Chapter 7
The Research on the Method of Traffic Area Dynamic Division and Optimization

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Abstract Based on the Temporal and spatial variation characteristics of traffic flow, this paper puts forward the traffic area dynamic division method and how to realize the merger and separation of nodes in the control area, as well as inter-regional automatic combination and split. First, according to the traffic relevance and traffic similarity between adjacent intersections in the traffic area, the application of clustering analysis method, the traffic area is divided into some dynamic control zones. Then, application node shrinkage method is to determine the key nodes of the control zone, and relying on the fuzzy cognitive map is to analyze the direct and indirect influence of the key nodes and the other nodes in the control zone. Finally, according to the traffic flow state changes forms: basic remains the same, crowded diffusion and crowded subsided, respectively, is corresponding to the dynamic changes of the control zones: remains unchanged, expansion combination and shrinkage decomposition, in order to achieve the merger and separation of the nodes in the control zone, as well as inter-regional automatic combination and split.

Keywords Traffic engineering · Dynamic division · Merger and separation · Fuzzy cognitive map · Control zone

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7.1 Introduction

At present, about the traffic control zone dynamic division, at abroad it was studied mainly from the degree of coupling, gravity, coordination coefficient [1], grading system classification technique [2], etc., while in domestic it was studied mainly from the angle of traffic flow, distance, cycle, etc. [3]. And the application of cycle is used to determine the changes of merger coefficient in SCATS system [4], in order to judge whether the control zone is merged.

In this paper, first according to traffic relevance and traffic similarity between adjacent intersections in the traffic area, it is divided into several traffic zones of strong internal relevance and similar traffic characteristics. Then, in order to make the control area adapt to the constant change of the traffic flow, according to the traffic flow state changes forms: basic remains the same, crowded diffusion and crowded subsided, respectively, is corresponding to the dynamic changes of the control zones: fine tuning, expansion combination and shrinkage decomposition, which achieve the merger and separation of the nodes in the control zone, as well as inter-regional automatic combination and split, thus can ease traffic congestion effectively.

7.2 Traffic Area Dynamic Division

Traffic zone is a set of nodes or lines with a certain traffic correlation degree and traffic similarity, which changes along with the time, correlation degree and similarity changes. It reflects the traffic characteristics of the spatial and temporal changes about the urban road network.

7.2.1 Traffic Correlation Degree

Traffic correlation degree reflects traffic correlation characteristic between nodes. Traffic correlation characteristic is represented by I_T, which refers to associated with the degree of traffic parameters between nodes. The calculation of sections relevance between adjacent intersections, using Whitson improved model is [5]:

$$I_T = \frac{1}{n-1}\left(\frac{n \cdot Q_{\max}}{\sum_{i=1}^{n} Q_i} - 1\right)\frac{1}{1+t} \tag{7.1}$$

n is from upstream intersection traffic flow into branch number; Q_i is from the upstream intersection traffic flow into the first i branch; Q_{max} is from upstream intersection traffic flow into the maximum; t is the average travel time between two intersections, unit: min, equals to the intersection spacing D divided by the average vehicle speed V.

7.2.2 Degree of Traffic Similarity

Degree of traffic similarity reflects the traffic similarity between nodes. It is represented by I_C, which refers to the degree of traffic parameters similarity between each node. Calculation between adjacent intersection traffic similarity, can be used to represent by the cosine of the angle between the adjacent intersection of state vector.

Among them, the node state vector is available saturation X, cycle T and flow Q to express. For the node v_i and v_j, the state vector is $X = (X_i, T_i, Q_i)$ and $y = (X_j, T_j, Q_j)$ respectively, so the degree of traffic similarity I_C is:

$$I_C = \cos\theta = \frac{x, y}{|x|, |y|} \tag{7.2}$$

7.2.3 Control Area Division

Fuzzy C-Means Algorithm (FCMA) is a typical kind of Fuzzy clustering Algorithm. According to the calculation of each group membership degree of data to determine the set of data belong to a certain degree of clustering, this will be multidimensional data space of discrete data to classify [6]. The specific method of calculation is not presented in this paper because of space limitations.

Using fuzzy C-means clustering analysis method based on the values of sections relevance and the traffic similarity carries on the control area division. Traffic area as shown in Fig. 7.1 can be divided into five control zone, as shown in Fig. 7.2. The relevance between the control zones is much smaller compared to the control zone associated with the node. The node number of control zone is 1at least.

In Fig. 7.1, the arc refers to association impact strength between the nodes. One-way line represents the direction of the association impact strength is far stronger than another direction, whichever takes the greater value. Two-way line shows that between the two directions of association impact strength is consistent. No arc indicates that it is not connected between the intersections.

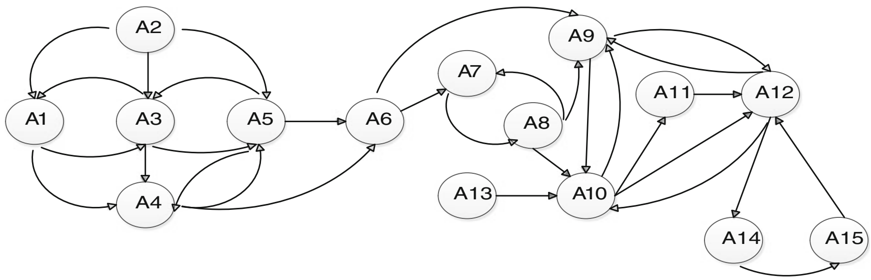

Fig. 7.1 Traffic area between nodes association diagram

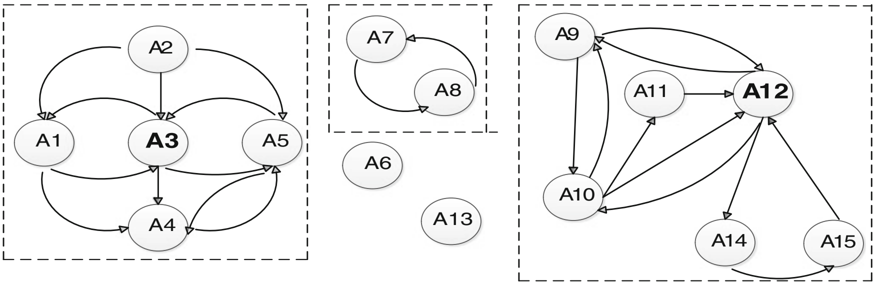

Fig. 7.2 Traffic area divided into control zones

7.3 Determine Key Nodes Within the Control Zone

Urban traffic network can be mapped a complex weighted network [7], namely: intersection corresponds to the node, the road corresponds to the edge, the vehicles on the road encountered impedance corresponds to the weight of the edge.

7.3.1 Road Impedance Function

At present more popular and use a wide range of road impedance function is that U.S. Bureau of Public Roads is based on a large number of sections to carry out a survey and regression analysis to get BPR function model. The basic form of this model is:

$$t = t_0(1 + \alpha(q/c)^{\beta}) \tag{7.3}$$

t is road impedance; Q is road traffic volume; t_0 is free flow travel time; c is road capacity; α, β is a regression coefficient, recommended value $\alpha = 0.15$, $\beta = 4$.

7.3.2 Average Path Length

In the Complex weighted urban traffic network, the length of the shortest path between two intersection nodes v_i and v_j is d_{ij}, which is defined as the connection between the two intersections weight minimum path length. The average path length L is the average length of the shortest path between all intersections.

$$L = \sum_{i,j \in V} d_{ij} * \frac{2}{N(N-1)} \tag{7.4}$$

N is the number of nodes, V is the set of nodes.

7.3.3 Node Important Degree

Definition 1 Complex network node important degree is the reciprocal of the product of network node numbers and average shortest path.

The definition can get the following formula:

$$\partial = \frac{1}{N * L} = \frac{N-1}{2\sum\limits_{i,j \in V} d_{ij}} \tag{7.5}$$

∂ is node important degree, and other parameters are the same meaning as above.

Obviously, $0 < \partial \leq 1$, when complex network only one node, we take the maximum value 1.

According to the weight of the road network, namely, road impedance, the use of node shrinkage method, calculates the degree of each node importance within the control zone, so as to determine the key nodes in the control zone. For each control zone in Fig. 7.2, separately calculated node importance, it can be concluded that the A3 and A12 is the key node of its control zone, while A7 and A8 node importance is equivalent, A13 node importance is 1.

7.4 Dynamic Adjustment and Optimization of the Control Zones

Because the network traffic flow is constantly changing, and traffic control also alters the original crowded state, control zone can't be fixed, as well as its control range is also in constant change. Therefore, we need make the appropriate adjustment according to the traffic flow change trend.

7.4.1 Merger and Separation of Nodes in the Control Zone

In order to determine influence degree of the direct correlation and indirect correlation between the nodes, the theory of fuzzy cognitive map is introduced. Bart Kosko proposed a fusion Zade fuzzy set concept and Alexrod cognitive map of the soft computing method on the basis of classical cognitive map, which is fuzzy cognitive map (FCM).

Definition 2 In a control zone of the road network, the node set $S = \{1,2,\ldots, n\}$ is the finite set, for S, there are two different nodes i, j, if the two nodes are connected and $W_{ij} \neq 0$, then called i to j have directly associated with the impact, denoted by $i \rightarrow j$.

Definition 3 In a control zone of the road network, the node set $S = \{1,2,\ldots, n\}$ is the finite set, for S, there are two different nodes i, j, if there are different node k_1, $k_2,\ldots, k_{(m-1)} \in S/(i, j)$, make $i \rightarrow k_1$, $k_1 \rightarrow k_2,\ldots, k_{(m-1)} \rightarrow j$ established, then i through the directed chain $e_1 = < i, k_1 >$, $e_2 = < k_1, k_2 >$,…, $e_m = < k_{(m-1)}, j >$ to j have indirectly associated impact, denoted by $i \rightarrow < e_1, e_2,\ldots, e_m > \rightarrow j$.

In order to get comprehensive associated impacts, the direct correlation classified to the indirect association will be considered together. Namely, make each node in the control zone join their associated link, and set the $w_{ii} = 1$, therefore, i → j is equivalent to the link $i \rightarrow < e_1, e_2 > \rightarrow j$, where $e_1 = < i, i >$, $e_2 = < i, j >$, via link $< e_1, e_2 >$, i to j of the associated weights is:

$$W'_{ij}\big|_{\langle e_1, e_2 \rangle} = w_{ii} w_{ij} = w_{ij} \tag{7.6}$$

If there are m links in the road network of the control zone to make the node i associated to j ($i \neq j$), the associated weights of the links are respectively:

$$W'^{(1)}_{ij}, W'^{(2)}_{ij}, \ldots, W'^{(m)}_{ij} \tag{7.7}$$

So, comprehensive associated impact of node i to j:

$$A(i,j) = \sum_{m=1}^{m} W'^{(m)}_{ij} \tag{7.8}$$

Thus, it can not only describe the node i through the different link to j associated impact strength, but also can determine i to j of comprehensive associated impact strength. Setting the threshold value λ is i to j of comprehensive associated impact strength, and realize the merger and separation of the nodes in the control zone.

Reference the concept of the "Merger Index" in SCATS system, each signal cycle should be carried out once the merger index calculation. First identify the key node of control zones in each signal cycle, and calculate comprehensive associated impact strength of the key nodes and other nodes. If the associated impact strength is greater than the threshold value, then the "Merger Index" value plus 1, conversely, the "Merger Index" value minus 1. If the "merger index" is accumulated to 3, then this several intersections should be combined with coordination control; If the "merger index" is 0, then there is no need to combine together to control this several intersections, should be separated to control alone or to merge with other nodes coordination control. Adjustment process of nodes within the control zone is shown in Fig. 7.3.

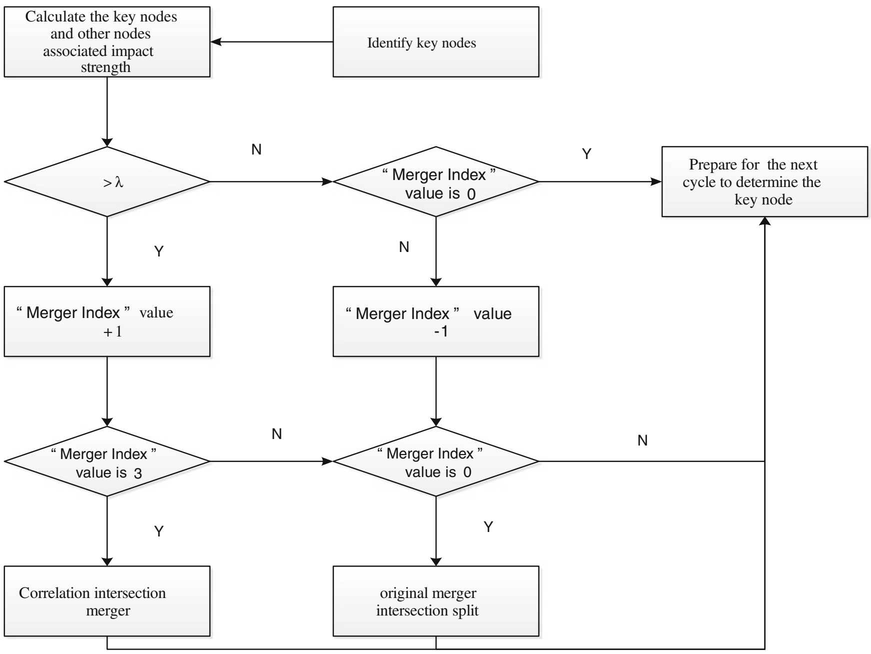

Fig. 7.3 Adjustment process chart of nodes within the control zone

7.4.2 *Automatic Combination and Split Between the Control Zones*

Automatic combination and split between the Control zones is adjusted and optimized on the basis of the original traffic area division. According to the spread of congestion and subside, for boundary intersections and sections between the control zones, by calculating traffic similarity and correlation degree of boundary intersection with adjacent intersection, the "merger index" is used to judge whether combination and split.

The boundary type of control zones (a) is shown in Fig. 7.4, for (a) provisions:

1. When two boundary intersections of the two control zone need to merge intersection B, respectively calculate traffic similarity of the intersection B and two boundary intersections to make a comparison, if the traffic similarity of control zone A's boundary intersection is larger than intersection B's, then B is merged into the control zone A; Conversely, B is merged into control zone C.
2. Calculating traffic similarity of the intersection B and connected intersection within the combined control zone A, if the associated impact degree is less than the threshold value and "merge index" is equal to 0, then intersection B will be separated from control zone A, considering whether automatic combination with other neighboring control zones. If the "merge index" of intersection B

and the intersections within the adjacent control zone C is also equal to 0, then intersection B will become an independent control zone, implements a single point of control.

The boundary type of control zones (b) is shown in Fig. 7.4, for (b) provisions:

1. When two boundary intersections of the two control zone need to be merged, calculated traffic correlation degree of the two boundary intersections, then respectively compared with the minimum value of the associated degrees of adjacent intersections in the control zone A and C, if the minimum value of the control zone A is much closer to the correlation degree of the two boundary intersections, then C's boundary intersection D is merged into A; conversely, A's boundary intersection is merged into C.

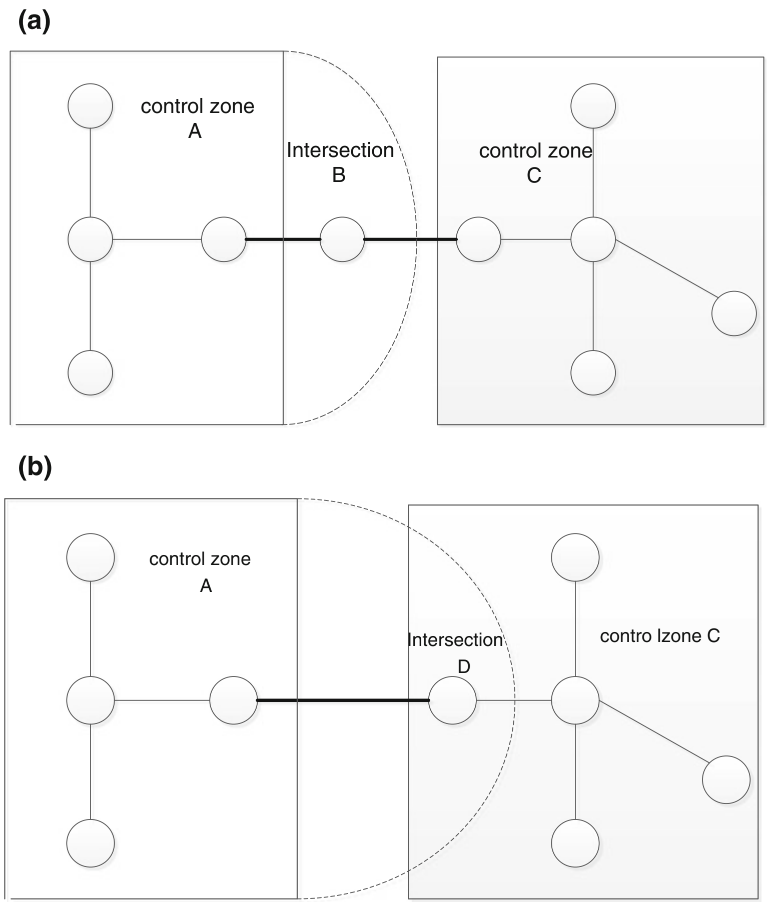

Fig. 7.4 Boundary type of control zones (**a**), (**b**)

2. Calculating traffic similarity of the intersection D and connected intersection within the combined control zone A, if the associated impact degree is less than the threshold value and "merge index" is equal to 0, then intersection D will be separated from control zone A, considering whether automatic combination with other neighboring control zones. If the intersection D is adjusted to control zone A because of congestion diffusion, so the intersection will be pulled back to the original control zone C.

So, in accordance with the rules of the merger and split, due to the crowded diffusion, original control zone can automatically extended combination, and as congestion is gradually dissipated, the extended control zone will gradually be shrunk to the original control zone.

7.5 Conclusion

Previous traffic zone division methods can't provide timely and effective decision-making basis for the management and control of the road network congestion. Based on the temporal and spatial variation characteristics of traffic flow, application of fuzzy theory, puts forward the traffic area dynamic division method and how to realize the merger and separation of nodes in the control area, as well as inter-regional automatic combination and split. The method is updated in real time to adjust and optimize the control zone, so as to make it adapt to the change of traffic flow, and can effectively alleviate traffic congestion.

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