Urban Regional Traffic State Analysis Software System Emphasizing Pattern Transition

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***Abstract*—Urban traffic state evolution analysis is very significant and constructive for traffic guidance and control. In this paper, a quantitative method for analyzing regional traffic state evolution was proposed by constructing traffic state pattern transition network to mine regional traffic state information and state pattern transition characteristics from massive data. Based on the method, a GIS-based urban regional traffic state analysis software system, URTSAS was designed and implemented. Application scenarios and effect shows that traffic state transition analysis in URTSAS has a wide application prospect in improving urban traffic management and decision-making.**

***Index Terms*—urban district, traffic state analysis, pattern transition, network, characteristics**

I. INTRODUCTION

Under the current urban traffic state of high density, strong coupling and frequent congestion, the traffic guidance and traffic control that are implemented for ensuring unblocked traffic should depend on the correct judgment of urban regional traffic state and its evolution [1]. Traffic state generally describes the macro-operation of traffic system at certain time. Each region has specific OD trip pattern, traffic distribution characteristics, and traffic flow variation trend, so the evolution of regional traffic state is relatively fixed and law-based.

Early research on traffic state analysis mainly concentrated on estimating unknown traffic parameters and threshold set for traffic congestion judgment using known parameters, including Calman Filtering [2], Floating Car method [3], Data Mining [4] and Machine Learning [5] to estimate traffic parameters. With the increasing development of GPS and GIS technology, traffic state analysis gradually turned from road section to network. Clustering analysis [6] and pattern recognition [7] are applied to urban regional traffic state analysis and pattern discovery. Traffic flow distribution in the network space can be visually shown in the GIS map with different color display, and traffic congestion trends over time can also be observed using animation technology [8]. In this case, theoretical basis and basic tools are thus provided for the analysis of traffic state evolution, which can offer great help for traffic researchers and managers to make traffic management solution and decision.

However, the current study of evolution analysis of urban regional traffic state mostly concentrated on discovering and defining the type and pattern of traffic state. So far, the formation mechanism of traffic state pattern and the evolution and transition process between pattern and pattern has been lack of thoroughly and systemically analysis, and until now a traffic state analysis software system for further application research has not been established.

In this paper, by targeting at the demand of "reduce traffic jam and ensure unblocked traffic" in urban regional traffic, an quantitative method for analyzing regional traffic state evolution was proposed, and a network model for analyzing traffic state was constructed, which can mine regional traffic state information and state pattern transition characteristics from massive data. Thereby, a GIS-based Urban Regional Traffic State Analysis Software System (URTSAS) was designed, which can support decision-making in urban regional traffic control, traffic guidance and traffic management, and ensure urban regional traffic safety and unblocked traffic.

II. REGIONAL TRAFFIC STATE TRANSITION ANALYSIS

A. Traffic state Clustering

A traffic parameter (e.g. traffic volume (used in this paper), density, speed, volume/capacity V/C) in all road sections is used to represent the current regional traffic state. F(t) is a traffic state vector composed of traffic volumes at all sections within a period t, and is expressed as:

$$F(t) = \left[f_1(t), f_2(t), \ldots, f_n(t) \right]^T \tag{1}$$

Where $f_i(t)$ means the traffic volume of section i at time t, and n is the section number in that region. Vector F(t) represents the traffic volume distribution in all road sections in this region. If F(t) is very similar at different time points, then similar traffic states will reoccur. In this case, the self-organizing map (SOM) from unsupervised

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learning can be used to cluster the dataset F(t), and thus each resulting class represents a traffic pattern [9].

SOM can map the input vectors from a high-dimension space to a low-dimension space, while maintaining the topological relations between vectors. The core structure of SOM includes an input layer and a competition layer. The neurons in the competition layer are arrayed in 2D rectangular or honeycomb-shaped grids, and their distances are called topo-distance. Each neuron has a corresponding weight vector $w_i = [w_{i1}, w_{i2}, \dots, w_{id}]$, and w_i represents the position of neuron i in the input space. SOM can be trained by iterating the weight vector for each neuron. In each iteration, vector F is input into SOM, and then Eq. (2) is used to identify the neuron c that is closest to F in Euclidean distance, so c is called a winning neuron.

$$\|F - w_c\| = \min_i \|F - w_i\| \quad (2)$$

After that, the weight of each neuron will be updated by using the learning rules in Eq. (3):

$$w_i(s+1) = w_i(s) + \eta(s)h_{ci}(s)[F - w_i(s)] \quad (3)$$

where s means the current iteration number, $\eta(s)$ means learning speed, and $h_{ci}(s)$ means the neighborhood kernel function from the winning neuron c to the updated neuron i. In order to ensure convergence during training, $\eta(s)$ and the radius σ_s of $h_{ci}(s)$ are both decreased with the increase of iterations, as in Eqs. (4-5), where k is the maximum iteration number.

$$\eta(s) = \eta(0)(1 - \frac{s}{K}) \quad (4)$$

$$\sigma(s+1) = \sigma(s)(1 - \frac{s}{K}) \quad (5)$$

Color figures will be appearing only in online publication. All figures will be black and white graphs in print publication.

B. Traffic State Pattern Transition Network

Each traffic state pattern is composed of a series of traffic states. Let $TS = \{F(t_1), F(t_2), \dots, F(t_N)\}$ be a traffic state set, N be the maximum traffic state number; after clustering by SOM, a traffic state pattern set $P = \{p_1, p_2, \dots, p_M\}$ is acquired, where M is the maximum traffic state pattern number. If $F(t_1) \in p_1$, $F(t_2) \in p_2$, if t_1 and t_2 are adjacent time points, then $F(t_1)$ and $F(t_2)$ are in a sequential traffic evolution relationship. Then, we believe p_1 and p_2 are in traffic state transition relationship, marked as $p_1 \to p_2$. Based on this, the massive traffic state data accumulated within a period (weeks or months) can be used to build a **traffic state pattern transition network (TSPTN)**, expressed as $G = (V, E)$, where V is a point set composed of all traffic state patterns; E is a edge set composed of transition relations between all state patterns; the weight of the directed edge between nodes p_1 and p_2, represents the number of sequential relations between all traffic states in p_1 and all traffic states in p_2. The structure of **TSPTN** is showed in Figure 1.

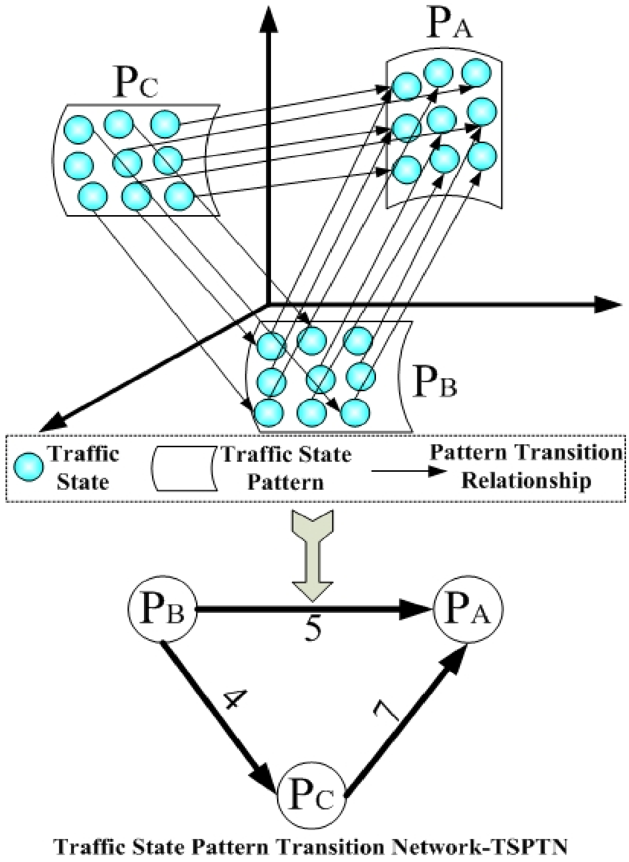

Figure 1. Structure of TSPTN

C. Traffic State Pattern Transition Analysis

State pattern transition was characterized on basis of TSPTN, and the characteristics, trend and trigger conditions during transition were studied.

(1) Traffic state pattern stability analysis

Stability is defined as the property that a disturbed system can remain in a finite region, or recover to the original balance. State pattern stability can be analyzed on basis of the spatial and temporal characteristics during state pattern transition. In TSPTN, the stability of traffic state pattern is jointly reflected by the number of transitions between internal states of its nodes, and the out-degree and in-degree of its nodes, and the weights of all adjacent edges.

(2) Traffic state pattern transition

The inter-edge weight between traffic state pattern p_1 and each transition object reflects the transition preference of p_1, and the transition probability with each transition object at the next time point.

(3) Space-time characterization of individual traffic state pattern transition

During a state transition, the variation situations at all variational sections include: traffic volume, velocity, density, share (up, down, unchanged), amplitude of variation (large, medium, small), process of variation (fast, smooth, slow), and order of variation (early, late, simultaneous).

(4) Space-time characterization of overall traffic state pattern transition

1) Temporal characterization of state pattern transition: frequent traffic state transitions at fixed time every day; the time periods when each transition happens every day.

2) Spatial characterization of state pattern transition: active road sections, the active periods in an active region, and active patterns.

III. SYSTEM DESIGN OF URTSAS

A. *Functional Module Design*

URTSAS is a type of traffic operation software system which was designed and developed for urban traffic state analysis and application. Its objectives are: to build a basic database management platform and a traffic state analysis system for urban traffic operation; to analyze and evaluate urban regional road-network traffic states in an objective, science-based and accurate way and through efficient inquiry, statistics and analysis of the collected basic traffic data; to provide traffic managers and decision-makers with accurate and reliable management decision support. URTSAS is composed of five modules as data management, inquiry statistics, state analysis, traffic prediction, and live-action application, as shown in Figure 2.

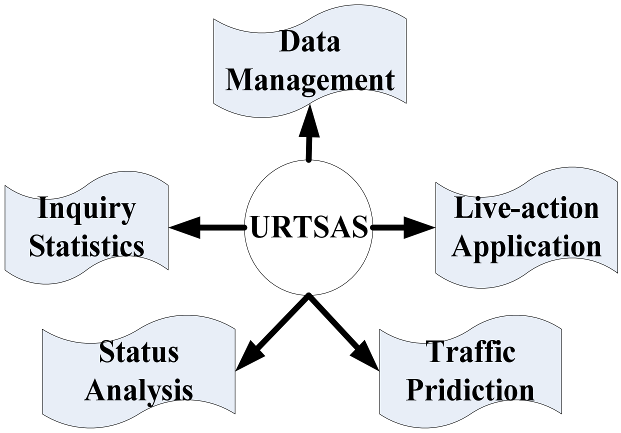

Figure 2. The Functional modules of URTSAS.

(1) Data management module

This module is responsible for the input, supplement, arrangement and storage of data. It can enrich, perfect and manage basic traffic operation parameter data, and produce traffic state data. It is the foundation for traffic state transition analysis.

Data input: several data import form are provided; the basic road data, and the basic traffic operation parameter data obtained from investigations are input into the appointed database as per specific format requirements; the abnormal traffic data will be corrected and cleaned as per the three traffic flow parameters and the traffic sequential variational laws, so as to ensure data integrity.

Data refresh: Temporally, the observed real-time traffic data will be refreshed: based on the variational laws of the observed data during missing periods, a corresponding empirical formula will be obtained to calculate the missing data; or an expert system can be built to calculate and repair the missing data. Spatially, the data from unobserved road sections will be reckoned. The probable traffic data like traffic volume and vehicle speed will be first reckoned and then amended on basis of influence factors. During reckoning, consideration should be given to the variational laws of traffic volume and speed, and the relationship between congestion degree and speed at adjacent sections, as well as to the local road network state where this section is in, especially the influences of flow amount and flow direction at adjacent intersections.

Data processing: based on traffic state pattern transition analysis, the basic traffic parameter data are processed first to produce traffic state at each period; then SOM classifier is used to obtain traffic state pattern; based on traffic state evolution, TSPTN is built, so the whole traffic state database is completed.

Data storage: to achieve effective relevance and storage management for traffic parameters, traffic states and traffic state patterns in traffic state database, so data can be rapidly accessed and exported, and the traffic state pattern based can be gradually supplemented, updated and perfected. The basic parameter data collected every day will undergo the above steps of input, supplement and processing, and be stored in traffic state database in separate backup, which helps to transversally and longitudinally compare data, and to obtain the traffic variational laws and trends.

(2) Inquiry statistics module

Based on traffic operation parameters, the inquiry statistics module provides users with diversified data display and export ways (text, data reports, graphs, variational trend curves), so users can easily inquire, summarize and analyze traffic operation parameters and traffic state pattern data, thus ensuring that subsequent traffic operation analysis and evaluation are accurate. Inquiry helps to search parameters as per preset conditions, e.g. the traffic volume or vehicle speed at certain time in a section. Statistics helps to summarize parameters as per target conditions, e.g. temporal and spatial trip characteristics such as average traffic volume or vehicle speed on a section; users can customize various inquiry and statistics services as needed. Inquiry and statistics cover the basic information such as traffic volume and vehicle speed, as well as the evaluation indices, such as peak hour coefficient, directional uniformity coefficient, traffic volume vehicle composition, sectional congestion degree, and sectional service level.

(3) State analysis module

The process, trend, and trigger conditions of transition are analyzed on basis of TSPTN. The results include the stability, transition preference, and trigger mechanism of individual traffic state pattern, as well as the temporal and spatial characteristics of the overall traffic state pattern transition. The results represent the characteristics and laws of transition, and are stored into a traffic state transition knowledge base as knowledge of the overall traffic state transition.

(4) Traffic prediction module

Short-term traffic prediction consists of two parts: first, short-term prediction for individual sections; second, short-term prediction for the whole road network. Namely, considering the traffic parameter variations at characteristic sections at next time point, and based on traffic state transition network, the road network state at next time point can be obtained, and thereby the traffic state of the whole road network at next time point can be obtained. Therefore, as long as the traffic parameter variations at several individual sections are acquired, the transition variation of the whole road network at next time point can be obtained, and thus the traffic state of the global road network can be accurately predicted.

(5) Live-action application module

Traffic state transition network and its transition characteristics comprehensively and deeply depict the overall evolution of road-network traffic operation, and play an important role in the objective and accurate assessment of urban regional road-network traffic operation state, and in ensuring that road network traffic operation analysis can be scientifically and efficiently conducted at each stage. This is reflected in the following aspects:

1) Regional traffic control: By analyzing real-time traffic state information, the current traffic state pattern can be determined. Based on TSPTN and the traffic parameter variations at all sections in road network, the transition extent of future traffic state can be roughly located. If road network traffic is at a congestion state or prone to congestion, then based on the characteristics and trigger mechanism of traffic state transition, specific traffic control can be implemented at some sections, so traffic state pattern can transit within a safe area.

2) Regional traffic organization: first, we determine which pattern the traffic state is in, and under TSPTN, seek the relatively safe target pattern that can be most easily transited to. Then based on the characteristics of traffic state pattern transition, a traffic organization guidance strategy can be formulated, which should meet the trigger mechanism to transit to this target pattern. Traffic guidance information will be released by the traffic management center to some vehicles in the road network.

3) Traffic congestion warning: Based on traffic state transition network, given the stability and transition preference of the current traffic state pattern, and by combining the variation trends of the current traffic operation parameters, the upcoming traffic congestion can be rapidly and accurately predicted, and its diffusing area and duration can be estimated. Such warning will help to constitute reasonable and effective traffic congestion guidance strategies in advance.

4) Travel Information services: Though the existing dynamic path guidance considers traffic state information, the traffic states are limited to the present time when the path is calculated, or namely, this path may lose optimality at the next time point. Therefore, the current and the future traffic state information provided by traffic state transition network can be utilized together to perform dynamic path guidance. In response to drivers' trip guidance requests, a set of optional paths can be produced; then based on traffic state transition network, the utility of this path set is re-calculated, so the most reasonable path will be decided.

B. Database Design

The database will store road network topological data, traffic state data, and state transition characteristics data, and provide data access interface, so the data processing layer can visit, process and inquire data, and the exhibition and display layer can export the inquired results.

1) GIS-based Traffic Network database: It includes road infrastructure, including geographical information elements like sections, intersections, monitoring stations, traffic districts, and regional boundaries. A GIS-based element data model and a geographical characteristic model will be built. The GIS platform in the application and display layer is used to achieve visualized display and format exporting, so users can easily search, analyze and manage.

2) Traffic state database: it includes basic traffic parameters, states and state patterns.

Traffic parameter base: basic traffic parameters and traffic state information in all sections in a road network at any time, including sectional traffic volume, density, average speed, volume/capacity V/C, congestion degree, and temporal-spatial trip characteristics.

Traffic state base: the road network traffic state vectors at certain interval (5 min) are treated as one record of data in the base. It includes traffic state pattern that each traffic state belongs to.

Traffic state pattern base: it stores all traffic patterns after clustering by SOM, including traffic parameter instruction of each pattern. In addition, the temporal sorting of traffic state data in the base is the just evolution process of traffic states. Based on traffic state evolution, the traffic state pattern transition relations can be obtained, and therefore, a traffic state transition network can be easily constructed.

3) Traffic state transition knowledge base: based on state transition theory, the traffic states at all sections in a road network will be comprehensively analyzed, and then the characteristics and laws of traffic state transition will be stored in the base.

Individual traffic state transition characteristics base: It includes the variational trend, amplitude, process and order of traffic parameters (traffic volume, speed, density and share) during each traffic state transition at all varying sections.

Overall traffic state transition characteristics base: it includes temporal characteristics, e.g. frequent traffic state transition at fixed period, and the periods when transitions frequently happen; spatial characteristics, e.g. active sections, active periods at active regions, and active patterns.

4) Traffic evaluation base: it contains evaluation information of real-time traffic operation.

5) Traffic management/control pre-arranged planning base: traffic management and control strategies at all traffic state patterns are formulated to implementation plans, and stored in this base.

6) Traffic data backup database: it includes current and historical traffic operation analytical databases.

C. Aarchitecture of URTSAS

The system architecture of URTSAS is shown in Figure 3, using three layer frame structure with the data layer, application layer and presentation layer. The data layer is the basic data platform of city traffic network operation, including all of the traffic database and knowledge base of traffic state transition, which provides basic data support for traffic operation. Application layer is the traffic state analysis and application platform, and can access, process and analyze data from the data layer. Display layer provides GIS, spreadsheets, charts and other data presentation and output format, and can presents the basic data in the data layer and the analysis and evaluation results of application layer.

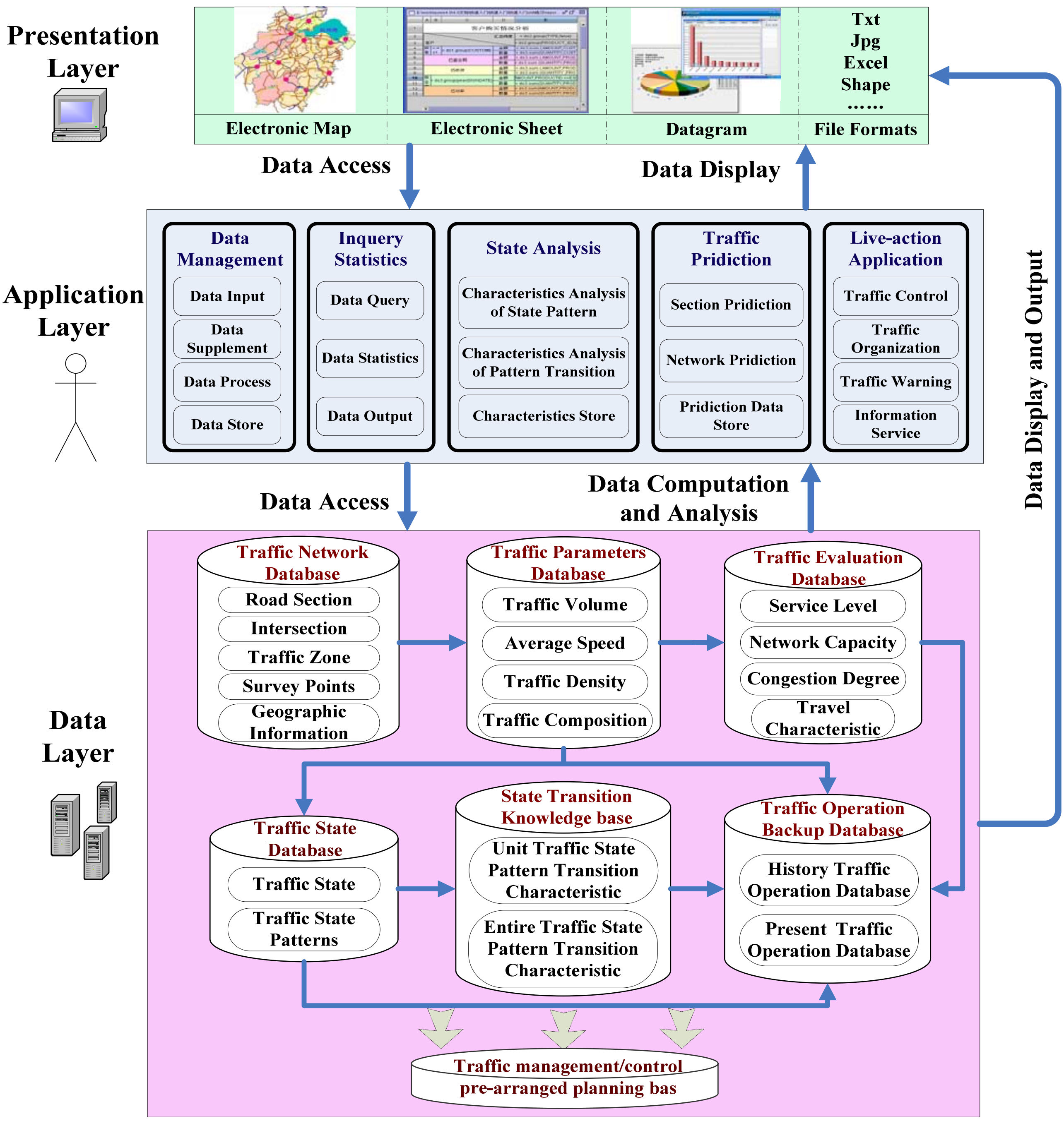

Figure 3. The structure of TSPTN.

IV. SYSTEM DESIGN OF URTSAS

To demonstrate the general technical concept analysis and design idea of URTSAS, a prototype system of URTSAS based on traffic flow simulation technology is developed using ArcGIS 9.2 as the geographic information platform, MySQL 5.0 as the database platform and Microsoft Visual Studio 2005 as development platform.

URTSAS chooses the network of Qujiang District of Xi'an, China as basis network to analyze traffic state and its evolution characteristics. The network's electronic map and topology is shown in Figure 4 and Figure 5 respectively, which consists of 66 intersections and 184 edges.

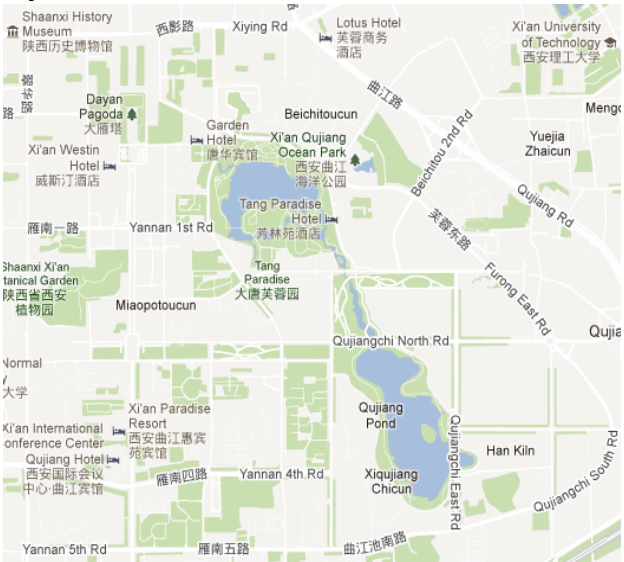

Figure 4. Electronic map of Qujiang district.

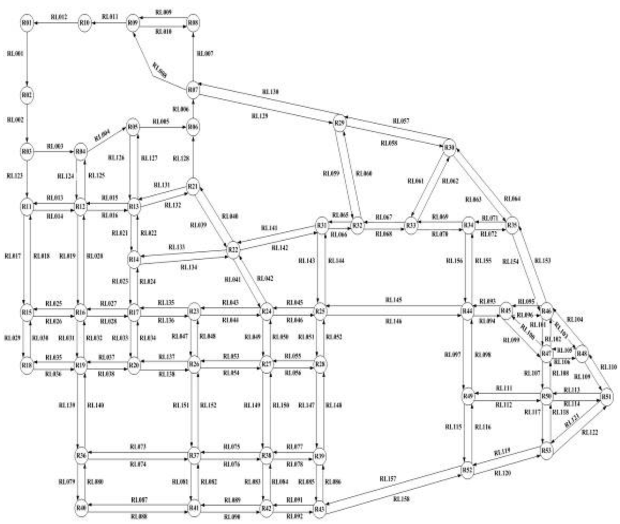

Figure 5. Topology of Qujiang district

The URTSAS prototype system adds a simulation module on designed architecture, as shown in figure 1, which can automatically generate traffic data. In order to obtain true and comprehensive traffic data, The track-oriented method of traffic survey and analysis based on plate number is adopted to Qujiang District. The method aimed at obtaining the track of all vehicles in the road network can make full use of the network characteristics and spatiotemporal characteristics of the survey data. The vehicle tracks obtained from traffic network can be regarded as a static database of dynamic traffic system by which rich traffic conditions information can be dug out and even complex and comprehensive traffic scene can be systematically reappeared [10]. The vehicle tracks contains abundant traffic information, including complete travel route, travel time and average speed of whole trip and each road section, OD pair, detailed passing information (survey point, intersections, road sections).

The traffic flow simulation module' working mechanism is shown in Figure 6. When URTSAS starts running, the traffic flow simulation engine starts to work in the background, receives dynamic traffic volume and direction information, OD distribution information and network structure information from all the tracks, generates traffic flow in the network and calculates traffic state information of road section, road and network respectively. All the traffic flow information, traffic statistics information and traffic state information are stored in the database of Data Layer of URTSAS for analyzing the traffic state transition and evolution in the next step, as shown in Figure 7.

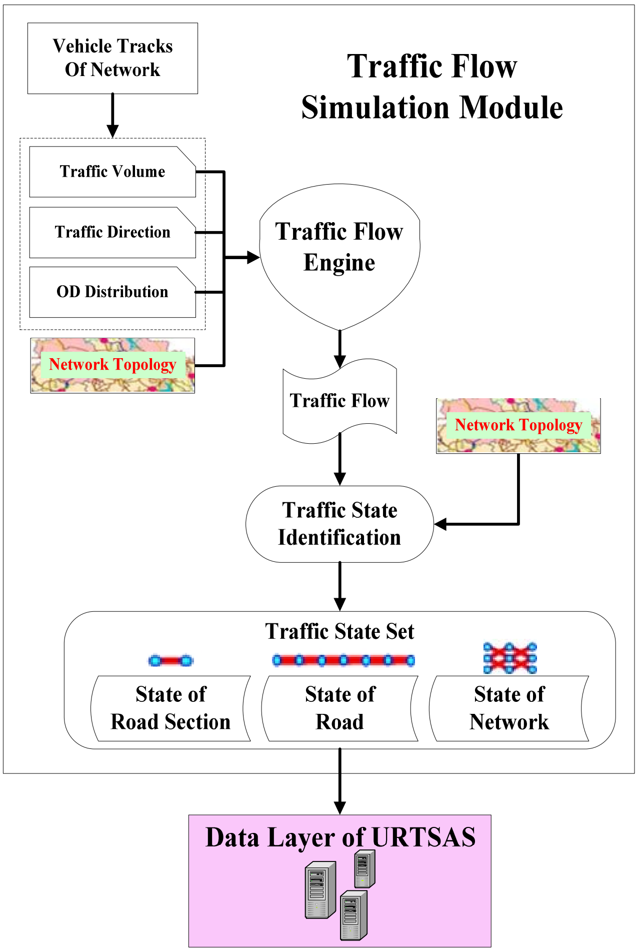

Figure 6. Working mechanism of traffic flow simulation module of URTSAS

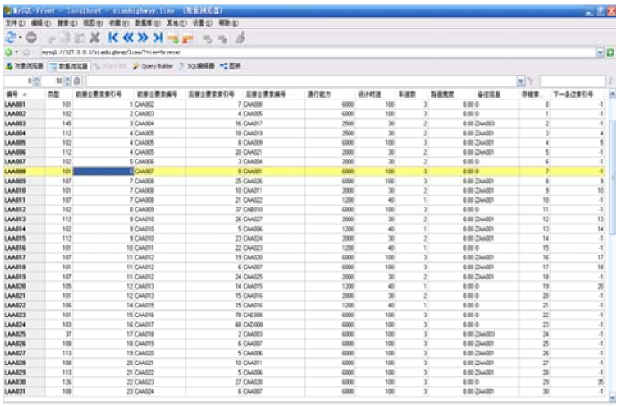

Figure 7. Database of URTSAS.

URTSAS can generate traffic flow in city road network, monitor real-time traffic state and analyze traffic state transition. All the application scenarios and effect based on traffic state transition analysis can be visually presented on URTSAS. The overall URTSAS working interface is shown in Figure 8.

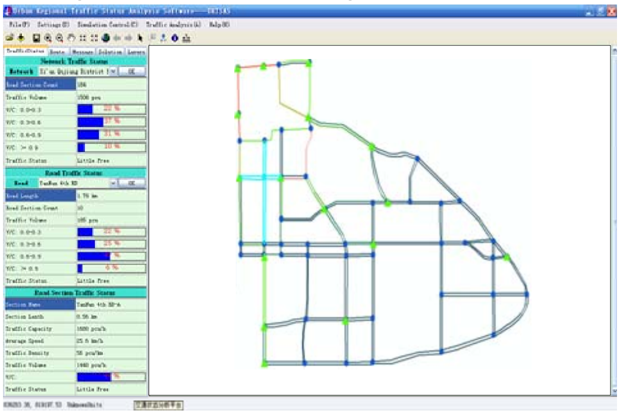

Figure 8. Main working interface of URTSAS.

When URTSAS starts running, the traffic state of road sections dynamically change in color according to traffic flow parameters, which can be directly presented in ArcGIS. In Figure 9, traffic state information query window shows the basic information and traffic information of various road sections in the network, the color of which represents the level of traffic state and the degree of road congestion, green for smooth and red for congestion. These comprehensive information of road sections can provide visual warning support.

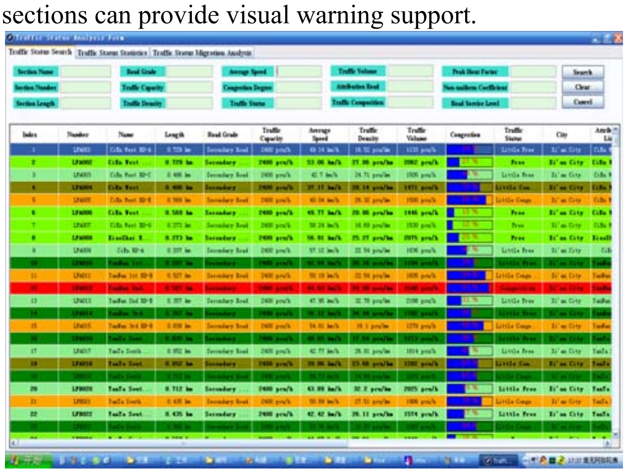

Figure 9. Traffic state search interface of URTSAS.

Figure 10 shows the window of traffic state transition analysis. The basic information of traffic state patterns that current traffic state pattern may migrate in the next moment, such as transition probability, are show on the upper half of the window. After selecting one of the patterns, detail information of the chosen pattern will be listed on the lower half part.

Figure 10. Traffic state transition analysis interface of URTSAS.

Figure 11 shows the window of route query based on traffic state transition analysis. The general shortest route can be queried and the most time-saving route can also be queried based on traffic state transition information.

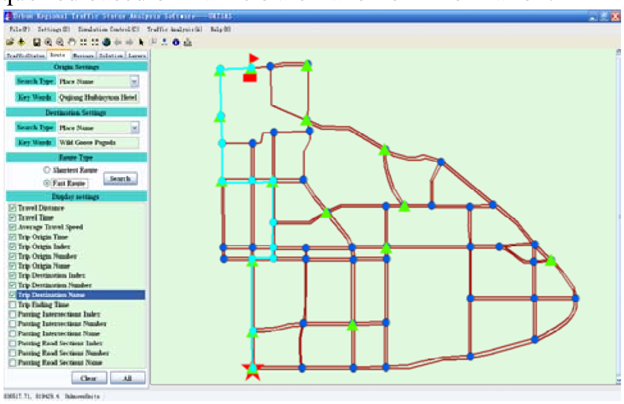

Figure 11. Route query interface of URTSAS.

Figure 12 shows the publishing window of dynamic traffic information based on traffic state transition analysis. On the left, traffic state warning of road section, road, and network are listed are detail information are shown below. On the right, the warning district is highlighted to users.

Figure 13 shows the traffic pre-arranged solution window of URTSAS. All solutions are generated based on the analysis and application of traffic state pattern transition. On the left, traffic control solutions including left-hand turn prohibition, pass through forbidding, one-way traffic and Detour are listed and application scene, detail information and notes information are shown down in turn. On the right, the working space of the chosen solution is highlighted to users.

V. CONCLUSION

In this paper, a network model and a quantitative method for analyzing regional traffic state evolution

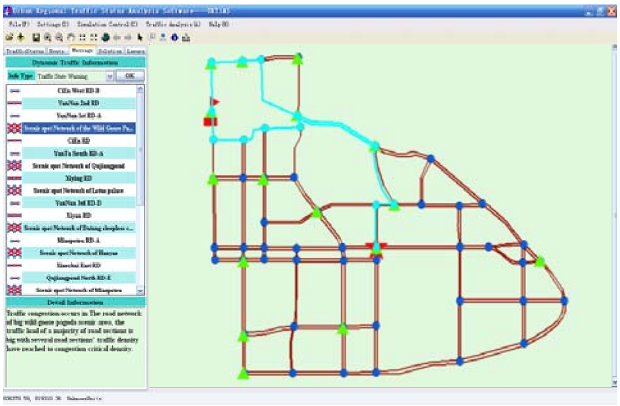

Figure 12. Traffic information publishing of URTSAS.

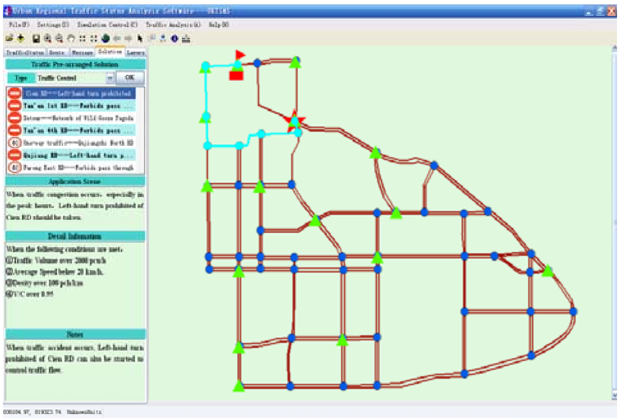

Figure 13. Traffic pre-arranged control solutions of URTSAS.

process was proposed firstly through mining regional traffic state pattern transition characteristics from massive traffic data, based on which a GIS-based urban regional traffic state analysis software system (URTSAS) was designed and implemented. Further works will consider using URTSAS to support real time data-managing and decision-making for urban regional traffic control, traffic guidance and traffic management.

ACKNOWLEDGMENT

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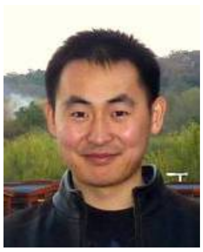

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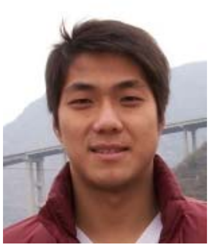

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