Traffic Congestion Measurement Based on Accumulating Volume

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Abstract
This paper demonstrated the limitations of traditional traffic congestion measurement methods which based on traffic volume, queue length, travel speed, travel time and the index integrated or derived from them, proposed a traffic congestion measurement theory based on accumulate volume of matching flowing-in and flowing-out sections in a finite networks to reflect the traffic congestion’s formation, development, dissipation procedure and its severity. This measurement method is measureable, related with the direct causes of congestion as well as non-subjective. This paper gave a new definition of traffic congestion based on accumulate volume of flowing-in and flowing-out sections, analyzed traffic congestion’s formation, developmental, dissipation procedure, demonstrated that the reduction of vehicles traveling-freedom, compression of front spacing as well as following behavior’s strengthening at the beginning of congestion occurrence and the congestion degree would have a short-time intensified at the beginning of dissipation, established traffic congestion measurement models of basic calculating segment, road links, intersections and network respectively and gave out the corresponding algorithm as well. Theoretical and simulation analysis shows that the congestion degree defined in this paper could reflect the formation, development, dissipation procedure and severity of traffic congestion by a continuous dynamic changes of congestion degree’s values, which can complement the congestion measure theory, effectively.

Key words: Urban Traffic; Congestion Measurement; Accumulating Volume; Flowing-in and Flowing-out Sections; Traffic Flow Conversation Law.

1. INTRODUCTION

With the rapid development of China’s national economy, the urbanization level gradually improved the size of cities larger and larger. Meanwhile, because of the dependence of automobile industry, the car ownership rate increased gradually and its velocity is far quickly than the infrastructures construction, which lead to the contradictory between the urban citizens traffic demand and the urban roads increasingly prominent and the congestion increasingly serious, the lost caused by traffic congestion also rise year by year. Traditionally, the existence and severity of congestion was acquired by comparing the traffic flows of links and intersections with the corresponding capacity, and then establish the congestion control and guide strategies.

However, by the opinion that congestion is a queuing or parking phenomena due to traffic demand exceeds the corresponding capacity, congestion only can be detected when it already occurred, these methods were describing the dynamic developing process of congestion by a series of static values on the time, which is post evaluation, actually, and cannot reflect the substantial change of congestion (Liu, 2013). Hence, a new congestion measurement model based on the accumulating volume of flowing-in and flowing-out sections was proposed in this paper, which focus on the relationship between the accumulating volume of flowing-in & flowing-out sections and the congestion of the corresponding segments, to reflect the formation, development and dissipation process of congestion dynamically, and establish a method in congestion measurement to provide reference to traffic congestion control method and practice.

Congestion measurement is the basis of the control and guide, and with the efforts of scholars and professionals, a considerable amount of findings produced. These findings can be divided as intuitive methods and comprehensive methods according to the complexity of the research means.

Intuitive methods are using the basic traffic parameters such as saturation (the ratio of volume and capacity), speed, and queue length to quantify congestion. For example, America defines unstable traffic flow which speed below 22km/h as congestion (Kurzhanskiy, 2015). Japan determines the queue length over 1km or...
delay time over 10min as congestion (Long, 2009); China’s Urban Road Traffic Management Evaluation Index System (2007) provided a classification standards of average speed on urban road as shown in table 1.

**Table 1. Classification of Urban Road Traffic State (km/h)**

<table>
<thead>
<tr>
<th>Classification Standard Levels</th>
<th>Smoothness</th>
<th>Ordinary Congestion</th>
<th>Heavy Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitans and Class A Cities</td>
<td>[22,60]</td>
<td>[16,22]</td>
<td>[0,16]</td>
</tr>
<tr>
<td>Class B Cities</td>
<td>[25,60]</td>
<td>[19,25]</td>
<td>[0,19]</td>
</tr>
<tr>
<td>Class C and D Cities</td>
<td>[27,60]</td>
<td>[21,27]</td>
<td>[0,21]</td>
</tr>
</tbody>
</table>

The intuitive methods are easy to operate and calculate, but it’s just a reflection of the history, even the real-time data is collected, it would only reflect the current traffic state, the procedural and dynamical characteristics cannot be covered.

Comprehensive methods are integration and fusion of the intuitive indicators, e.g. volume, speed, queue length and so on, to create new indicators by means of macroscopic measures to reflect traffic congestion. For instance, a travel-time based Congestion Index was created to calculate the severity of congestion by (Liu, 2007), a description of congestion based on the variability of influenced time, influenced vehicles or people and the severity of congestion is proposed by (David Schrank, 2009), the index of travel time based on the gap between the actual travel time and the travel time under free flow was introduced by (Lomax, 1997) in Quantifying Congestion.

At the same time, some researchers described congestion from the traffic motion process, such as the California Algorithm for accident detection on freeways, pattern recognition algorithm and multi-objective accident detection algorithms (Long, 2009). Cambridge Systematic Inc defined different congestion severity by researching on lane-change behaviors at different traffic state (2005). Benjamin Coifman developed an algorithm by calculating the total delay, periodical delay and the aperiodical of a segment with two monitoring stations, to measure its congestion (Coifman, 2003). And there are also dynamic traffic flow models based on ITS and fuzzy fusion of multi-indicators, traffic parameters data to quantifying congestion (Li, 2014).

In summary, the existing research on congestion measurement based on traffic flow, queue length and space mean speed, with the integration of time, space, subjective perception and other variables, dealing with neutral networks, genetic algorithmic, ant colony algorithm and other intelligent methods is a presentation of resultant state, which is passive reaction methods, only can be used to do the post-assessment but cannot to forward control. The volume and speed based in the procedure of congestion judgment are observed quantities scattered over time and space, and cannot directly related with the process of traffic arrival and departure, that result in the untruthful and inaccurate reflection of the dynamic process of congestion formation, development, dissipation. Hence, we gathered the matching flowing-in and flowing-out sections, to investigate and analyze the traffic flow rates of the sections, and the accumulating volumes of the corresponding segments to mirror congestion formation, development, dissipation factually and objectively.

2. CONGESTION CALCULATION BASED ON THE ACCUMULATION OF FLOWING-IN AND FLOWING-OUT SECTIONS

2.1. Concepts
The common view on traffic congestion is traffic demand above its capacity, which is capacity analysis essentially. Another opinion on congestion is that congestion is generated from the imbalance of traffic flowing-in volume and flowing-out volume (Zhai, 2004), but without comprehensive analysis and calculation. Hence, congestion in this paper is defined as a phenomenon that vehicles forced to go slowly, stop and go, or even stagnation due to flowing-in rate exceeds flowing-out rate in certain period time and at certain space(Liu and Miao, 2016). This conception mentioned congestion occurs in a certain special and temporal scales, indicates that:

a. The processing of congestion is the accumulations of flowing-in rates exceed the flowing out;

b. The criterion of congestion is the influence of the accumulated volumes of the flowing-in and flowing-out sections with matching relationships and meeting the conservation law of traffic flow;

c. The direct reflection of congestion is the freedom of driving falls, with the following behavior enhanced, meanwhile, the decline of velocity, increase of occupancy, elongation of travel time, and occurrence of queuing, etc will appear.

2.2. Analysis of Congestion Formation & Dissipation Procession on Basic Calculating Segment
According to the concept given in 3.1, a basic calculating segment with two matched sections, one is the flowing-in section and the other is the flowing-out, is showed in Fig.1. Suppose: The distance of the two
matched sections is L, the flowing-in rate is $q_{in}(t)$, the flowing-out rate is $q_{out}(t)$, the average length of vehicles is $l$ and the average space interval is $h$, with a time duration of $T$, the accumulating volume of the flowing-in section is showed in (1).

$$N_{in}(t_0, t_0 + T) = \int_{t_0}^{t_0 + T} q_{in}(t) dt$$  

Where $t_0$ is the start time of the calculation.

Similarly, the accumulating volume of the flowing-out section is showed in (2).

$$N_{out}(t_0, t_0 + T) = \int_{t_0}^{t_0 + T} q_{out}(t) dt$$  

According to the conversation law of traffic flow, the accumulating volume between the flowing-in and flowing-out sections, $N(t_0 + T)$, at $t_0 + T$, can be expressed

$$N(t_0 + T) = \int_{t_0}^{t_0 + T} q_{in}(t) dt - \int_{t_0}^{t_0 + T} q_{out}(t) dt + N(t_0)$$  

Where $N(t_0)$ is the initial accumulating volume of the flowing-in and out sections at $t_0$, in accordance with its physical significance, $N(t_0) \geq 0$ and $N(t_0 + T) \geq 0$, i.e., the accumulating volume is nonnegative.

However, the number of vehicles, application in the practical, cannot be anything but integers, so the discrete version of formula (3) is

$$N(t_0 + T) = \sum_{t_0}^{t_0 + T} [q_{in}(t) \Delta t] - \sum_{t_0}^{t_0 + T} [q_{out}(t) \Delta t] + N(t_0)$$

Where $\Delta t$ is the minimum interval of detection time and $T$ is integer multiple of $\Delta t$.

According to (4), the accumulating volume of the flowing-in and flowing-out sections at $t_0$ is $N(t_0)$, in line with the principle of first come first service, the accumulating volume of the flowing-out section, the flowing-in section and the accumulating volume between them as shown in Fig. 2.

Where the upper boundary of the dash area at each detection time is the accumulating volume of flowing-in section, as the lower boundary is flowing-out section’s and the altitude of the dash is the segment’s. The accumulating volume functions of the flowing-in and flowing-out sections can be obtained, respectively, from their phase step curve by approximately smoothing method. The derivative of the functions with respect to time is the traffic volume at $t$, the volume gap at the same time is the accumulating volume of the flowing-in and flowing-out sections( the black solid line), and the time gap at the same accumulating volume is the travel time of the vehicles through the segment( the black dotted line).

According to formula (3), (4) and Fig. 2, we can obtain that: (i) when $q_{out}(t) > q_{in}(t)$, i.e., the flowing-out rate is more than the flowing-in, the accumulating volume of the segment will decline as time goes on, the
traffic state of the segment tend to free-flow and its ultimate state is free-flow; (ii) when \( q_{\text{out}}(t) = q_{\text{in}}(t) \), i.e., the flowing-out rate is equal to the flowing-in, the accumulation will stay constantly and the traffic of the segment will keep its original state; (i) and (ii) can be summarized as when \( q_{\text{out}}(t) \geq q_{\text{in}}(t) \), i.e., the flowing-out rate no less than the flowing-in, the accumulating volume of the segment will not increase, the traffic state will not going worse. (iii) When \( q_{\text{out}}(t) < q_{\text{in}}(t) \), i.e., the flowing-out rate is less than the flowing-in, the accumulating volume of the segment will increase with the passage of time, however, congestion will not formed immediately, as the influence and restriction among the vehicles travel through the segment will enhance, which act as the space headway’s lessen and the car-following behavior strengthen at the beginning. As \( q_{\text{out}}(t) < q_{\text{in}}(t) \) hold from \( t_0 \) to \( t_i \), the occupied road length of the accumulating volume is

\[
L(t_0^+, t_i) = [N(t_0, t_i)(l+h) - h] / n
\]  

(5)

Where \( n \) is the lane number of the segment. As the continuance of the imbalance relationship, the accumulating volume keeps increasing, and vehicles will be force to parking and queuing from the flowing-out section, at the same time, the state of the segment verge to forced flow. The maximum accumulating volume, \( N_{\text{max}} \), between the flowing-out and flowing-in sections with a distance of \( L \), can be calculated as

\[
N_{\text{max}} = \left[ \frac{L}{l + h_{\text{jam}}} \right] \times n
\]  

(6)

Where \( h_{\text{jam}} \) is the special interval at jam density. The critical time of the accumulating volume reached Nmax is the solution of the following equation (7).

\[
\int_{t_0}^{t_0 + T_{\text{critical}}} q_{\text{in}}(t) dt - \int_{t_0}^{t_0 + T_{\text{critical}}} q_{\text{out}}(t) dt + N(t_0) = N_{\text{max}}
\]  

(7)

If \( N(t_0 + T) \leq N_{\text{max}} \), vehicles enter the segment can be “swallowed” by the compression of vehicles’ space headway, and without the occurrence of congestion. The worst situation is \( N(t_0 + T) = N_{\text{max}} \), as the segment of flowing-out and flowing-in sections is fully occupied by accumulating vehicles. However, when \( N(t_0 + T) > N_{\text{max}} \), the segment will cannot “swallow” the accumulating vehicles, vehicles will spill and the possessive road length, \( L_{\text{extra}} \), by the spilling vehicles is

\[
L_{\text{extra}} = \left[ N(t_0, t_0 + T) - N_{\text{max}} \right] (l + h_{\text{jam}}) / n
\]  

(8)

When the flowing-in rate decrease or the flowing-out rate increase, in other words, \( q_{\text{out}}(t) > q_{\text{in}}(t) \) from \( T_{d} \), the queue on the segment began to dissipate, suppose the accumulating volume before the dissipation is \( N(t_0 + T) \), the dissipation rate is \( q_{\text{out}}(t) - q_{\text{in}}(t) \), the dissipation time, \( T_{d} \), needed, with different final condition, can be obtained from equation (9) or (10).

\[
\int_{t_0 + \Delta}^{t_0 + T} \left[ q_{\text{out}}(t) - q_{\text{in}}(t) \right] dt - N(t_0 + T_1) = N_{\text{steady}}
\]  

(9)

\[
T_{d} = T_{2} - T_{1}
\]

\[
\int_{t_0 + T_1}^{t_0 + T} \left[ q_{\text{out}}(t) - q_{\text{in}}(t) \right] dt - N(t_0 + T) = N_{\text{free}}
\]  

(10)

\[
T_{d} = T_{2} - T_{1}
\]

Where \( N_{\text{steady}} \) and \( N_{\text{free}} \) are the accumulating volume of steady state and free-flow state, respectively, which can be alternatively selected by the final state, as in (9), the final state is steady and (10)’s is free state. In summary, the duration of congestion, \( T_{\text{duration}} \) is

\[
T_{\text{duration}} = T_{2} - T_{\text{critical}}
\]  

(11)

2.3 Congestion calculation

Assume a segment with two sections, the flowing-in section and the flowing-out, as shown in Fig.1. The process of congestion formation and dissipation had been analyzed in 2.2, which indicated that when \( q_{\text{out}}(t) < q_{\text{in}}(t) \) and \( T = T_{\text{critical}} \), the accumulating volume, \( N(t_0 + T) \), would reach the maximum, \( N_{\text{max}} \), and the
segment would be filled with parking vehicles, define the congestion degree (CD) at this moment as 1. Before the moment, \( N(t_0+T) < N_{\text{max}} \), vehicles travel along this segment with lower speed and degree of freedom and strongly car-following behaviors; after the moment, parking queues spill over the flowing-in section, congestion spread to the upstream rapidly and impact the traffic on which as well. The CD in this paper is defined as the accumulating volume ratio (AVC) of the segment, as follows:

\[
CD = \frac{N(t_0+T)}{N_{\text{max}}} = \frac{\int_{t_0}^{t_0+T} q_m(t)dt - \int_{t_0}^{t_0+T} q_{\text{out}}(t)dt + N(t_0)}{N_{\text{max}}} 
\]

(12)

From the former analysis and (12), we can arrive several conclusions:

(i) When \( q_{\text{out}}(t) \geq q_m(t) \), \( N(t_0+T) \leq N(t_0) < N_{\text{max}} \), the accumulating volume of the segment would not increase, the traffic of which at steady or free-flow state, and the ultimate state is free-flow.

(ii) When \( q_{\text{out}}(t) < q_m(t) \) and \( T < T_{\text{critical}} \), \( N(t_0+T) < N_{\text{max}} \), \( CD < 1 \), the accumulating volume of the segment would increase, vehicles travel limited with lower degree of freedom and lower speed act as car-following.

(iii) When \( q_{\text{out}}(t) < q_m(t) \) and \( T = T_{\text{critical}} \), \( N(t_0+T) = N_{\text{max}} \), \( CD = 1 \), vehicles blocked in the segment with queuing.

(iv) When \( q_{\text{out}}(t) < q_m(t) \) and \( T > T_{\text{critical}} \), \( N(t_0+T) > N_{\text{max}} \), \( CD > 1 \) and aggrandize promptly, parking queues spread to and influence the traffic of the upstream, even developing into gridlock in urban traffic networks.

In the realistic road environment, after the determination of the flowing-in and flowing-out sections, the segment length, L, the lane numbers, n, the flowing-in rates, qin(t), the flowing-out rates, qout(t), the maximum accumulating volume, Nmax, the special interval of jam density, hjam, the average vehicle length, l, etc. can be obtained from observation or computation of the measured value. The situation of traffic congestion, occurrence, or developing, or dissipating and its severity can be calculated from the accumulating volume of the segment and CD defined before.

Traffic flow has a time-dependent characteristic, so the relative magnitudes of the flowing-in and the flowing-out rates, in reality, cannot consistent in the detection duration. The duration of same relative size relationship, trc, would return to zero and re-clocking as the relative size changes, which would influence the continuity and precision of the congestion measurement (Liu, 2013). The congestion measure function defined in this paper would overcome the limitations and provide a more continuous and precise measurement.

2.4 Congestion calculation of links

The matching relationship of the flowing-in and flowing-out sections on links is rather definite, as Fig.3 shown the basic links and Fig. 4 is the links with ramps. The matching flowing-in and flowing-out sections can be chosen reasonably by the position of detectors, accesses and ramps. For links with multi-lane, we defined that the travel status of each lane as the same, so a multi-lane is the extension of basic unit in geometrical dimension, the CD of basic links and links with ramps are:

\[
CD_{\text{basic}} = \frac{N(t_0+T)}{N_{\text{max}}} = \frac{\int_{t_0}^{t_0+T} q_m(t)dt - \int_{t_0}^{t_0+T} q_{\text{out}}(t)dt + \sum_{i} \int_{t_0}^{t_0+T} q'_i(t)dt - \sum_{i} \int_{t_0}^{t_0+T} q'_{\text{out}}(t)dt + N(t_0)}{N_{\text{max}}} 
\]

(13)

\[
CD_{\text{basic-ramp}} = \frac{N(t_0+T)}{N_{\text{max}}} = \frac{\int_{t_0}^{t_0+T} q_m(t)dt - \int_{t_0}^{t_0+T} q_{\text{out}}(t)dt + \int_{t_0}^{t_0+T} q_{\text{ramp-in}}(t)dt - \int_{t_0}^{t_0+T} q'_{\text{ramp-out}}(t)dt + N(t_0)}{N_{\text{max}}} 
\]

(14)
2.5 Congestion calculation of intersections and networks

Intersections are transfer nodes, where for direction transformation of vehicles, in the traffic system. Meanwhile, intersections are collision points of concentration in the system, as vehicles from different directions through intersections have three kinds of conflicts, divergences, convergences and conflicts, which make intersections as the bottleneck of traffic network due to the capacity of an intersection far less than the sum of its connected links. The green time must be split for different directions to reduce conflicts and ensure smoothness of traffic transformation.

Intersections could be divided into two types, interchange and plane intersections, by the elevation of the cross points. The interchanges separated conflict traffic flows by the altitude of crossing roads and could be treated as links, which CD could be calculated according to 2.4. The ordinary plane intersections’ every approach had three directions traffic flow, left-turn, straight, and right-turn. According to the basic principle of “stop-line method”, that is if a vehicle passes the stop-line, it through the intersection, setting the stop-line of every approach as the flowing-out section, the flowing-in section could be settled on the upstream which made the segment between the matching flowing-in section and flowing-out section could accommodate certain threshold vehicles(setting the threshold of signalized intersections as the capacity of one cycle, i.e., Nmax= C1cycle, at which the time need to dissipate the queuing vehicles on the approaches at least two cycles; similarly, the unsignalized intersections threshold can be set as the 2min capacity, Nmax=C2min). Assume an intersection with code i, which approaches are j, where j=1,2,3,4, and represent the north, east, south, west approach, as the north approach is 1, and the others numbered clockwise, the corresponding flowing-in and flowing-out sections are sj iin and sj iout, flowing-in and flowing-out rates are qj iin(t) and qj iout(t), as shown in Fig.5. For the approach j of a signalized intersection, the CD after time T is:

$$\text{CD}_i = \frac{N_j (t_0 + T)}{N_{\text{max}}} = \int_{t_0}^{t_0 + T} q_{\text{in}}^j (t) dt - \int_{t_0}^{t_0 + T} q_{\text{out}}^j (t) dt + N_j^j (t_0)$$

(15)

In the same way, the CD of approach j of an unsignalized intersection after T is:

$$\text{CD}_i = \frac{N_j (t_0 + T)}{N_{\text{max}}} = \int_{t_0}^{t_0 + T} q_{\text{in}}^j (t) dt - \int_{t_0}^{t_0 + T} q_{\text{out}}^j (t) dt + N_j^j (t_0)$$

(16)

There are generally at least three approaches compose an intersection, the CD of one approaches would different from the others due to the imbalance of traffic flow’s directional distribution. The purpose of the congestion measurement is to control and dissipate the severe congested approaches to avoid the sprawl of congestion, based on the precise recognition of the CD of each approach. So the congestion degree of intersection i, CDi is:
The CD of links reflect the congestion of segments, while the CD of intersections reflect the most congested approaches, however, the urban traffic networks is a collection of links and intersections with difference and connectivity. Meanwhile, the size of an intersection is comparatively small that can be measured by an approach, but the entire traffic networks is too huge to be reflected by local intersections or/and links. Comprehensively reference the former CD definitions of links and intersections, the CD of traffic networks can be expressed as:

\[ CD_i = \max \{CD_{ij}, j = 1, 2, 3, 4\} \quad (17) \]

Where I is the urban networks set with links and intersections, while i is the intersections, and k is the links.

3. CONGESTION MEASUREMENT ALGORITHM

(1) Determine the matching flowing-in and flowing-out sections, and the interval of detection, Δt.

(2) Initialization. Counting the initial accumulating volumes, \( N_i(t_0) \), and survey the basic parameters, such as the length of links, \( L_i \), number of vehicles, \( n_i \), the space headway at jam density, \( h_{jam} \), the average vehicle length, l, calculating the maximum accumulating volumes, \( N_i \text{ max} \), set the iterations, \( n=1 \).

(3) Detect the flowing-in and flowing-out rates, \( q_{in}(t) \) and \( q_{out}(t) \), of the matching sections of the time duration \((t_0, t_0+n\Delta t)\).

(4) Calculate the accumulating volumes, \( N_i(t_0, t_0+n\Delta t) \), of every segments according to 2.2.

(5) Calculate the congestion degree of the links, intersections, and the networks in terms of 2.4 and 2.5, and then export the results.

(6) Convergence test. If \( t_0+n\Delta t \) reach the convergence time, congestion measurement completed, stop the current iteration, and output the measured outputs; otherwise, set \( n=n+1 \) and go to (3).

4. SIMULATION

To verify the availability of the model and algorithm proposed before, we use the traffic survey data of Jiaoda Road in Jinniu District, Chengdu to do simulation analysis by VISSIM. The Jiaoda Road has 6 lanes, bi-directional, where 5 lanes from south to north (limiting speed: 60km/h) and 1 lane from north to south for public transit (speed: 20~30km/h). Set the flowing-in section at 50m and the flowing-out at 500m, where stay away...
from intersections to reduce whose influence, as shown in Fig.6. Take the traffic data of the evening peak to do the simulation, set the time interval to be 300s, the flowing-in and flowing-out rates and the accumulating volume of the public transit lane and the lanes from south to north are shown in Fig.7 and Fig.8, respectively, while the accumulating volume ratio (AVC) is shown in Fig.9.

**Figure 7.** Flowing-in and Flowing-out Rate & Accumulating Volume from South to North

**Figure 8.** Flowing-in and Flowing-out Rate & Accumulating Volume of Sections of Bus Transit Lane

**Figure 9.** Diagram of Accumulating Volume Ratio (CD)

**Figure 10.** The Simulation Shots (Segment from South to North)
Fig. 7 shows that the accumulating volume of the transit lane, where the maximum is 9 vehicles and the minimum is 0, correspondingly, the maximum AVC is 0.28 and the minimum AVC is 0, and the speed of the segment is above 20km/h, in the range of design speed, at most of the simulating time, without occurrence of congestion, which agree with the observational results. The accumulating of the lanes from south to north with its maximum volume is 257 vehicles and minimum volume is 74 vehicles, as the corresponding maximum AVC is 0.93 and minimum AVC is 0.27, the speed of the segment is lie in [0, 16] at most time, which means the traffic state is severe congestion, according to Urban Road Traffic Management Evaluation Index System (2007), except 0 to 600s, when the speed above 22km/h, this accord with the phenomena that vehicles go slowly, stop and go on the direction of south to north. This is due to this direction of Jiaoda Road is one of the main channels and the demand out of town at evening peak is very high.

From the variation tendency of accumulating volumes and speed shown in the preceding figures, we can see the space of the links may store vehicles to prevent congestion occurring at the beginning of flowing-in rates exceed the matching flowing-out rates, the occurrence of congestion has a certain time lag; meanwhile, congestion may not dissipate when the flowing-out rates exceeds the flowing-in, the dissipation has a time lag, either. The congestion degree proposed may reflect the general changing process of congestion precisely, distinguish the self-organization process of traffic flow compression from the congestion forming process, and measure the severity of congestion.

5 CONCLUSIONS

The above analysis of traffic flow movement shows that the formation, development and dissipation of congestion are completed in certain networks, and closely related with the parameters such as the flowing-in rates, flowing-out rates and the accumulating volumes and the maximum accumulating volumes of matching flowing-in and flowing-out sections. A traffic congestion measurement model, which based on the accumulating volumes of the matching flowing-in and flowing-out sections, is proposed in this paper. The model can reflect the congestion procedure from its formation to dissipation directly and avoid the mixture of self-organization process of traffic flow compression and the congestion forming process in traditional analysis. The congestion degree proposed in this paper can directly correspond with the free-flow, steady flow, limited flow, parking and queuing and spilling to measure the formation, development and dissipation of congestion intuitively and quantitatively. And the congestion measurement models for links, intersections and networks could reflect their traffic state under a uniform measuring standard, which will provide technical support to traffic control and guidance in the future. Future work involves the interval subdivision of congestion degree to corresponding traffic state and the operability and expanding to complex traffic networks.

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