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Correlation Degree Model of Urban Signalized Intersection Group Based on turning flows

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Abstract: This article analyzes the limitations of calculating correlation degree based on road sections and built correlation model based on the turning flow of the intersection. In addition to the traditional contributing factors, the model considers two other key factors——turning proportion of intersections and signal phase. Therefore, the proposed model can reflect the spatial and temporal heterogeneity between each turning flows on a road section. A case study to four actual intersections is conducted to test the effectiveness of this model. The results show that the proposed correlation model can better descript the relationship of adjunct intersections and find the critical route for signal coordination.

Introduction

Correlation Degree can be used to analyze the characteristics of traffic flow between two adjacent intersections and determine the necessity for coordinated control. Efforts have been made in the past to study how to determine the relevance of the intersection. For example, a study conducted by Li[1] has applied wavelet transform to decomposition, noise reduction and reconstruction in a set of traffic flow time series collected from several detectors in signalized related intersections group. Critical route can be acquired by applying hierarchical cluster method to the reconstructed traffic count profiles. Lu[2] put forward to correlation degree quantitatively to describe the correlation between two neighboring intersections and the corresponding calculation method is proposed .Then the rationality of the parameter is analyzed and the definition and calculation formula of the multi intersections combinatorial correlation degree are presented. Some new principles for the coordinative division of traffic control subareas are given based on the correlation degree analysis. In one study, Yagoda[3] and others developed a "Coupling Index",(I),which was the simple ratio of link volume and link length, as shown in Equation(1):

$$\mathrm{I} = \frac{V}{L} \tag{1}$$

Where
I – Coupling Index
V –Approach Link Volume(VPH)
L –Link Length to Next Signal(feet)

By computing this index for each link in the potential coordination system, a measure of the need for interconnecting the signal is determined.

It can be seen from the above findings that current correlation degree models mainly focuses on the factors like volume of link traffic, the intersection distance, number of lanes, mostly for road facilities rather than traffic flow parameters. It is known that coordinated control is fundamentally coordination between neighboring traffic flow. however, the current models see the traffic flow between two intersections as a whole and ignore the impact of the turning flows at intersections.

This paper built a turning flow based correlation model by not only taking the traditional factors into consideration such as the intersection distance and queue at approaches but also the critical factors: the signal phases and volume distribution.

Analysis of contributing factors

Research has found that main factors affecting the adjacent intersection correlation are intersection spacing, traffic volume, signal timing dial parameters, platoon dispersion etc.

1.Intersection distance

Intersection distance is a critical factor to determine the correlation intension. If the distance of the adjacent intersections is too long, the platoons from upstream will gradually become discrete as the distance become longer. Thus, situations occur where traffic arrives at the downstream randomly, contributing to the reduction of coordination control and adjacent intersection correlations. On the contrary, when adjacent intersections are short, the coordination control and adjacent intersection correlations will be enhanced.

2.Traffic volume

Another important factor affecting the correlation intension is the total traffic volume. If the traffic flow is heavy, the free driving distance is restricted and the traffic is less discrete, resulting in higher correlations[2]. Meanwhile, the increase of the traffic volume also leads to the increase of queue length before the downstream intersection. Therefore, the decrease of the upstream free driving distance enhances the correlations between intersections.

3.Signal timing parameters

The set of signal period, green-light-rate and phase difference, as an important factor, can control the road traffic and decide the coordination control effect effectively. To ensure a well coordination control effect in each intersection, a stable phase is necessary to uniform the signal periods of each intersection. If the signal periods differs a lot and a common period that covers all intersections cannot be found, the correlation is light. Conversely, if the signal periods are similar, slight adjustment can reach a common period which satisfies both coordination effect and efficiency of all intersections, leading to a heavy correlation. When the upstream green-light-rate is smaller than the downstream, the traffic between the intersections will become less and less, leading to a light correlation. The phase difference between adjacent intersections will determine the possible maximum traffic flow and influent the real-time adjacent intersection correlations. However, this kind of influence doesn’t has a time cumulative effect as the green-light-rate does.

4.Platoon dispersion

The platoon dispersion is also a significant factor in coordination control. In city transportation network, signalized intersections divide traffic stream into platoons. Due to the differences in driving velocities, the traffic will gradually be dispersed, which is called platoon dispersion. It is critical to describe the dispersion principle for coordination control. If the downstream platoon is obviously dispersed, the distance between the first and last cars is long and the number of vehicles crossing the green light is small, which weakens the coordination control effect and reduces the relevance. Otherwise, the coordination control effect is increased and relevance enhanced.

A qualitative analysis of the factors finds that most of the essential elements focus on the road facility itself, such as intersection distance, numbers of lanes, etc. From the perspective of traffic flow, the overall traffic characteristics like velocity, platoon, overall traffic volume etc. are factors mainly concerned. The influence of turning traffic flow ratio is ignored. The comprehensive analysis of main factors affecting the intersection correlation lays a solid foundation for the construction of the correlation coefficient model.

Proposed correlation degree model

In this paper we explore the influences of multiple factors such as intersection traffic flows and trends, distance between intersections and queue condition along downstream intersections. Then a correlation coefficient model based on intersection traffic flows and trends is proposed.

1. Basic model

Researcher Chang [4]consider the properties of the flow fluctuation at the upstream intersection and platoon dispersion on the link, and developed a simplified procedure to evaluate the need to interconnect signalized intersections by using an interconnection warrant called Interconnection Desirability (I):

$$\mathrm{I}=\frac{1}{1+\mathrm{T}}\left[\frac{\mathrm{X}\cdot q_{\max}}{q_1+q_2+q_3}\right]-(n-2) \tag{2}$$

Where:

T - Link travel time, link length divided by average speed, expressed in minutes;

X – Number of departure lanes from upstream intersection;

q_{max} – Straight through flow upstream intersection;

q_1 , q_2 ,q_3 -traffic flow arriving at the downstream approach from the right-turn, left-turn and through movements of upstream traffic signals; and

n – Number of arrival lanes to the entering link of downstream intersection.

As a representative of existing correlation coefficient model, the above model combines most influencing factors of relational grade, and therefore illustrates relational grade of adjacent intersections objectively. However, in this correlation coefficient model, general traffic flow along intersections is considered only, and the traffic diversion along both intersections are not account for. Due to the fact that traffic flows of different direction arrive at the downstream intersection during the different interval, evaluating the correlation degree of two specify flows is unavailable by employing the above model. Fig.1 shows the turning flows between two adjacent intersections.

Fig.1 The turning flows between two adjacent intersections

2. Model correcting

The original model has not include the effects of traffic diversion and signal phase of upstream intersection as well as the influence of queue length, so a few correction is made to compensate the above neglects[5].

(1)Imbalance index

The general volume feeding from upstream intersection can be divided into volume of different directions by introducing two constants, $k_i(p)$ and θ_{ij} as follows:

$$q_j(p)=\sum_{i=1}^{I} k_i(p)\times q_i\times\theta_{ij},\quad n=1,2,3 \tag{3}$$

where $k_i(p)$ is given by the ratio between volume of each phase on upstream intersection and general volume feeding from upstream intersection while θ_{ij} represents the percentage of volume turning to j direction on downstream intersection in volume q_i feeding from upstream intersection.

By eqn (3), the $\frac{\mathrm{X}\cdot q_{\max}}{q_1+q_2+q_3}$ in the original model can be substituted by an imbalance index as follows:

$$F(q_j)=\frac{P\cdot\max\left(q_j(p)\right)}{\sum_{p=1}^{P}q_j(p)},n=1,2,3 \tag{4}$$

(2)Influence of queue

We next discuss the influence of queue on travel time. In eqn (2), T refers link travel time and calculated as link length divided by average speed. However, the formula does not hold for the case when serious queue occurs, in which case the queue length is relatively long while free travel distance is significantly shorter than the distance between upstream and downstream intersection, thus the travel time is reduced.

The range of influence brought out by queue can be divided into three parts as illustrated in Fig.2.

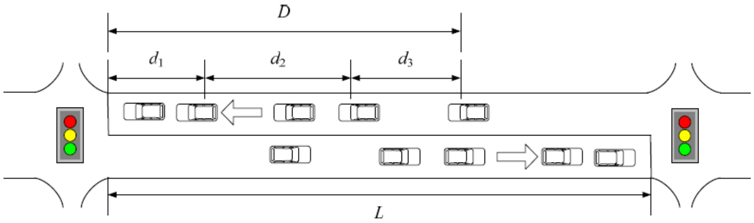

Fig.2 Affected zone length D of downstream intersection

d1: the queue length;

d2: deceleration distance;

d3: travel distance during driver's response time[6].

The travel time can be replaced by t' which is defined theoretically as follows:

$$t' = \frac{L-D}{v} \tag{5}$$

Here we can get d1 by observation and calculate d2 and d3 according to the formula fromsome literature.[7]

3. Corrected correlation model

By combining the previous correcting methods, the corrected correlation coefficient model implies:

$$\mathrm{I}\left(q_j\right) = \frac{1}{1+t'}\left[\frac{P \cdot \max\left(q_j\left(p\right)\right)}{\sum_{p=1}^{P} q_j\left(p\right)}\right] - \left(j-2\right) \tag{6}$$

Where

D – The influence distance brought out by queue;

t' - The travel time;

P - Number of departure lanes from upstream intersection.

By this corrected correlation coefficient model, we can evaluate the relational grade between two specific flows respectively at the upstream and downstream intersection, indicating the desirable situation for interconnection.

Case Study

1. Site Description

The purpose of the case study is to verify the reliability of the corrected correlation model and to find an efficient and usable procedure in deciding warrants for interconnecting isolated arterial traffic signals to optimize traffic operations.

The detailed field data collection efforts was performed on four adjacent intersections in the city of Chuzhou to collect data on signal timing, volumes of different movements, geometric properties and platoon characteristics. The cross streets are HuXin, NanJiao, DaoXiang and ZiWei.

The labels of each intersection and their signal timing programs are shown in Fig. 3.

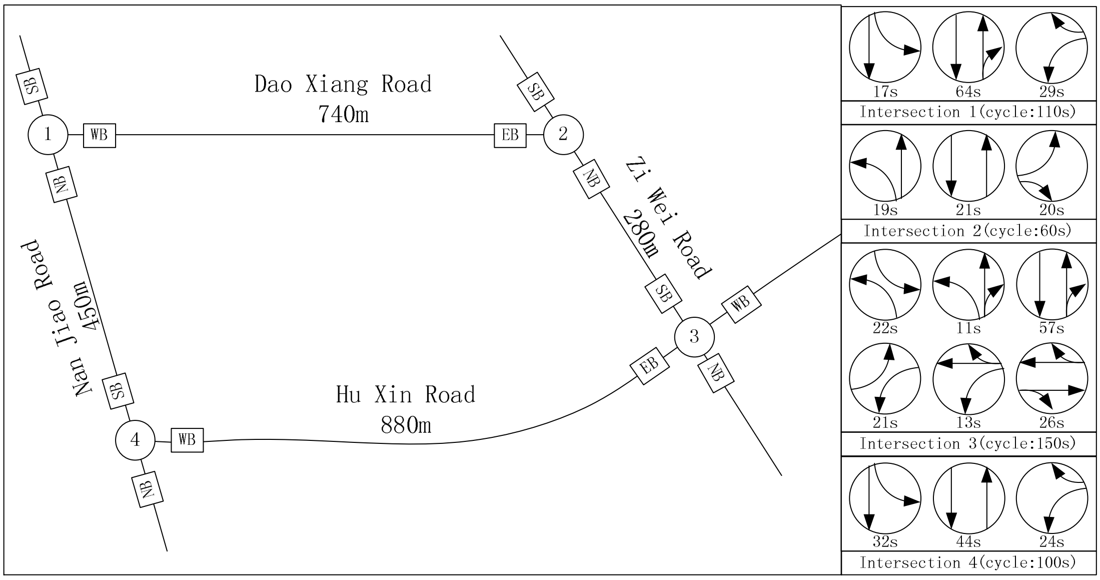

Fig.3 Intersection group and signal timing

Volumes of each movement are provided in Fig.4:

Intersection 1	lanes	Turn left	Go straight	Turn right
WB	↰ ↱	372	-	512
NB	↑ ↑ ↱	-	1775	280
SB	↰ ↑ ↑	190	1615	-
Intersection 2	lanes	Turn left	Go straight	Turn right
EB	↰ ↱	200	-	270
NB	↰ ↰ ↑ ↑	720	762	-
SB	↑ ↑ ↑↱	-	1078	164
Intersection 3	lanes	Turn left	Go straight	Turn right
EB	↰ ↑ ↱	103	331	182
WB	↰ ↑ ↱	530	203	140
NB	↰ ↑ ↱	492	1042	329
SB	↰ ↑ ↑↱	316	936	96
Intersection 4	lanes	Turn left	Go straight	Turn right
WB	↰ ↱	336	-	359
NB	↑ ↑ ↑↱	-	1696	152
SB	↰ ↑ ↑	464	1523	-

Fig.4 Turning flows of each entrance lane of intersections

The percentages of turning traffic at each intersectionare provided in Table1:

Table.1 The percentages of turning traffic at each intersection

	1—2		2—1		2—3		3—2		
Steering	NB	SB	NB	SB	SB	EB	NB	EB	WB
Turn left	31	60	51	88	22	29	53	61	75
Go Straight	-	-	-	-	75	47	47	39	25
Turn right	69	40	49	12	3	24	-	-	-
	1—4		4—1		4—3		3—4		
Steering	SB	WB	NB	WB	SB	NB	SB	WB	NB
Turn left	21	34	-	-	11	34	49	58	54
Go Straight	79	66	89	74	64	22	-	-	-
Turn right	-	-	11	26	25	44	51	42	46

2. CorrelationDegreeAnalysis

Combing the collected dataset, the correlation degree indexes of each movement could be captured as shown in table 2 by employing equ. (6) as an estimation of the reliability for making recommendations on interconnections from the simulation programs under various factor levels.

When the correlation degree index approaches 0, the effect of the entering flow on the fluctuation of downstream intersection is immaterial. With increasing value of correlation degree index, the candidate application sites become more desirable for interconnection.

Specifically, the left turn traffic flow at #2 feeding from #3 with the greater correlation degree index is expected as the most desirable situation for interconnection signal control as shown in the table2.

The results of the correlation degree provide evaluation in interconnection signal sites decision and the performance of the interconnection control would be test with the help of simulation software named Synchro 8.

Table 2 The correlation degree index for each turning flow

trend of the path	Turn left downstream	go straight downstream	turn right downstream
1—2	0.031	—	0.039
1—4	0.070	0.077	—
2—1	0.052	—	0.039
2—3	0.131	0.151	0.118
3—2	**0.278**	0.233	—
3—4	0.052	—	0.053
4—1	—	0.078	0.061
4—3	0.021	0.038	0.027

3. Experimental Design

The major variables studied influencing the effects of traffic operation with interconnecting guideline include:

(1)Number of signals phases;
(2)Phase sequence;
(3)Preferred movement;
(4)Allowable cycle length;
(5)Volume level;
(6)Speed variation;
(7)Left turn percentage; and
(8)Intersection spacings.

Basically, a large number of simulation runs were required to make for the range of factors considered. With the limitation of the utilization of the street system and fiscal resource, it is difficult to compare the impact of the improvements on the total arterial system operations without the aids from traffic simulations. Present technology suggests that Synchro 8 can be used to thoroughly evaluate the simulation of existing isolated traffic control conditions and determine the traffic signal interconnection warrants.

Synchro 8 runs was first made to optimize phase sequence and offsets for pretimed and traffic responsive signals under isolation versus interconnected operations. Then, Synchro 8 was used to simulate to compare the results of each strategies.

Basically, alternative traffic interconnection control with different controlled intersections were devised to test the effectiveness of interconnection.

The major concern is: Given existing installed traffic signalized intersection, proposed guidelines will recommend whether the interconnection can provide effective operation without adverse effect and undue delay to the arterial system, as well as, the intersection itself.

In this study, the Synchro 8 runs were made to evaluate the effectiveness of interconnection of isolated signal intersections.

Five representative interconnection control strategies were chosen for simulation to verify the effectiveness of the corrected correlation coefficient model with respecting to the candidate application sites which are shown in Fig.5 to Fig.8:

(1) The candidate application sites are #3 and #4 with the common cycle length of 150s. The straight flow at the #3 feeding from #4 is the proposed interconnection guidelines with 36s arterial band.

(2) The candidate application sites are #1 and #4 with the common cycle length of 120s. The straight flow at the #4 feeding from #1 is the proposed interconnection guidelines with 88s arterial band.

(3) The candidate application sites are #1 and #2 with the common cycle length of 100s. The straight flow at the #1 feeding from #2 is the proposed interconnection guidelines with 25s arterial band.

(4) The candidate application sites are #2 and #3 with the common cycle length of 140s. The straight flow at the #2 feeding from #3 is the proposed interconnection guidelines with 62s arterial band.

(5) The simulation model for present situation without interconnection signal control.

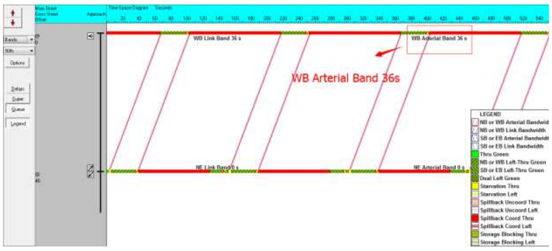

Fig.5 Green-wave signal control for the intersection 4 and 3

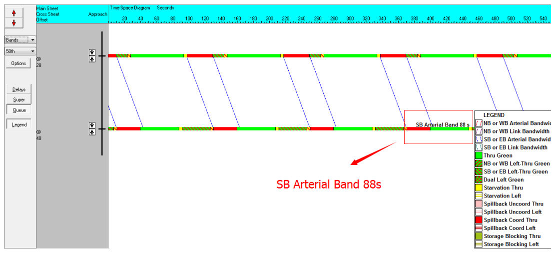

Fig.6 Green-wave signal control for the intersection 1 and 4

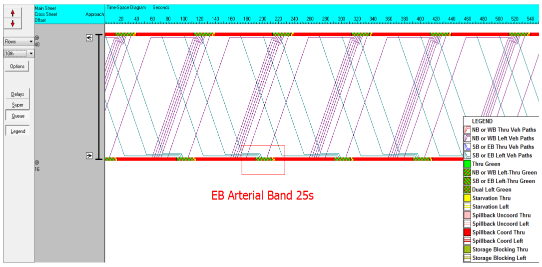

Fig.7 Green-wave signal control for the intersection 1 and 2

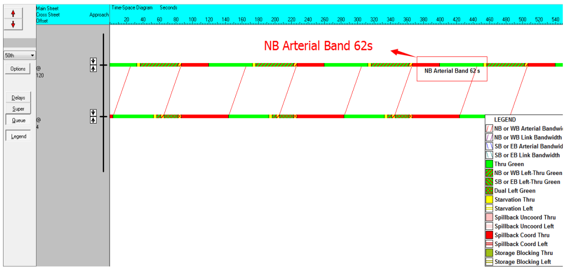

Fig.8 Green-wave signal control for the intersection 3 and 2

4. Simulation Evaluation

The field and simulation data were used along with guideline elements to determine where interconnection of a series of isolated signal is desired. The field and simulation data collected were used to verify the guidelines established to evaluate whether signal interconnection is helpful in improving traffic operation through isolated intersections.

The major objective of simulation is to establish realistic and quantitative relationship among the study factors which has important influences on operational performance measurement. One measure related to the desirability for interconnecting isolated traffic signal is the estimated arterial link delay experienced by themotorists.

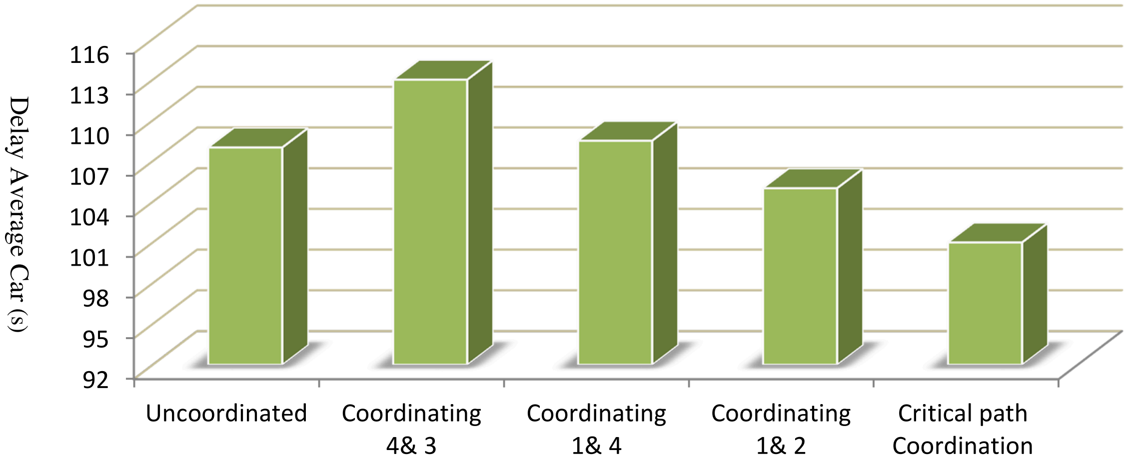

Fig.9 Comparison of the delay average car of the five programs

The simulation study presents the relationship between the proposed interconnection guidelines developed and the estimated average delay per vehicle measurement upon the operational performance once the potential interconnection became operational.

From the simulation, the lowest value of the arterial delay per vehicle occurs at the situation in which the objective link is selected as the proposed guideline.

As is shown in Fig.9,special attention should be given to the simulation model which interconnecting intersections of #2 and #3, and the traffic arterial system in this model present the most serious delay condition. According to the calculated resulted of Interconnection desirable index in table 2, the interconnection control in this model is expected to plays an insignificant role in traffic system performance.

Based on the above delay analysis, the application of corrected correlation coefficient model to optimize phase sequence and signal timing.

The guideline and procedure developed in this study can assist in designing beneficial signal interconnection and provide better utilization of the street system.

Conclusions

This paper presents a tractable approach for incorporating influence of the percentage of turning traffic, signal timing and queue in a model to evaluate the feasibility of interconnecting isolated traffic signals.

We apply the approach to an calculation of correlation degree of adjacent intersections to work, where the assumption is that all traffic flows of different direction can not cross the intersection during the same interval, and therefore, the objective of the calculation of relational degree of intersections should be the traffic flow of each different directions instead of the total traffic flow feeding between the upstream and downstream intersections.

We employ a simulation study to verify the correcting correlational degree of intersections calculated model, where the result indicate the adaptability of the correcting model in a traffic system consisting of several intersections. Furthermore, the procedure of the simulation study provide a approach for defining the critical path for signal interconnection operation.

The research result of this paper contribute to the research of relational degree of intersections, division of traffic zones as well as signal coordinated control.

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