Signal Coordination Control Based on Comprehensive Correlation Degree

Ling Wen¹,a, Baotian Dong²,b*, Pengcheng Li³,c, An Yan⁴,d
¹,²,³Transportation, Beijing jiaotong University, Beijing, China
⁴Operation branch of Xi’an rail transit group co.ltd, Xian, China
aemail: wenling0507@163.com ,
b*Corresponding author’s e-mail: btdong@bjtu.edu.cn
c e-mail: 18114039@bjtu.edu.cn
d-e-mail: yanan034100@163.com

Abstract. The correlation degree between nodes of urban traffic network is the basis of sub-area division, and the signal coordination control in sub-area is very effective to improve the traffic efficiency of road network. In this paper, based on the study of unsaturated traffic state, the paper first analyzes the shortcomings of the existing correlation degree model, and constructs a comprehensive correlation degree model to measure the relationship between the two nodes by considering the factors of section spacing, section flow, signal period, traffic flow dispersion and queue length. Through VISSIM simulation experiment, the examples of 15 sections of 10 nodes are compared with the classical Whitson model and the merging index. The sub-region based on the DBSCAN algorithm is more close to reality, which can provide a good basis for the signal coordination strategy.

1. Introduction
With the increasingly severe problem of urban traffic congestion, the realization of dynamic control of traffic signals is the future development direction. By using the correlation degree calculation model, the intersections with similar traffic conditions are divided into the same sub-area, and the coordinated control of signals in the sub-area is studied, which is of guiding significance to alleviate urban traffic congestion.

First correlation model proposed by Yagoda[1], he considered the sum distance of the flow rate to characterize the degree of association between two intersections by coupling index. According to the interconnection expectation index of Chang[2], if the high density motorcade can keep the traffic flow characteristics through the upstream and downstream intersections, the coordinated control effect of the two intersections will be better. Based on this model, the Handbook of American Control Systems[3] has published a classic Whitson model, which considers traffic flow and travel time. Considering the distribution of road network traffic flow OD, Hu Hua[4]puts forward the road section correlation model and the path correlation degree model which can reflect the main coordinated path. Ma Wanjing[5]refines the flow rate to phase, and the flow imbalance coefficient can determine the coordination direction. Lin Xiaowei[6]combines traffic guidance with traffic cooperation, sub-regions are divided according to correlation degree, and phase difference is optimized to achieve regional coordination.
For traffic control sub-area division, Li Ruimin [7] uses fuzzy theory to combine the nodes according to the coordination coefficient of reasoning, and the five factors are composed of period, flow, disperse coefficient, spacing and traffic flow. Chen Shanshan [8] Based on the degree of correlation between nodes, the self-organized neural network algorithm is used to cluster. Feng Yuanjing [9] uses the second division. At the first time, the intersection correlation degree is divided, and then the green wave band maximization is taken as the target subdivision control subarea.

In the above study, there are still some problems in the correlation degree model, such as the consideration of factors is not comprehensive, the data value is not clear, the selection method of sub-region division is mostly limited, and the result of division can be further clarified. A comprehensive correlation degree model is constructed by considering six factors: section spacing, flow rate, disperse characteristics, queue length, signal period and section density. A DBSCAN clustering algorithm which is not limited to cluster shape is used to divide sub-regions.

2. Analysis of Integrated Correlation Model
By improving the classic Whitson model and considering the influence of intersection signal cycle difference and section traffic density on the correlation degree, a comprehensive correlation degree calculation model for adjacent intersections is proposed.

2.1. Improved Whitson models
Considering different types of intersections, the classical Whitson models such as formula (1).

\[
I_{AB} = \frac{1}{2(1+t_{AB})} \left( \frac{nq_{\text{max}}}{\sum_{i=1}^{n} q_i} - (n - 2) \right) \tag{1}
\]

Where \(t_{AB}\) is the travel time between the AB, \(q_{\text{max}}\) is the maximum traffic flow in the upstream direction (usually the direct traffic flow), \(\sum_{i=1}^{n} q_i\) is the total traffic flow from the upstream intersection to the downstream intersection, \(n\) is the exit direction of the upstream intersection. For crossroads, the flow \(n\) is 3, and for T-intersections, the flow \(n\) is 2.

Formula (1) \(t_{AB}\) By calculating the dividing value of length of the section AB with the average speed of the traffic flow, the influence of the queue length of the downstream intersection on the travel time is not considered. Therefore, reference is made to Gao Yunfeng [10] The research results of formula (1) are improved as follows, as shown in formula (2).

\[
I_{AB} = \frac{1}{(n-1)(1+t'_{AB})} \left( \frac{nq_{\text{max}}}{\sum q_i} - (n - 2) \right) \tag{2}
\]

\[t'_{AB} = \frac{L_{AB}-l}{v}\] Among them, \(l\) is the average queue length of downstream intersection, \(L_{AB}\) is the length of section AB, and \(v\) is the average speed.

Formula (2) \(t'_{AB}\) refers to the average travel time of all vehicles on the road AB in a time period, but in practice, the dispersion of traffic flow should also be considered. In the same average travel time, the traffic flow distribution of the two kinds of traffic flow with different degree of dispersion is different when they reach the downstream intersection, and the resulting road delay and intersection delay will be different.

Yao Zhihong [11] Considering the dispersion characteristics of the motorcade, the Robertson dispersion model is adopted, in which the dispersion coefficient \(F\) is related to the arrival and departure of the upstream and downstream vehicles, such as formula (3).

\[
q_d(t) = F \times q_u(t - T_a) + (1 - F) \times q_d(t - 1) \tag{3}
\]

\(q_d(\cdot)\) refers to the number of vehicles arriving at the end of the queue at the downstream intersection within a certain time interval, \(q_u(\cdot)\) is the number of vehicles leaving the upstream intersection within a certain time interval, and \(T_a\) is the minimum travel time between the upstream intersection and the tail of the downstream queue. \(F\) is the dispersion coefficient. According to formula (3), the discrete coefficients of the motorcade in different time intervals can be calculated.

According to Robertson [11] dispersion model, see formula (4).
3. Subdivision based on DBSCAN algorithm

The travel time considering the dispersion characteristics of traffic flow can be calculated instead of $t'_{AB}$ in formula (2). See formula (5).

$$T_{AB} = \frac{1-F}{aF}$$  \hspace{1cm} (5)

Li Ruimin[12] According to the actual situation of road in China, it is proposed that $\alpha$ the value of at low saturation is 0.305.

The improved model is as follows (6).

$$I_{AB} = \frac{F_a}{(n-1)(1-F+aF)} \left( \frac{nq_{max}}{\sum_{i=1}^{n} Q_i} - (n-2) \right)$$  \hspace{1cm} (6)

If the road section AB needs to be coordinated and controlled, it is coordinated in two directions, so we should $I_{AB}$ take the larger of the two directions, see formula (7).

$$I_{AB} = \max(I_{AB}, I_{BA})$$  \hspace{1cm} (7)

2.2. Correlation Degree Model for 2 Cycle Differences

As an important signal control parameter of road network node, the difference of cycle can also be used as the basis for sub-region division of nodes. The relationship between cycle difference and correlation value is expressed as follows (8).

$$CI_{AB} = \frac{2}{R-1} \left[ \frac{R+1}{2} - \frac{\max(C_A C_B)}{\min(C_A C_B)} \right]$$  \hspace{1cm} (8)

Where: $C_A C_B$ respectively represents the period length of the node A and node B, generally $R$ take 2.

When the period difference between node A and B is small, $CI_{AB}$ is close to 1, which indicates that the correlation between two nodes is relatively large, and when the period difference between node A and B is large, $CI_{AB}$ close to 0 or even less than 0, which indicates that the correlation between two nodes is relatively small.

2.3. Association Degree Model for Section Density

Section density can reflect traffic state, two nodes with strong correlation, and the general traffic state will be similar. Therefore, the section density between the two nodes is used as the basis for sub-area division, in which the influence of lane number is considered. The relationship between traffic state and correlation degree is as follows (9).

$$X_{I_{AB}} = \frac{\sum_{i=1}^{k} Q_i}{kL}$$  \hspace{1cm} (9)

Among them: $Q_i$ is the number of vehicles at a certain time in the $i$ lane, $k$ is the number of lanes, and $L$ is the length of the road section.

2.4. Integrated Association Model

Based on the previous research results, the node correlation is analyzed from many angles, the travel time is modified in the improved classical Whitson model, the dispersion characteristics of traffic flow and the influence of queue length are considered, and the period difference and section density are combined. A comprehensive correlation model is obtained (10).

$$\begin{cases} I_{AB} = \frac{F_a}{(n-1)(1-F+aF)} \left( \frac{nq_{max}}{\sum_{i=1}^{n} Q_i} - (n-2) \right) \\ CI_{AB} = \frac{2}{R-1} \left[ \frac{R+1}{2} - \frac{\max(C_A C_B)}{\min(C_A C_B)} \right] \\ X_{I_{AB}} = \frac{\sum_{i=1}^{k} Q_i}{kL} \end{cases}$$  \hspace{1cm} (10)
clustering and density-based clustering. Compared with other clustering methods, density-based clustering DBSCAN algorithm does not stick to fixed shape, and obtains samples with similar characteristics according to density division between data. \((\varepsilon, \text{MinPt})\) By describing the degree of tightness between samples, it represents the radius of the region and the minimum number of samples in the region. Based on DBSCAN density clustering, the index of dividing sub-region is the comprehensive correlation degree vector of adjacent nodes. The process are as follows:

1. **Establish a local area network**
2. **Determine critical and non-critical nodes**
3. **Calculate the comprehensive relational degree model**
4. **Set parameters, DBSCAN algorithm clustering, get the associated node and non-associated node**
5. **Connect the associated node to the region, and the non-associated node to the edge**
6. **Determines whether there is only one critical node in an area**
   - **Yes**
   - **No**
7. **The final clustering result is obtained**

**Figure 1. DBSCAN clustering algorithm to divide sub area process**

4. **Simulation Case**

Based on the simulation local road network at the junction of China Beijing Haidian District and Xicheng District, it consists of 10 intersections and 15 sections, including three bidirectional eight lanes, one bidirectional seven lanes, three bidirectional six lanes and eight bidirectional four lanes.

**Figure 2. Network node topology**

4.1. **Divisional programme**

Programme I, the correlation degree is calculated by the classical Whitson model, and the correlation degree threshold is set to 0.35. Programme II uses the method of merging index[8] to divide sub-regions. The partition results are shown in the figure:
Figure 3. Division results by Programme I and II

Figure A shows the Programme I division results, region is divided into three sub-regions, sub-regions I (1, 4, 5, 8), sub-regions II (2, 3), sub-regions III (7, 9, 10), and node 6 is controlled separately. Figure B shows the Programme II division results, regions are also divided into three sub-regions (1, 4, 8), (2, 3), (7, 9, 10), and nodes 5 and 6 are individually controlled.

According to the comprehensive correlation degree model proposed in this paper, the DBSCAN clustering algorithm is used to divide the sub-regions. DBSCAN algorithm is realized by Python programming. The clustering results are shown in the table below.

| Node  | $I_{AB}$ | $C_{I_{AB}}$ | $X_{I_{AB}}$ | Cluster Results |
|-------|---------|-------------|-------------|-----------------|
| 1-2   | 0.33    | 0.51        | 0.58        | 0               |
| 2-3   | 0.91    | 0.84        | 0.90        | 1               |
| 1-4   | 0.76    | 0.91        | 0.88        | 1               |
| 4-5   | 0.36    | 0.64        | 0.55        | 0               |
| 5-6   | 0.33    | 0.65        | 0.58        | 0               |
| 6-7   | 0.30    | 0.74        | 0.59        | 0               |
| 2-5   | 0.61    | 0.66        | 0.49        | 2               |
| 3-6   | 0.71    | 0.72        | 0.57        | 2               |
| 4-8   | 0.87    | 0.95        | 0.89        | 1               |
| 8-9   | 0.35    | 0.33        | 0.61        | -1              |
| 9-10  | 0.74    | 0.81        | 0.76        | 1               |
| 5-9   | 0.82    | 0.87        | 0.79        | 1               |
| 7-10  | 0.34    | 0.65        | 0.52        | 0               |

The breakdown is shown in the figure below.

Figure 4. Division results by Programme III

regions are divided into (1, 4, 8), (2, 3), (5, 9, 10) three sub-regions, nodes 6 and 7 are controlled separately.
4.2. Simulation results
Input traffic flow data, use VISSIM software simulation, in order to avoid errors, the average value of three tests, the experimental results.

Table 2. Contrast of average delay effect of diving scheme

| Node Number | Average delay | Average queue length |
|-------------|--------------|----------------------|
|             | | Before optimization | Programme I | Programme II | Programme III |
| 1           | 138.65 | 155.00 | 117.23 | 128.00 | 117.91 |
| 2           | 141.28 | 157.00 | 113.35 | 130.00 | 115.84 |
| 3           | 142.36 | 102.00 | 141.53 | 95.00 | 140.05 |
| 4           | 70.12  | 37.00 | 72.89 | 39.00 | 58.36 |
| 5           | 95.64  | 48.00 | 97.43 | 51.00 | 89.38 |
| 6           | 57.63  | 33.00 | 60.46 | 35.00 | 58.72 |
| 7           | 61.96  | 48.00 | 56.18 | 45.00 | 58.32 |
| 8           | 78.31  | 82.00 | 75.35 | 73.00 | 75.12 |
| 9           | 98.34  | 109.00 | 101.52 | 111.00 | 99.26 |
| 10          | 91.52  | 89.00 | 93.89 | 91.00 | 94.26 |

Table 3. Comparison of evaluation parameters

| Evaluation indicators | Before optimization | Programme I Reduction rate | Programme II Reduction rate | Programme III Reduction rate |
|-----------------------|---------------------|---------------------------|-----------------------------|-----------------------------|
| TDT (s)               | 975.81              | 929.32                    | 4%76                       | 907.22 | 7%03 | 859.25 | 11.94% |
| ASN (times)           | 3.34                | 3.08                      | 7%87                       | 2.72 | 18.56% | 2.13 | 36.23% |
| ADV (s)               | 91.20               | 85.44                     | 6%32                       | 83.44 | 8.51% | 81.71 | 10.41% |
| TTT (h)               | 859.31              | 854.86                    | 0.52%                      | 852.17 | 0.83% | 849.62 | 1.13% |

Where: TDT is total delay time, ASN is average stops number, ADV is average delay vehicle, TTT is total travel time.

The research shows that the three schemes have improved the traffic efficiency of road network. Programme I and II reduced the total delay at intersections by 4.76 percent and 7.03 percent, respectively, and programme III reduced the total delay at intersections by 11.94 percent; on average, Programme III reduced the number of stops and the delay time by 36.23 percent and 10.41 percent, both of which were better than the coordination effect of the previous two programme; and from the point of view of the overall road network traffic, programme III saved the road network travel time by 1.13 percent, which improved the overall efficiency of road network coordination and control compared with the first two programmes.

5. Summary
Based on the classical Whitson model, the travel time and the dispersion coefficient are corrected, and the comprehensive correlation degree model is constructed from the angle of cycle difference and road traffic state. DBSCAN clustering algorithm is used to eliminate the error caused by the set threshold and reduce the gap between theory and practice. This model fully considers the influencing factors of correlation, and the results of dynamic subdivision of intersection are more practical, which provides a good basis for the formulation of signal coordination control scheme.

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