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Study on Traffic Congestion Patterns of Large City in China Taking Beijing as an Example

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Abstract

Urban traffic congestion has different typical characteristics under the influence of different conditions, such as different day of week, holiday and weather etc. It is necessary to set up the relationships between traffic congestion patterns and those influencing factors, when we conducting macroscopic analysis on the causes of traffic congestion. Based on Traffic Performance Index (TPI), a dynamic macroscopic index showing the whole area congestion intensity developed in 2007, typical congestion patterns are identified by using clustering method. A comparative analysis is conducted on setting rules for different clustering indexes. TPI pattern curves are derived and verified under combinations of date, transportation demand management policy, holiday, weather condition and etc., according to the actual traffic operational status. The analysis and verification results show that the method used in this paper is effective and feasible. TPI patterns indicate that traffic congestion has inherent characteristics which are primary and essential for transportation managers. This paper lays the foundation for traffic congestion prediction and early warning and proactive alleviation of traffic congestions.

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Keywords: Traffic congestion; Traffic Performance index (TPI); Congestion pattern curve; Cluster method; Data mining

1. Introduction

Traffic congestions in large cities are becoming a hot issue concerning people's livelihood and social and economic development. The cardinal rule for alleviating traffic congestion is to scientifically and quantitatively describe traffic congestion. On one hand, the central government needs quantitative indexes to evaluate and assess

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the congestion alleviation work of governments at all levels; on the other hand, in the multimodal transportation system, the public are more inclined to make choices for the travel mode and travel time instead of simple path choice when they goes out. Therefore, they need to know not only the condition on a certain road but also the overall congestion condition in the destination area or even the whole city. The development of new-generation Intelligent Transportation Systems technologies such as floating car traffic information collection technology makes it possible to scientifically, objectively, quantitatively and dynamically evaluate congestion. The studies on the traffic congestion evaluation have been carried out both in United States (Turner et al.., 2004) and in China's megacities led by Beijing, Shanghai and Shenzhen. In 2011, Beijing took the lead in officially releasing the technical standard (Wen and Sun, 2011) of the urban road traffic performance evaluation indexes, forming the quantitative description indexes for traffic congestion conditions with the TPI as the core and realizing the unity of theoretical methods for measuring dynamic traffic congestion characteristics of the whole road network.

The application of TPI in Beijing for nearly six years proves the accuracy and sensibility of the TPI on time spans with different characteristics such as vehicle banned according odd-and-even license plate rule during the Olympics, vehicle ban one day a week by license plate tail number, holidays and rain or snow. The TPI provides important support to special traffic work such as study and assessment of Transportation Demand Management (TDM) policies, appraisal of traffic congestion alleviation tasks for six districts of Beijing, screening of congested segments and intersections for congestion relieving projects and their effect evaluation, setting of dedicated bus lanes, setting of reversible lanes and guarantee for traffic emergency dispatching.

The TPI realizes the breakthrough from qualitative description to quantitative analysis for regional traffic congestions. After a large amount of data is accumulated, traffic congestion rules can be discovered to identify congestion patterns, find out the corresponding influencing factors and eventually realize the prediction on the traffic congestion trend. In this paper, different patterns of traffic congestion are studied mainly on the basis of TPI variation rules, namely, TPI fluctuation characteristics at morning peak and evening peak, characteristics of traffic congestion peaks and characteristics of traffic congestion duration, etc. The TPI pattern analysis technique is put forward to identify typical TPI curves representing different congestion characteristics, laying the foundation for grasping traffic congestion rules and proactively alleviating traffic congestions and guiding transportation development.

2. Analysis on Typical Traffic Congestion Characteristics

A floating car traffic information processing and traffic congestion evaluation system is established operated in real time. The system can obtain GPS location data transmitted every minute by nearly 40,000 taxies in Beijing in real time, and process GPS data every five minutes to obtain the speed of each link (Guo and Wen, 2007; Zhu and Wen, 2008). Based on the congested mileage of each link weighted by VMT (Wen and Sun, 2011), dynamic TPI of the central area of Beijing city (roughly within the Fifth Ring Road) is calculated every 15 minutes. TPI is the core index in the road traffic evaluation index system of Beijing. The value of TPI ranges from 0 to 10, indicating five congestion levels. Where, [0,2) indicates smooth traffic; [2,4) indicates basically smooth traffic; [4,6) indicates slight congestion; [6,8) indicates moderate congestion; [8,10] indicates severe congestion. The higher the value is, the severer the traffic congestion is. We have accumulated the data of more than 200,000 data points on more than 2,000 days from 2008 to now. Fig. 1 shows the TPI variation curve of weekdays in September 2013. Fig. 2 shows the TPI variation curve of weekends in September 2013. We can see that characteristics such as congestion start time and end time and congestion intensity of each weekday are obvious and that there are clear differences between weekdays and weekends.

Travels on weekdays mainly occur during the commuting periods of the morning peak and evening peak. The morning peak mainly spans from 7:00 to 9:00; the evening peak mainly starts at 17:00 and ends around 19:00.The most congested morning peak of the week basically occurs on Monday; the most congested evening peak of the week basically occurs on Friday; the TPI curve on Tuesday is similar to that on Thursday; the number of vehicles with tail numbers of 4 and 9 restricted on Wednesday is less; therefore, the traffic on Wednesday is more congested than that on Tuesday and Thursday. The travel peaks on weekends are different from those on weekdays; the morning peak occurs after 9:00; the forenoon travel peak occurs at 10:00 to 12:00; the afternoon travel peak occurs at 15:00 to 18:00. The traffic congestion on Saturdays tends to be more severe than that on Sundays.

In addition, some time periods are peak periods of traffic congestion in the whole year. Due to the influence of factors such as beginning of autumn term, approaching of the Mid-autumn Festival and National Day holidays, more large events and family visits before holidays, the traffic of the whole September of each year is the most congested months in the year. The most congested day tends to occur before holidays. Fig.3. shows the monthly TPI variation of 2010 to 2012.

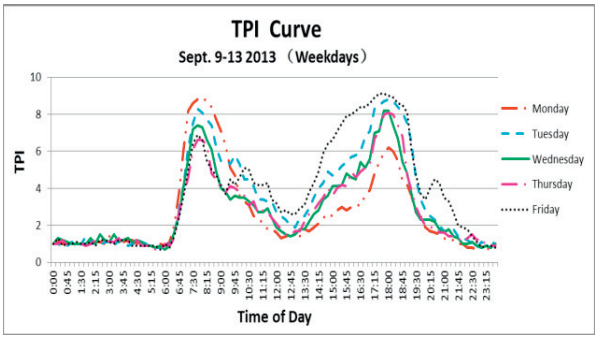

Fig. 1.TPI curves of weekdays

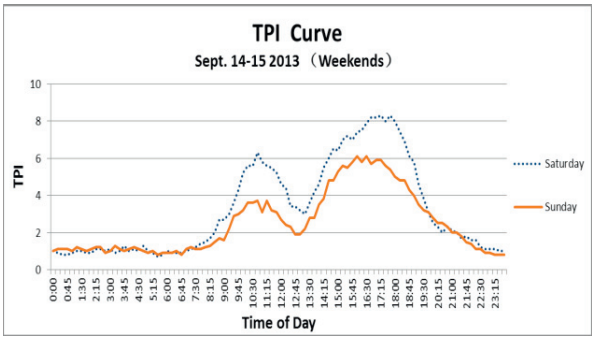

Fig. 2. TPI curves of weekends

TDM measures also greatly affect congestion level. After the Olympic Games private cars were booming in households in Beijing. Approximately 400,000 to 500,000 new vehicles are registered, corresponding to 10% to 15% increasing rate per year, meanwhile the road mileage increased only by about 2% percent. Traffic Congestion became extremely severe by the year 2010, in which about 800,000 new automobiles were sold. A new set of TDM measures named as “28 measures” was implemented on January 1st, 2011. Parking fee increased a lot and license-plate lottery was set with only 20,000 per month, 240,000 per year limit. As showed in Fig. 3, Congestion level variance is described by TPI clearly and sensitively.

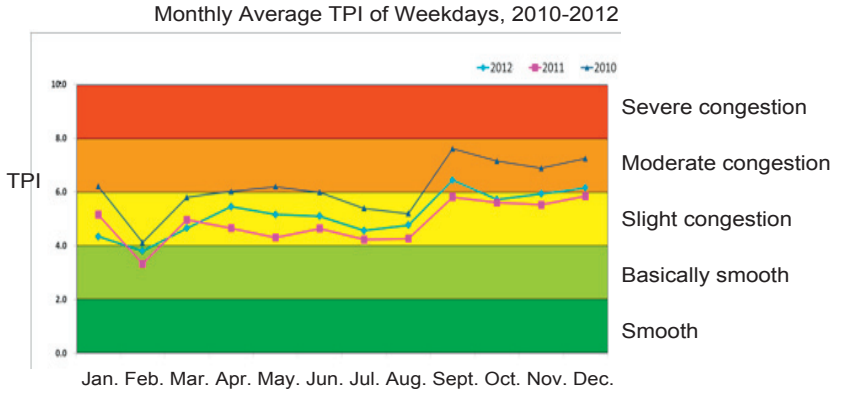

Fig. 3. Variation of monthly TPI from 2010 to 2012

3. TPI Pattern-based Clustering Method

The TPI pattern-based clustering is a data mining process. That is, a mining tool is used to identify the hidden relationship and patterns of known data. Clustering indicates grouping of samples according to certain similarity requirements. During the clustering process, there is no priori information about sample categories and training sample sets; only the similarity between samples is used as the criterion for generic classification. It belongs to unsupervised learning. The aim is to divide the given data sets into several categories based on a similarity measure

so as to ensure the largest similarity between data points of each category and the smallest data point similarity between categories.

The TPI curve is a series constituted by several characteristic values. The TPI curves of different dates may be highly similar or totally different. They have various intrinsic characteristics. In order to discover the essence through phenomena, this document associates the sets after clustering to the traffic congestion characteristics and influencing factors of each day in the sets. Fig. 4 shows the processing flowchart.

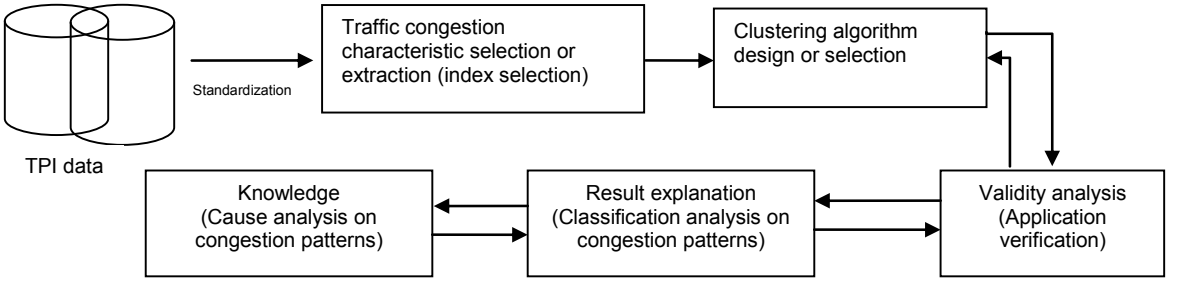

Fig. 4. Flowchart of pattern-based clustering method

3.1. Clustering method

The hierarchical clustering method is one of the most commonly used clustering analysis methods. The basic idea of the hierarchical clustering method is as follows: First, regard each of *n* samples as a category and specify the distance between samples and the distance between categories; then merge the two nearest categories into one new category and calculate the distance between the new category and the other categories; repeat the operation of merging the two nearest categories into one category until all the samples are merged into one category.

Assume that there are n samples and each sample has p indexes. d_{ij} indicates the distance of sample j. G_1 , G_2 to G_n indicates the category. D_{KL} is the distance between G_k and G_L. Median method is used in this paper, that is to say the distance between two categories is subject to neither the distance between the two nearest samples of the two categories nor the distance between the two farthest samples of the two categories. The distance between categories is subject to the median of the distance between the two nearest samples of the two categories and the distance between the two farthest samples of the two categories.

Assume that class G_k and G_L are merged into G_M in one step, for category G_j , use D_{KL} , D_{LJ} and D_{KJ} as side lengths to form a triangle and use the median of the side D_{KJ} as D_{MJ}. The formula for D_{MJ} is as follows, which is the recursion formula of median method.

$$D_{MJ}^2 = \frac{D_{MJ}^2}{2} + \frac{D_{LJ}^2}{2} - \frac{D_{KL}^2}{2} \tag{1}$$

3.2. Data standardization

During the clustering analysis, most data cannot directly participate in operation and needs to be standardized first. Assume that x_{ik} is the index *k* of sample *i*, the standardization process is as follows:

$$x_{ik}^* = \frac{x_{ij} - \bar{x}_j}{s_j},\ i = 1, 2\cdots\cdots n,\ j = 1, 2\cdots\cdots p \tag{2}$$

$$\bar{x}_j = \sum_{k=1}^{n} x_{kj},\qquad s_j = \frac{1}{n} \times \sum_{k=1}^{n} (x_{kj} - \bar{x}_j)^2 . \tag{3}$$

3.3. Selection of indexes

Through observation, all daily TPI curves (hereinafter referred to as curves) have something in common: The curves have two crests during the morning peak (7:00-9:00) and evening peak (17:00-18:00); the curves are flat on the other time segments. The curve shape may be related to the following indexes (see Table 1).

Table 1. TPI curve pattern analysis indexes

Index	Actual meaning	Meaning in the curve
x_1	Maximum TPI value during the morning peak	Highest point of the first crest
x_2	Maximum TPI value during the evening peak	Highest point of the second crest
x_3	Average TPI value during the morning peak	Height of the first crest
x_4	Average TPI value during the evening peak	Height of the second crest
x_5	TPI variance during the morning peak	Width of the first crest
x_6	TPI variance during the evening peak	Width of the second crest
x_7	Number of time points of severe congestion	Characteristic of local feature on the curve
x_8	Number of time points of moderate congestion	Characteristic of local feature on the curve

Evaluation criterion for clustering results: The general characteristics of curves are found and the clustering results are of actual significance to traffic.

4. Analysis on Typical TPI Patterns

The occurrence time and intensity of urban road traffic congestions vary mainly with the change of background traffic conditions of the transportation system. For example, on weekdays from Monday to Friday, the time to go to school and the time to go to work are concentrated at 8:00 to 9:30; therefore, the travel peak occurs at 7:00 to 9:00; traffic congestion accumulation and dispersion are completed on the road network during this time segment. The traffic on weekends is more dispersed. It is reflected in characteristics such as postponed peak time in the morning and prolonged congested duration in the afternoon. In addition, traffic congestion characteristics are also influenced before and after holidays. On the weekdays before holidays, the travel demand and trip rate increase; the feeling of all-day congestions is prominent; the congestion duration and intensity increase compared with other weekdays in the same period. During holidays, people have a strong demand to travel outside of the city and tend to go out around noon; the TPI shows that morning peak is obvious on holidays.

Due to beginning of new term for middle and primary schools, the traffic congestion in September of each year is dramatically intensified compared with the traffic congestion during the summer vacation. In addition, the arrangement for the Mid-autumn Festival and National Day holidays varies from year to year, which may make some weekends change to workdays. As a result, the background traffic changes of September are complex. Therefore, the pattern analysis is conducted on the TPI curve of September 1, 2013 to October 7, 2013 in order to see whether the traffic congestion characteristics under the complex background can be classified. Table 1 lists the timetable of September 1, 2013 to October 7, 2013.

The curve shape is related to the Indexes in Table 1. Based on the preceding consideration, two clustering processes are organized in this study. In the first process of clustering, $x_1, x_2, x_3 \cdots\cdots x_6$ are selected for analysis. The six indexes focus on describing the congestion degree during the morning peak and evening peak and lack the description of the congestion duration on other time segments. Therefore, in the second clustering, x_7, x_8 are added, and clustering is conducted from the aspects of the congestion degree during the morning peak and evening peak, duration of severe congestion and duration of moderate congestion. Finally, compare the results of the two clustering processes and determine the optimal clustering based on the actual traffic status. The experiment is as follows:

(1) Select $x_1, x_2, x_3 \cdots\cdots x_6$ to conduct clustering analysis on all curves.

Table 2. Calendar from September 1st, 2013 to October 7th, 2013

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Sept. 1 (rest day)	Sept. 2 (weekday)	Sept. 3 (weekday)	Sept. 4 (weekday)	Sept. 5 (weekday)	Sept. 6 (weekday)	Sept. 7 (rest day)
Sept. 8 (rest day)	Sept. 9 (weekday)	Sept. 10 (weekday)	Sept. 11 (weekday)	Sept. 12 (weekday)	Sept. 13 (weekday)	Sept. 14 (rest day)
Sep. 15 (rest day)	Sept. 16 (weekday)	Sept. 17 (weekday)	Sept. 18 (weekday)	Sept. 19 (Mid-autumn Festival)	Sept. 20 (Mid-autumn Festival)	Sept. 21 (Mid-autumn Festival)
Sept. 22 (weekday)	Sep. 23 (weekday)	Sept. 24 (weekday)	Sept. 25 (weekday)	Sept. 26 (weekday)	Sept. 27 (weekday)	Sept. 28 (rest day)
Sept. 29 (weekday)	Sept. 30 (weekday)	Oct. 1 (National Day holiday)	Oct. 2 (National Day holiday)	Oct. 3 (National Day holiday)	Oct. 4 (National Day holiday)	Oct. 5 (National Day holiday)
Oct. 6 (National Day holiday)	Oct. 7 (National Day holiday)					

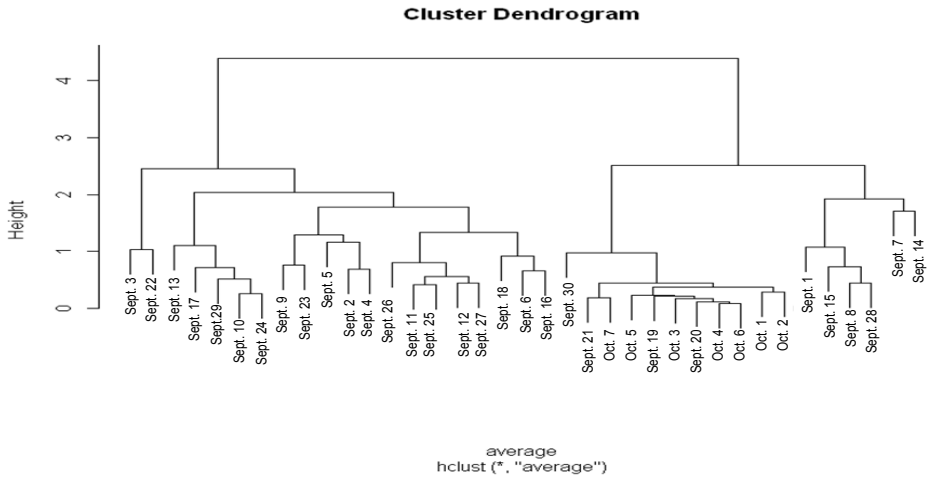

Fig. 5. Clustering analysis dendrogram -method 1

The clustering results can be obtained from the clustering dendrogram. The height on the left of the diagram indicates the distance value between individual cases. The value describes the degree of closeness between samples. The smaller the distance value is, the more similarity it is. Samples with the nearest distance are classified into one category. Based on the actual traffic significance, the classification results are as follows:

Table 3. Date category-method 1

Category	Characteristic	Date
Category 1	Rest days-normal weekends	Sept. 1, Sept. 7, Sept. 8, Sept. 14, Sept. 15, Sept. 28
Category 2	Rest days-Mid-autumn Festival and National Day holidays	Sept. 19, Sept. 20, Sept. 21, Sept. 30, Oct. 1, Oct. 2, Oct. 3, Oct. 4, Oct. 5, Oct. 6, Oct. 7
Category 3	Weekdays-average weekdays	Sept. 2, Sept. 4, Sept. 5, Sept. 6, Sept. 9, Sept. 11, Sept. 12, Sept. 16, Sept. 18, Sept. 23, Sept. 25, Sept. 26, Sept. 27
Category 4	Weekdays-severely congested weekdays	Sept. 10, Sept. 13, Sept. 17, Sept. 24, Sept. 29
Category 5	Weekdays-other weekdays	Sept. 3, Sept. 22

According to Fig. 5 and Table 3, the travel characteristics of weekdays, weekends and holidays can be clustered using the first method, but there are deviations in the classification of weekdays and actual feelings. For example, according to the actual monitoring data in this year, the most congested work week in September is the week before the Mid-autumn Festival from September 16 to September 18 (September 19 to September 21 are Mid-autumn Festival holidays. See Table 1); with this method, only September 17 is clustered as the severely congested weekday; September 16 and September 18 are classified as average weekdays. According to the preliminary analysis, $x_1, x_2, x_3 \cdots\cdots x_6$ only consider the travel characteristics during the morning peak and evening peak and do not consider the travel characteristics on flat travel time segments. Therefore, the variation characteristics of congestion duration are not reflected. Therefore $x_1, x_2, x_3 \cdots\cdots x_8$ are selected to conduct clustering (the second method) again.

(2) Select $x_1, x_2, x_3 \cdots\cdots x_8$ to conduct clustering analysis on all curves.

According to the clustering dendrogram in Fig. 6 and Table 4, with the second method, September 17 (the most congested weekday in September) is separately clustered as one category; other weekdays are more obviously subdivided; Saturdays and Sundays of weekends are separately clustered as two categories; the experimental results are consistent with the actual monitoring results.

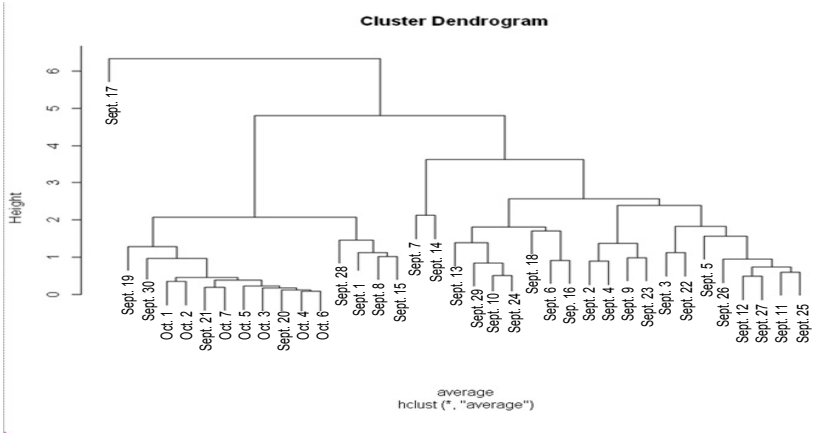

Fig. 6. Clustering analysis dendrogram-method 2

Table 4. Date category-method 2

Category	Characteristics	Date
Category 1	Rest days-Saturdays	Sept. 7, Sept. 14
Category 2	Rest days-Sundays	Sept. 1, Sept. 8, Sept. 15, Sept. 28
Category 3	Rest days-Mid-autumn Festival and National Day holidays	Sept. 19, Sept. 20, Sept. 21, Sept. 30, Oct. 1, Oct. 2, Oct. 3, Oct. 4, Oct. 5, Oct. 6, Oct. 7
Category 4	Weekdays-average weekdays	Sept. 2, Sept. 3, Sept. 4, Sept. 5, Sept. 9, Sept. 11, Sept. 12, Sept. 22, Sept. 23, Sept. 25, Sept. 26, Sept. 27
Category 5	Weekdays-severely congested weekdays	Sept. 6, Sept. 10, Sept. 13, Sept. 16, Sept. 18, Sept. 24, Sept. 29
Category 6	Weekday-most congested weekday of the month	Sept. 17

Compared with the first method, except the clustering using the morning peak and evening peak as sensitive indexes, the second method also considers the all-day congestion duration variation; that is, x_7, x_8 (number of time points of severe congestion and number of time points of moderate congestion) are used to conduct a comprehensive analysis on the all-day urban traffic congestion variation. The experimental results show that the second method is optimal. We conduct the characteristic description on the clustered six types of traffic pattern curves and provide standard curves.

(1) Pattern Curve 1 (Saturdays)

The peak time segment on Saturdays is clearly different from that on average weekdays. The morning peak on Saturdays starts from 9:30 and ends at about 12:00. Congestion occurs at 10:30 to 11:00; the congestion level is moderate congestion. The afternoon peak occurs from 14:00 to 19:00, severe congestion concentrates 16:45 to 18:00. The duration of all-day moderate congestions and severe congestions is about 3.5 hours.

(2)Pattern Curve 2 (Sundays)

The morning peak on Sundays starts at about 10:00, and reaches to slight congestion. The afternoon peak starts at about 14:15; the slight congestion state lasts until 18:30. The values of all-day TPIs on pattern curves (Sundays) do not exceed 6 (moderate congestion). Due to the arrangement for National Day holidays, September 29 (Sunday) is a workday; September 28 (Saturday) is a rest day. Different from usual Saturdays, September 28 shows the travel characteristics of Sundays. That is, the travel intensity of September 28 is smaller than that of Saturdays in the same period.

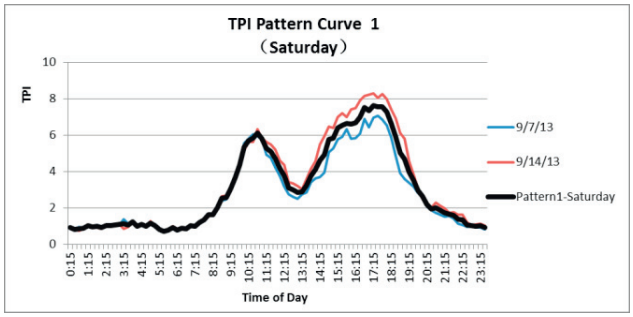

Fig. 7. TPI pattern curve 1 (Saturdays)

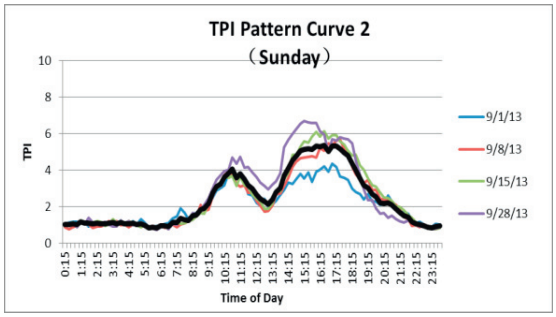

Fig. 8. TPI pattern curve 2 (Sundays)

(3)Pattern Curve 3 (Mid-autumn Festival and National Day Holidays)

Different from the travel characteristics of weekends, the travel peak of holidays occurs only in the morning; congestions are concentrated at 10:00 to 12:00. The traffic is basically at the smooth level and basically smooth level on other time segments.

(4)Pattern Curve 4 (Normal Weekdays)

The traffic on normal weekdays has obvious morning peak and evening peak commuting characteristic. The morning peak starts from 7:00 and ends at 9:45. The evening peak starts from 16:45 and ends at 19:15. The duration of all-day moderate congestions and severe congestions is two hours and 45 minutes.

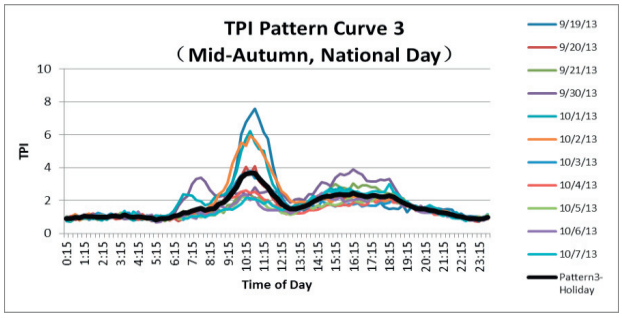

Fig. 9. TPI pattern curve 3 (Mid-autumn and National Day)

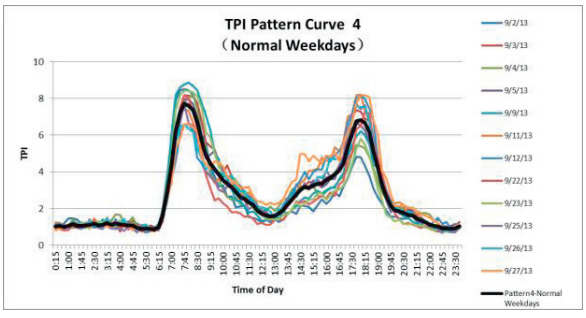

Fig. 10. TPI pattern curve 4 (Average Weekdays)

(5)Pattern Curve 5 (Key Congested Weekdays)

On the days before holidays, when restricting the vehicles with tail numbers of 4 and 9, or the weekdays without restrictions, the road traffic congestion intensity is obviously higher than that on normal weekdays because the travel demand and car usage increase. According to the experimental results, the traffic characteristics on September 6 (Friday), September 10 (Teachers' Day; the day on which vehicles with tail numbers of 4 and 9 are restricted),

September 13 (Friday), September 16 (the day before the Mid-autumn Festival), September 18 (the day before the Mid-autumn Festival), September 24 (the day on which vehicles with tail numbers of 4 and 9 are restricted), September 29 (the day before the National Day holidays; workday without restrictions) are similar. The traffic congestion intensity (TPI > 8) is extremely high at the morning peak and evening peak; the all-day congestion duration is prolonged; the morning peak starts from 7:00 and ends at 11:00; the evening peak starts from 14:15 and ends at 19:45; the duration of all-day moderate congestions and severe congestions reaches five hours.

(6)Pattern Curve 6 (Most Congested Weekday)

According to the actual monitoring data, September 17 is the most congested weekday in September 2013. It is approaching Mid-autumn Festival, rains all daytime and the vehicles with tail numbers of 4 and 9 are restricted. All the preceding factors overlaid resulted in the duration of all-day moderate congestions and severe congestions reaching 11 hours, while severe congestions reaching 6 hours and 15 minutes. Congestion is unbearable in such kind of pattern.

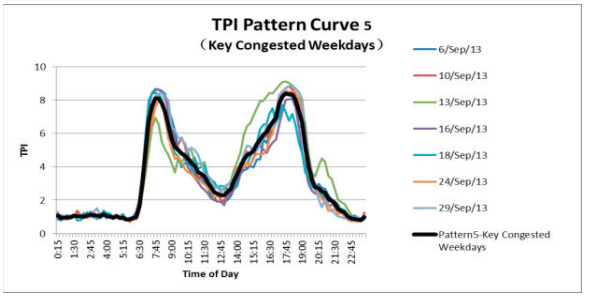

Fig. 11. TPI pattern curve 5 (Key Congested Weekdays)

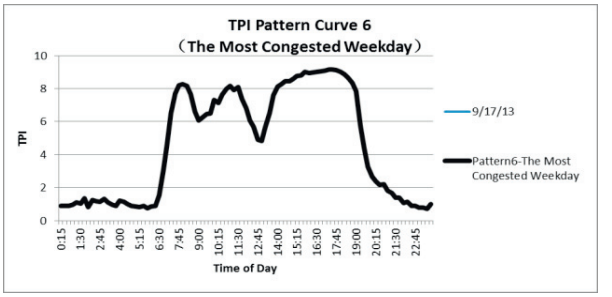

Fig. 12. TPI pattern curve 6 (Most Congested day)

5. Conclusion

Congestion is an appearance of urban traffic which we could see easily. But evaluation of congestion with TPI is only the first step. Why congestion occurred, what is the essence of congestion, which factors contribute congestion most? We need to discover not only the phenomena but also the essence. That is, we should grasp the traffic congestion patterns and the influencing factors. Then governments can implement measures to alleviate traffic congestions accordingly in advance. In this paper, on the basis of the TPI, an objective expression for traffic congestions, the clustering analysis method is used to divide the pattern characteristics of traffic congestions in large cities. Then the representative curves of traffic congestions in large cities can be concluded. Furthermore the factors influencing traffic congestions such as TDM policies, weather, holidays, weekdays, activities and events could be connected with TPI. Finally, the future congestion level, occurring time, duration time could be forecasted like weather forecast. This document focuses on classification on the basis of traffic congestions in morning and evening peak hours and selects eight evaluation indexes. The next step is to select indexes on the basis of all-day TPI variation characteristics and capture more subtle congestion variation characteristics except the morning peak and evening peak; on this basis, establish a massive traffic congestion pattern database and develop the traffic congestion prediction algorithm to conduct prediction and early warning for traffic congestions.

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