and Fotouhi, 2011), Support Vector Machine (SVM) (Yu *et al.*, 2013) and Functional Data Analysis (FDA) (Guardiola *et al.*, 2014). However in this school of research, these studies only applied to a small section or a portion of the road network due to its limited availability of data and feasibility of the work.

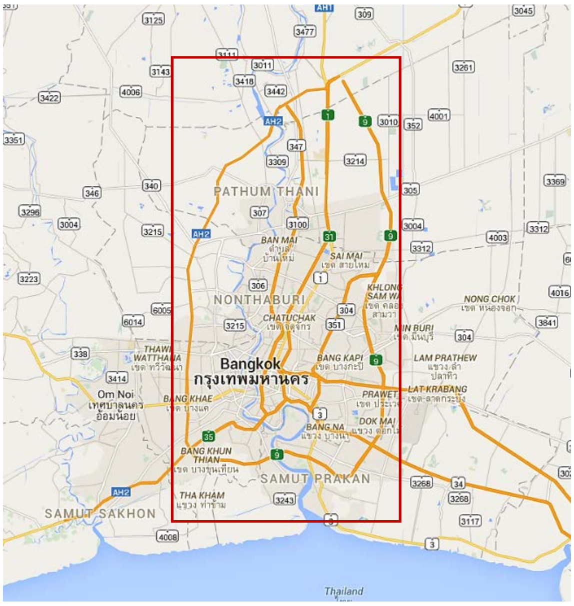
In this study, an attempt to investigate the traffic state patterns of an urban road network was made by using the traffic state data from web-based mapping services such as Bing Maps, Google Maps, and OpenStreetMap. The statistical features of the data were calculated in order to find the recurrent patterns of traffic. Then the diurnal and spatio-temporal patterns of traffic state were presented by different days of week. Lastly, the city was divided into zones by the distance from the central business district (CBD) to find the common and different patterns among them.

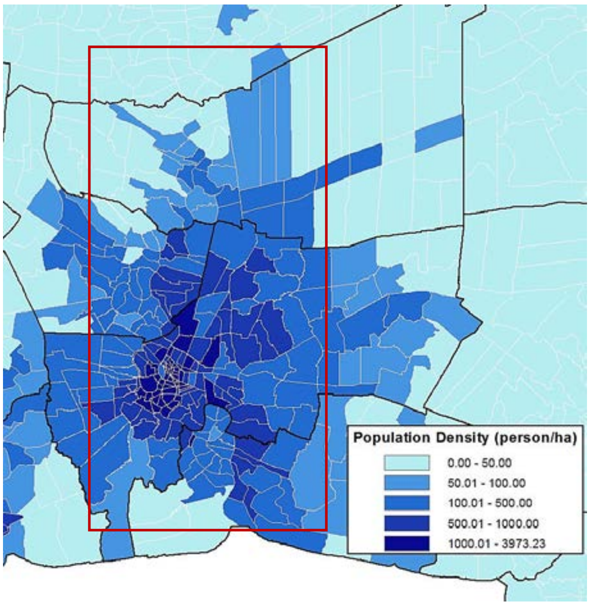
This paper is organized as follows. Section 2 describes the data collection and the study area. Section 3 discusses about the temporal pattern of daily traffic for the urban road network and for different days of the week. Then, the spatio-temporal traffic patterns are presented in section 4. Finally, the conclusion and recommendation for further research are summarized in section 5.

2. DATA PREPARATION

The development of the new technologies in transportation, especially in the field of Intelligent Transportation System (ITS), allows us to collect many kind of data and to have many analytical tools. With the advancement of mobile technology, the mobility data of road users can be obtained by GPS-enabled devices such as mobile phone and GPS receiver. This possibility allows the crowd sourcing technology to collect traffic data which is known as GPS floating car data. Comparing to the traditional methods of collecting traffic data such as fixed detector (inductive loop detector, video camera and other traffic sensors), the GPS floating car data provide the location and speed of individual vehicle on the road with more cost effective and larger scale in real time. Collecting across thousands of devices then combining them together, the actual traffic state on the road network can be obtained. The traffic state information is referred to the traffic flow condition of the road section compared with its capacity. It also represents the level of service which is a qualitative stratification of performance and quality of service provided by that facility. In consequence, many web-based mapping services such as Bing Maps, Google Maps, and OpenStreetMap adopt this technology to give users the traffic condition on the road. There is a small number of studies which focus on this traffic state data. Among them, Tostes *et al.* (2013) used the traffic data from Bing Maps to investigate the city-wide traffic flows and also to predict the future traffic state on the road. This study aims to gather these information in order to build the traffic state pattern of the whole urban network and further investigate the underlying patterns of traffic.

For the purpose of this study, Bangkok, the capital city of Thailand, and its surrounding area was selected as the area of study. Covering the urban area of Bangkok, a study area of 35 km x 70 km containing the road network inside the outer ring road was selected as shown in Figure 1(a) and (b). The area was discretized into 2450 1 km x 1 km cells. Traffic states were collected once every 10 minutes from September 1, 2014 to September 30, 2014.





(a) **(b)**

Figure 1. (a) Study area (35 km x 70 km), within outer ring road of Bangkok (image source: Google Maps). (b) Population density map of Bangkok, Thailand (adapted from Transport Fundamental Geographic Data Set (FGDS), Ministry of Transport of Thailand, 2007)

In the data collection process, the traffic states of the urban road network were recorded in the form of image data. Points with the distance of 250 meters apart from each other along the road, served as artificial traffic sensors, were set to capture the traffic condition at those locations. Because traffic condition is a qualitative measure, a classification index is needed for the purpose of study as shown in Table 1.

Table 1. Traffic state classification indexes

Traffic State	Index assigned
Free flow condition	1
Moderate flow condition	2
Heavy flow condition	3
Congested flow condition	4
No data available	N/A

3. TEMPORAL PATTERNS OF TRAFFIC CONDITION

3.1 Area Based Analysis

To investigate the temporal behavior of the traffic conditions based on the area setting, the data were grouped into 1 square kilometer cells. In this study, we organized the data into 70 rows, 35 columns and 4320 ten-minute time bins for a duration of one full month (30 days). For each cell, the intensity of traffic condition for every 10 minutes is denoted by a four dimensional matrix $\boldsymbol{I}[i, j, d, t]$, where $i = 1,\ldots, 35$; $j = 1,\ldots, 70$; $d = 1,\ldots, 30$ and $t = 1,\ldots, 144$. The arithmetic mean and the standard deviation of the traffic state of the points within an individual cell were computed as follows,

$$\bar{I}_{ijdt} = \frac{\sum_{k} I_{kdt}}{K} \tag{1}$$

$$\sigma_{ijdt} = \sqrt{\frac{1}{K-1}\sum_{k}^{K}(I_{kdt} - \bar{I}_{ijdt})^2} \tag{2}$$

Here $\bar{I}_{ijdt}$ and σ_{ijdt} are the average intensity of traffic of cell C_{ij} of day d and time t and its standard deviation. I_{kdt} is the intensity of traffic of each point k located within a cell of day d and time t and K is the number of artificial sensors that are located within a cell. Cells with $k = 0$ were excluded from the calculation because of the unavailability of traffic data.

3.2 Temporal Patterns of Traffic in the Whole Urban Area

To visualize the time variation pattern of the whole area, the traffic intensity of each cell was calculated, and then combined to find the average value which represent the overall traffic intensity of the whole area (I_{dt}^{W})

$$I_{dt}^{W} = \frac{\sum_{i}^{35}\sum_{j}^{70} \bar{I}_{ijdt}}{N} \tag{3}$$

Where N is the total number of cells where artificial traffic sensors are located in the study area. The result of 10 minutes time bin pattern of the whole area for the duration of one month is plotted in Figure 2. A total number of 30 temporal sequences of traffic state in the study area with a one full day cycle can be identified. It is observed that the traffic pattern repeats itself within one full day. In most of the repeating sequence, there are also the inner pattern (2 peaks in one day). This pattern will be discussed in the next section.

3.3 Traffic Patterns for Different Days

By differentiating between weekdays and weekends, significant differences between traffic patterns can be found. During weekdays as shown in Figure 3, the temporal sequences share similar characteristics; two main peaks corresponding to the morning peak which starts around 7:30 and ends around 9:30 and the evening peak from 17:00 to 20:00. This pattern can be associated to trips during weekdays which are non-recreational trips (working trip, school trip, etc.). On the other hand, the diurnal traffic pattern of the weekend is different from the one of the weekday. Figure 4 and 5 show the average traffic intensity on Saturday and Sunday along with its variations, respectively. There is only the evening peak which starts around 17:00 and ends around 20:00. The morning peak disappears due to the non-working day and people tend to start their trips late (around 10:00). However, there is also distinctive differences between traffic patterns on Saturday and Sunday. There is more traffic on Saturday, especially high evening peak. These trips can be associated to the trips with the recreational purposes.

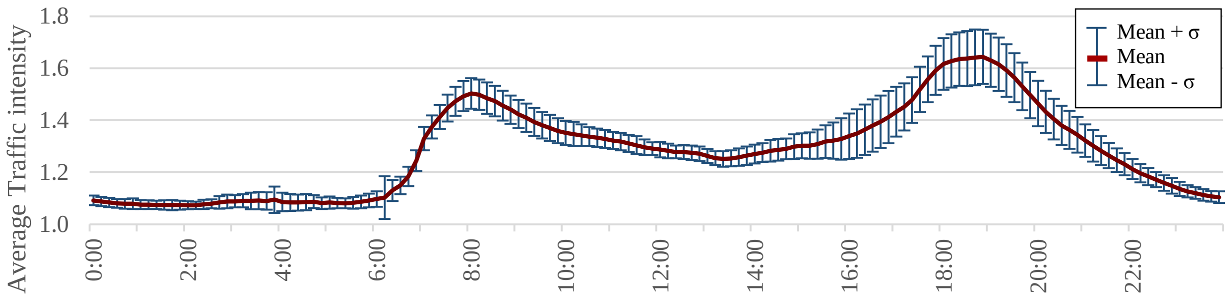


Figure 3. Temporal pattern of traffic intensity during weekday for the entire study area

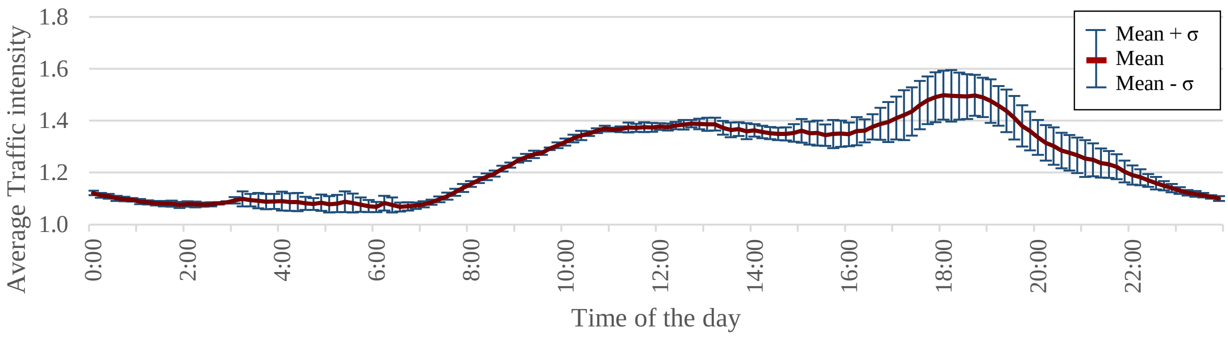


Figure 4. Temporal pattern of traffic intensity during Saturday for the entire study area

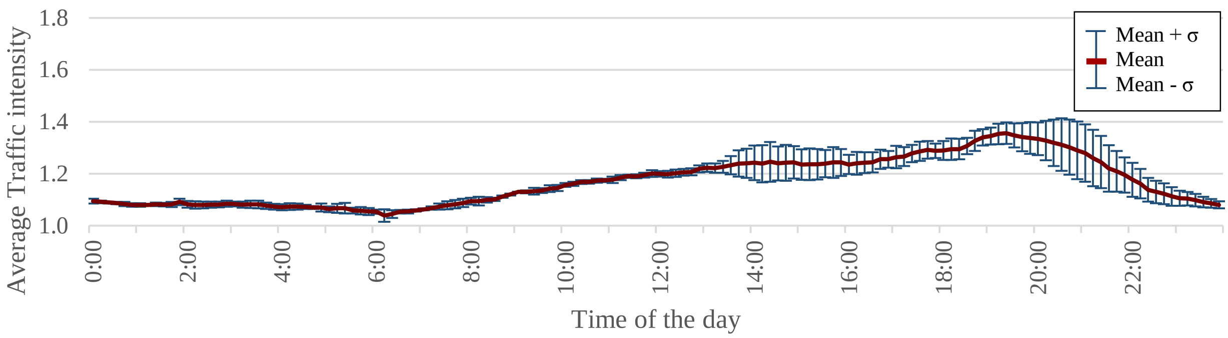


Figure 5. Temporal pattern of traffic intensity during Sunday for the entire study area

4. SPATIO-TEMPORAL PATTERNS OF TRAFFIC CONDITION

4.1 Spatio-Temporal Traffic Patterns for Different Days

With the understanding of the traffic pattern differences between different days of the week, we would like to further investigate how the traffic evolve in terms of space (different location). As discussed in the previous section, the whole study area was discretized into 2450 small cells. Then the average traffic intensity for each cell was computed with different time of the day and different days of the week. As the result, heat maps of the whole area were plotted where the colors ranging from red to green correspond to traffic intensity from high to low. Figure 6(a), 6(b) and 6(c) show the spatio-temporal evolutions of traffic during the weekdays, Saturdays and Sundays, respectively. In addition to the diurnal temporal patterns of the traffic, the spatial patterns are also clearly seen. This spatio-temporal patterns of traffic are consistent with the temporal patterns discussed above. Moreover, we found that there is a concentric pattern of traffic where the most congested location is in the downtown area. By this revelation, the traffic pattern with the different distance from the center of the city will be investigated in the next section.

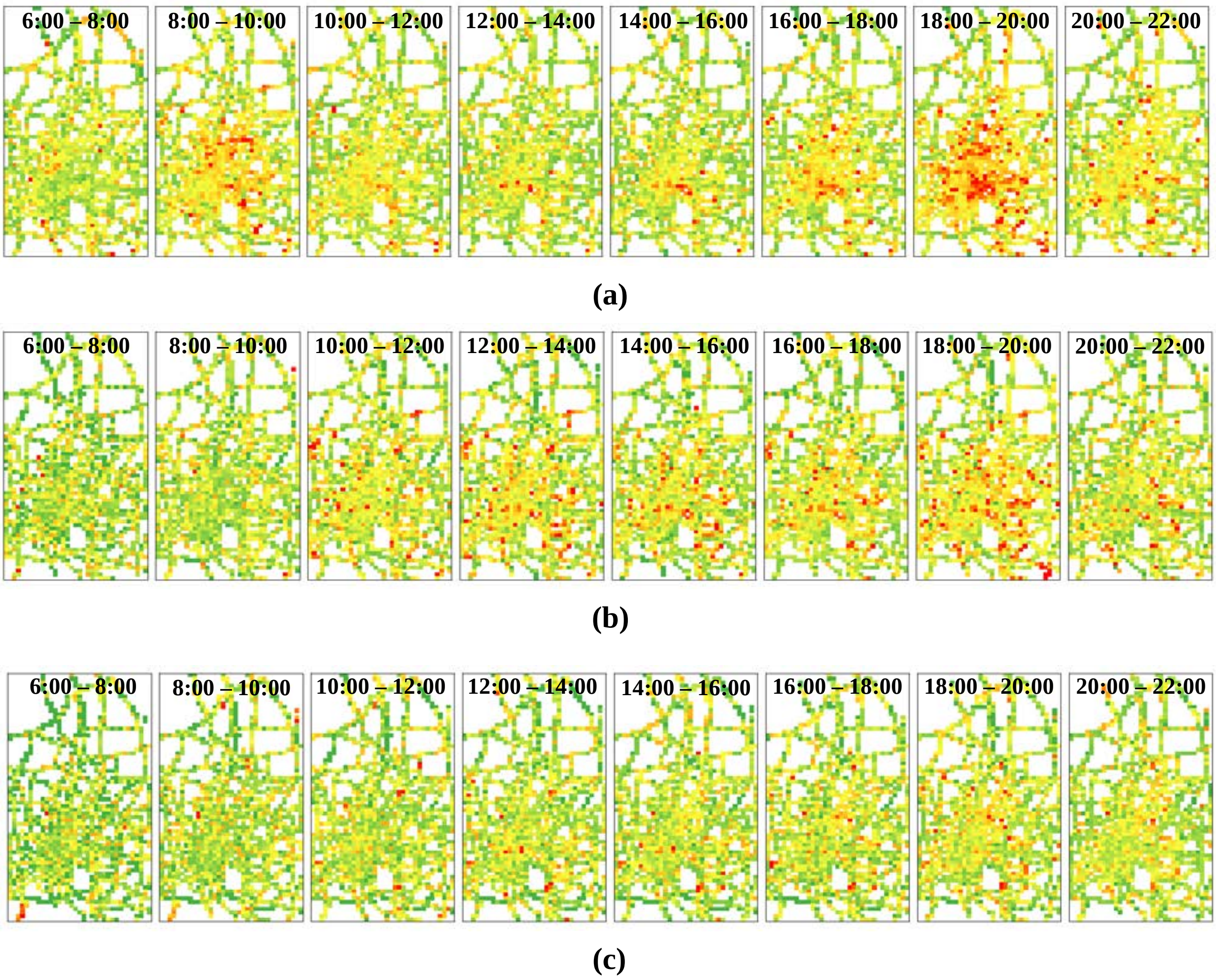


Figure 6. Heat maps represent spatio-temporal patterns of traffic intensity from 6:00 AM to 10:00 PM during (a). Weekdays (b). Saturday (c). Sunday

4.2 Relationship of Traffic Patterns with the Distance from Central Business District

The purpose of this analysis is to reveal the difference of the traffic intensity pattern by the location of the area in terms of the distance from the central business district (CBD) of Bangkok. Silom area, the center point in Figure 7, is considered as the CBD (Tipakornkiat *et al.*, 2012). In Figure 7, four circles with the same center have been drawn on the map in order to classify the study area into four different zones with the radius of 2 km, 6 km, 10 km and 14 km from the center, respectively. For each zone, the average intensity of the traffic is computed by the time of the day as shown in Figure 8. It can be seen that the pattern of each zone is similar but different in traffic intensity. In the morning, there is not much variations between each zone; but the difference is clear after the middle of the day (12:00). This can be interpreted as the traffic in the CBD area is the most congested, and the intensity decreases as the distance from the center increases. This traffic pattern is consistent with result of the study of Liu *et al.* (2012) which revealed the concentric urban structure by investigating the trip pattern. Furthermore, it is also consistent with the finding of concentric pattern of urban area by using census and survey data in the study of Li *et al.* (2007) and the concentric zone theory of the urban area which was first introduced by Burgess (1925).

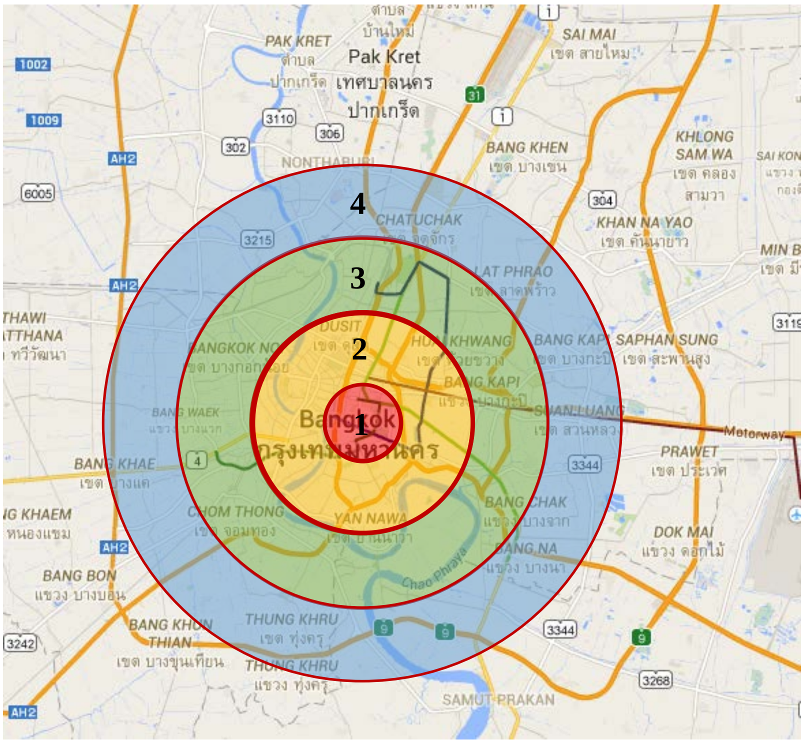


Figure 7. Four zones defined by four circles with radius of 2 km, 6 km, 10 km and 14 km

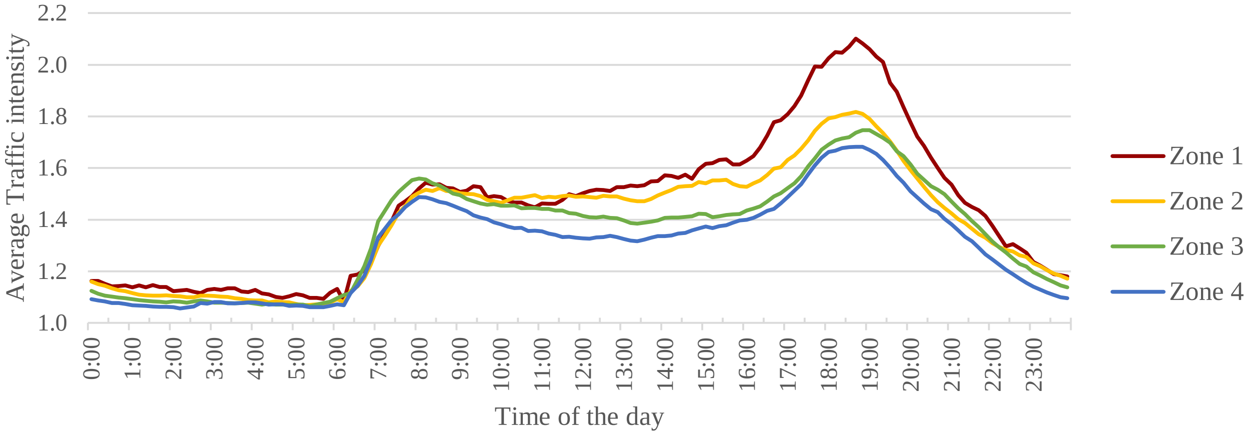


Figure 8. Temporal pattern of average traffic intensity for each zone

5. DISCUSSION AND CONCLUSION

In general, the study of traffic patterns shows relationships between volume of traffic and speed of vehicle moving on the road. The traffic condition or traffic intensity of the road is usually regard as the final result of study or the output information for road users. In contrast, in this study, the traffic condition on road network was used as the data input for analyses. Using the traffic state data from the web-based service provides advantages in terms of large area coverage, cost effective and real-time data.

From the result of the temporal traffic state pattern, repetitive sequences were revealed with the cyclic behavior of 24 hours. The significant difference between traffic patterns of weekdays and weekends was also detected. With detail observation on local calendar in Thailand, there is no public or national holidays during weekdays of the study period. Hence the following correlations can be made; weekdays to working days and weekends to non-working days. Based on these arguments, certain solid reasons can be explained for the traffic patterns as follows. For weekdays, first peak in the pattern corresponds to trips to work or school in the morning. Then the traffic intensity is moderate throughout the day until in the evening when people leave from work and school, the intensity of traffic is at high peak again. In contrast, the traffic state pattern of weekends is different. The overall traffic intensity for urban area is lower during the non-working day. The morning peak disappeared due to unrestraint time schedule of people during weekends which leads to wider distribution of departure time. People have more freedom of choosing when to start their trip and generally tend to stay at home or start their trip later than during weekdays. There is only evening peak in the pattern which can be explained by the trips with recreational purposes such as go to shopping mall, restaurant and visiting some attractions, etc. in the evening.

Further investigation was made to get spatio-temporal traffic state patterns. During weekdays, high traffic intensity mostly occurs in the center of the city where there are a lot of work related locations such as office building, government office, shopping mall, etc. To the contrary, the spatial distribution of traffic intensity during weekends is not only in the city center but scattered all over the area. This can be correlated with the location of leisure attractions. Finally, with the location of central business district (CBD) as the center, four different zones were generated in terms of distance from the center. Zone 1 which is the central business district has the highest traffic intensity due to presence of many bank headquarters, financial institutions and office buildings. This area is also famous for entertainment and nightlife activities which cause a very high traffic intensity during evening period. For zones with the distance farther away from the center, the traffic intensity keeps decreasing which is a result of less density of working related place.

In conclusion, this study demonstrated that traffic information from web-based service can be used as a traffic data source which benefit to the research community. The findings also provide a better understanding of the traffic state pattern in urban area; what the traffic is like in terms of time and space. In the practical point of view, the findings from this study would contribute as useful information for traffic engineers and authorities. For instance, time and location of congestions were detected according to the spatio-temporal traffic pattern, so detail study can focus directly on the problem. In addition, the finding of traffic state patterns of the four identified zones can be used as an input into some solutions that alleviate the traffic congestion in urban area such as congestion charging policy. Congestion charging is an effective measure in the traffic demand management where the motor vehicles will be charged when entering into some region in certain time interval. Detail descriptions and practices in some cities such as Singapore and London can be found in the study of Ye (2012). With our result, boundary of charging area can be appropriately suggested.

Further investigation is needed to reveal how traffic state changes and how it evolves from one state to another. Many other factors can also be related to the variation of traffic state such as land use, weather, road blockage (accident, road work, etc.), special event, etc. As the study covered only the data for one month, extending the data collection to cover longer period of time is also expected. By finding the historical traffic pattern, the identification of traffic problem can be done by comparing the irregular traffic state patterns to the historical ones.

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