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Research on signal coordination control model of joint area at the expressway conventional networks

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Abstract: It's necessary to study the signal coordination control of joint area for alleviating traffic congestion. The signal coordination control model of joint area is proposed based on single-point control schemes which include on-ramp, off-ramp, upstream and downstream auxiliary road intersections. The additional lane length of expressway weaving section is used as a condition which controls the on-ramp and off-ramp. The signal control schemes of upstream and downstream intersections are optimized by the adjustable ratio of auxiliary road on-ramp and off-ramp.

Keywords: Expressway, Conventional Road Network, Single-Point Signal Control, Signal Coordination Control

1. Introduction

With increasing traffic demand in recent years, urban traffic congestion problem has gotten worse. Traffic expressway system can undertake main urban traffic trips because of its characteristics of rapidness and large capacity. So it's necessary to study the signal coordination control of joint area for alleviating traffic congestion and improving current road capacity. Zong Z. et al. proposed an integrated control algorithm, on the basis of the research object of an adaptive-controlling intersection and a dynamic-control ramp (Zong, 2007); Zheng Jianhu et al., taking the traffic density and vehicle queue length as inputs, put forward the on-ramp fuzzy control method (Zheng, Chen, & Dong, 2006); Ci Yusheng et al. applied neural network and fuzzy logic algorithm to study the on-ramp control algorithm of urban expressway (Ci, Wu, & Pei, et al.,2006); Yuan Changliang et al. used a small-step adjustment algorithm to calculate the signal cycle and green ratio of the downstream intersection, as well as the signal timing of the upstream auxiliary road (Yuan & Li, 2010). Therefore, the paper studied the signal coordination control method in order to improve the urban expressway capacity.

2. Signal Coordination Control

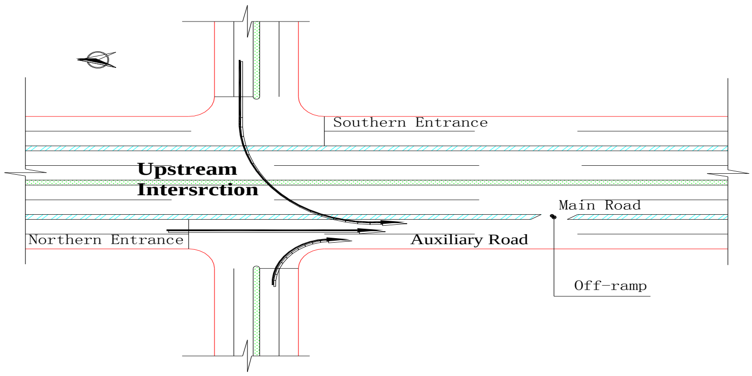

Fig. 1: Connection schematic diagram of western expressway in upstream intersection.

There are four signal control points in the joint area: auxiliary road on-ramp, auxiliary road off-ramp, upstream and downstream intersection of auxiliary road. (Fig. 1 and Fig. 2)

The adjustable ratio of traffic volume is used as the signal control index of on-ramp and off-ramp.

$$r(k) = Q_r(k-1) + K_r(\mathrm{O}_{rc} - \mathrm{O}_{rd}(k-1)) \quad (1)$$

Where: $r(k)$ - the traffic volume adjustable ratio of on-ramp (off-ramp) in the k time interval; $Q_r(k\text{-}1)$ - the (k-1) traffic volume of on-ramp (off-ramp), (pcu/h); K_r -the adjustment coefficient; O_{rc} -the critical time occupancy of on-ramp (off-ramp), (pcu/h); $O_{rd}(k\text{-}1)$ -the (k-1) critical time occupancy of on-ramp (off-ramp), (pcu/h).

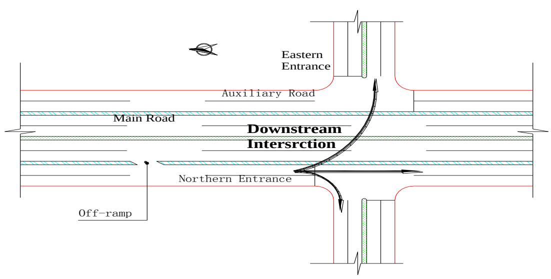

Fig. 2: Connection schematic diagram of western expressway in downstream intersection.

1) Coordination Control of Entrance and Exit

In the paper, a new coordination control method is proposed based on the vehicle number that can be contained in the additional lane of weaving area.

$$n_1 = \frac{C_1 r_1}{3600} \qquad n_3 = \frac{q_d - q_3}{3600} g_{e2} \tag{2}$$

Where: n_1——the queuing vehicle number of on-ramp in one cycle, (pcu); n_3—the queuing vehicle number of off-ramp in weaving section, (pcu); C_1——the signal control cycle of on-ramp, (s); r_1——the traffic volume adjustable ratio of on-ramp (pcu/h); q_d-the vehicle arriving rate of off-ramp, (pcu/h); q_3 - the traffic volume of off-ramp, (pcu/h); g_{e2}- the off-ramp green time, (s).

Suppose that the additional lane vehicle number of main road weaving section is N, the vehicle number of on-ramp in every signal cycle time is n_1, the queuing vehicle number of off-ramp on the main road weaving section is n_3. Then:

(1) $n_1+n_3>N$

The off-ramp traffic flow should be firstly satisfied, the traffic volume adjustable ratio of auxiliary road is a value calculated by single-point control model.

(2) $n_1+n_3<N$

This case shows that on-ramp vehicles could be added, the traffic volume adjustable ratio of auxiliary road is a value calculated by single-point control model.

2) Coordination Control of On-ramp and Upstream Intersection

In order to reduce the on-ramp queue length of auxiliary road, the upstream intersection green time of straight-going and left-turning should be reduced, then

$$S_s g_s' \alpha_s / C_3 + S_l g_l' \alpha_l / C_3 = r_1 \tag{3}$$

Where: S_s-the straight-going saturation volume, (pcu/h); S_l-the left-turning saturation volume, (pcu/h); g_s'-the adjusted straight-going green time, (s); g_l'-the adjusted left-turning green time, (s); α_s- the ratio of straight-going vehicles through on-ramp; α_l- the ratio of left-turning vehicles through on-ramp; C_3-the intersection signal period, (s); r_1-the traffic volume adjustable ratio of on-ramp, (pcu/h).

The compression rate of the straight-going green time and the left-turning green time is:

$$\frac{g_s'}{g_l'} = \frac{g_s S_s \alpha_s}{g_l S_l \alpha_l} \tag{4}$$

Where: g_s-the original straight-going green time, (s); g_l-the original left-turning green time, (s).

3) Coordination Control of Off-ramp and Downstream Intersection

Based on the relationship between the off-ramp traffic volume and the auxiliary road traffic volume, the left-turning and straight-going green time of the downstream intersection could be calculated.

$$q_2\alpha_{fl}g_{e2}/C_2 + q_3\beta_l = S_l g_l / C_4 \quad (5)$$

$$q_2\alpha_{fs}g_{e2}/C_2 + q_3\beta_s = S_s g_s / C_4 \quad (6)$$

Where: q_2-the maximum traffic volume of auxiliary road, (pcu/h); q_3- the off-ramp traffic volume, (pcu/h); α_{fl}- the auxiliary road left-turning ratio; α_{fs}- the auxiliary road straight-going ratio; β_l- the off-ramp left-turning ratio; β- the off-ramp straight-going ratio; g_{e2}- the off-ramp green time, (s); g_l- the downstream intersection left-turning green time, (s); g_s- the straight-going green time in downstream intersection, (s); C_2- the off-ramp signal cycle, (s); C_4-the signal cycle in downstream intersection, (s); S_l- the left-turning saturation volume, (pcu/h); S_s-the straight-going saturation flow, (pcu/h).

4) Intersection Control Fusion

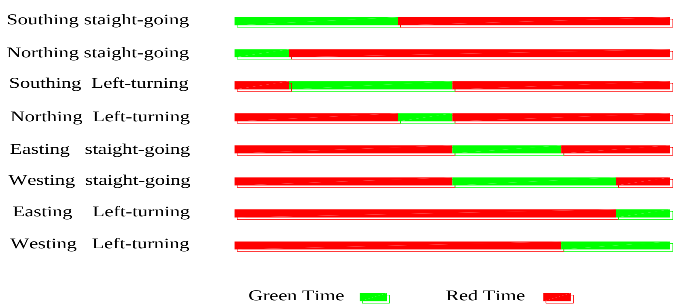

Fig.3: Signal fusion adjustment scheme of four signal phases intersection.

In the coordination control model, the intersection signal control scheme may use two kinds of different regional division at the same time. So it’s necessary to fuse the signal control scheme. Two factors are taken into account: (1) no twice-release during one cycle; (2) signal is adjusted to minimize the interference of other phase.

Based on this, the signal adjustment scheme at the upstream intersection is" Stop straight-going phase of northern entrance ahead of time + Lag release left-turning phase of eastern exit" (Fig. 3); the signal adjustment scheme at the downstream intersection using " Stop straight-going phase of southern entrance ahead of time + Lag release left-turning phase of southern entrance " (Fig. 4).

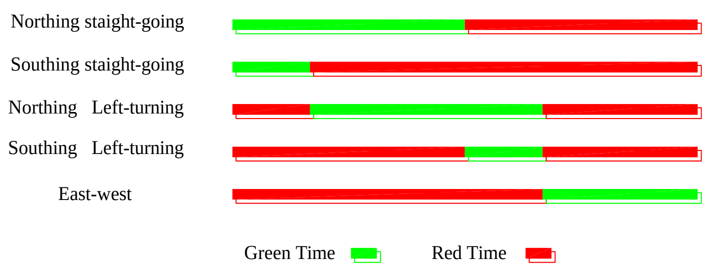

Fig. 4: Fusion Adjustment Scheme of Three Signal Phases Intersection

5) Coordination Control of Auxiliary Road

The signals of the off-ramp, upstream and downstream intersection are optimized by the main road coordination control theory.

The off-ramp and on-ramp signal cycle is equal to half of the intersection and it sets twice release, while the green time and red time are determined by the green ratio. The intersection, which has the longest signal cycle, is regarded as the key intersection. The critical intersection signal cycle is the system unified signal cycle length. For the non-key intersection, all excessive green time is added to the main-line phase to improve the capacity of auxiliary road. To ensure the signal coordination control of upstream and downstream intersection, the green phase difference should be determined by average speed and distance.

3. Model Validation

The regional road network, from Wenhui Bridge to Mingguang Bridge, is selected as the model validation case. The signal control parameters, which are determined by the above-mentioned signal coordination control method, can be obtained by traffic survey. Phase sequence is shown in Fig. 3 and Fig. 4. VISSIM is used as the simulation platform, and the simulation interface is shown in Fig. 5. The simulation results show that the traffic volume on the western side of main road increases by 18.9%, and average speed increases by 40.7%. Therefore, the coordination control model proposed in the paper is feasible.

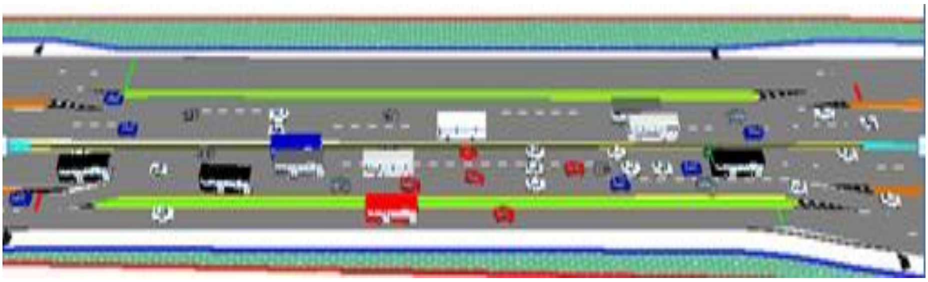

Fig. 5: Operation effect of simulation for weaving section.

Tab. 1: Comparative analysis of expressway western main road.

Evaluation Index	Traffic Volume(*pcu*/5*min*)			Operation Speed (*km/h*)		
Time Interval	Non-control	coordination control	Increase%	Non-control	coordination control	Increase%
8:35~8:40	356	383	7.7	26.26	40.50	54.2
8:40~8:45	339	350	3.5	36.28	56.80	56.5
8:45~8:50	340	361	6.4	22.17	28.95	30.6
8:50~8:55	353	363	2.9	32.64	45.20	38.5
8:55~9:00	373	383	2.9	28.92	45.88	58.6
9:00~9:05	354	443	25.3	29.71	45.92	54.6
9:05~9:10	329	468	42.2	36.31	45.68	25.8
9:10~9:15	364	478	31.4	42.76	57.50	34.5
9:15~9:20	327	438	33.9	42.07	57.05	35.6
9:20~9:25	374	438	17.3	44.21	57.40	29.8
9:25~9:30	374	505	35.1	44.51	57.60	29.4
Average			18.9			40.7

4. Conclusion

1. In the signal coordination control model of joint area, the additional lane length of weaving section is taken as a factor which controls both the on-ramp and off-ramp traffic volume, and the traffic occupancy is used to determine the adjustable ratio of auxiliary road, and Webster is used to adjust the signal cycle schemes of the upstream and downstream intersection. Moreover, a new intersection signal control fusion method is proposed in order to optimize the intersection signal control.

2. From our VISSIM simulation results, the traffic volume on the western side of main road increases by 18.9%, and the average speed increases by 40.7%. Therefore, it is reliable to use the coordination control model proposed above.

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