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A NEW OPTIMIZATION METHOD FOR TIME-OF-DAY SIGNAL TIMING TRANSITION OF ARTERIAL TRAFFIC

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Abstract: It is an important aspect in urban traffic control to make the arterial traffic operate under good condition. The prevalent method is by coordinating the traffic signal lamps to obtain the progression on a corridor. In China, a majority of loop detectors are broken and not working because of the lack of maintenance. Time-of–day (TOD) timing plans were developed offline on these arterial nodes. A coordination signal timing plan consists of three parameters, namely cycle length, phase split and offset. Because of the difference of traffic volume, speed, etc., a timing plan implemented in a certain time interval is different to those in other intervals in one day. So it needs to be solved to make timing plan smooth transition from one to the next. In this paper, the practical methods were improved by selecting reasonable offset and cycle length to make signal transitions smooth and speedy.

Key Words: urban traffic control, signal timing transition, time of day (TOD), arterial control, offset

1. INTRODUCTION

Urban traffic control is an effective method to alleviate traffic congestion. Moreover, it is a symbol of urban traffic modernization. Since urban arterial streets bear heavy traffic volume. Therefore, it is a research focus in traffic field.

On these arterial streets, intersections are coordinately controlled to make vehicles across the corridor continuously. It is realized by three parameters that are cycle length, phase split, and offset. Generally there are two techniques to calculate them, namely online and offline. In Chinese cities, most loop detectors installed in the major intersections can not work normally because of the frequent breakdown and the lack of maintenance. So, TOD timing plans

developed using offline technology is widely used, such as Jiefang Road in Changchun City, Jilin Province; Gaoerji Road (one-way) in Dalian City, Liaoning Province. Even in developed countries, for example American, many intersections are controlled by this mode due to the advantages of it, such as simple technology, inexpensive cost, no use for detectors, etc.

In TOD systems, a day is segmented into a number of intervals. Different timing plans are used in these intervals. At the beginning of one interval, there is a timing plan's correction mainly resulted from the difference of offset in different timing plans. Experience has shown that these transition periods can disrupt vehicle platoon, especially the unreasonable transition parameters settings. Thus, one challenge in operating a TOD system effectively is to reasonably handle the transition between two successive intervals. It needs consider two aspects: smooth transition and rapid transition. Generally smooth transition is more important than the latter.

In this paper, the timing plans optimization and the problem of plan transition was first described. Then the main methods found in literature were reviewed and classified. The advantages and disadvantages of them were analyzed in detail. At last, the practical methods were improved to optimize traffic flow during the transition period. Offset were first optimized to minimize the disturbances caused by the transition. Then cycle length was optimized to minimize transition duration and supply sufficient capacity.

2. SIGNAL TIMING PLAN OPTIMIZATION

The signal timing plans directly affect the operation benefit of traffic control system. Poorly timed signals can waste time, fuel, and money. Therefore, timing is the key technology of urban traffic control. The essential of optimal traffic signal control is to determinate the optimum timing parameters based on historical traffic condition collected by investigators (see Figure 1).

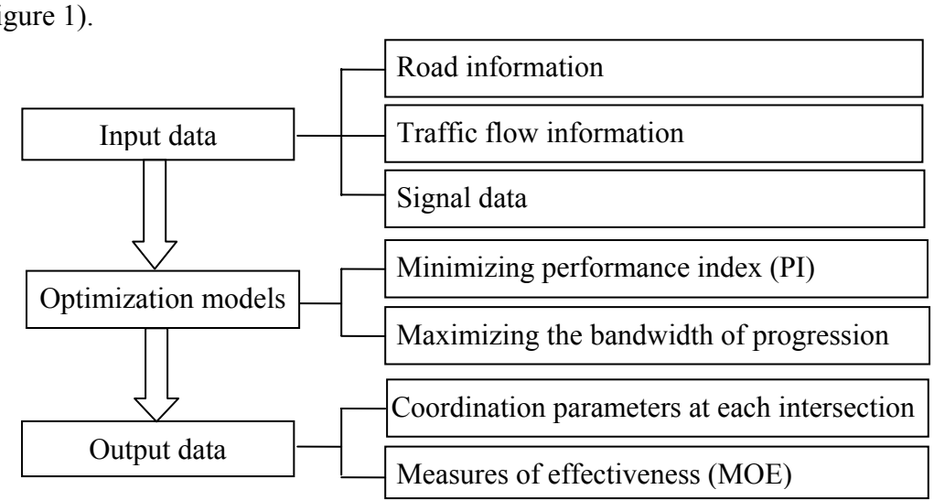

Figure 1. Process of Determining of the Timing Parameters

Traffic signal operation can be described in terms of cycle length, phase split, and offset. The cycle length is the total time required for a complete sequence of signal phases. It must be common to all intersections within the coordinated system. The longer cycle lengths are

generally applied during the peak periods. Split is the proportion of green time given to a particular phase within a cycle. The offset is the time difference between the start of the green phase at an intersection as related to the start of the green phase at the critical intersection.

With the development of computer technology, computer models have replaced manual setting and optimization of timing plans. These powerful models use historical data and computer simulation to create an optimal signal timing plan.

3. PROBLEM STATEMENT

In the input data, it is obvious that traffic flow information is various over the time. Figure 2 illustrates the traffic volume at three intersections in one day. Therefore, a day is generally divided into several continuous time segments by traffic engineers. Timing plan is obtained respectively reflected the corresponding average traffic demand of certain period. So, there are a series of timing plans to be implemented in every day. When a time segment comes in, how to adjust the timing parameters from the preceding to the next is a noticeable problem (see Figure 3).

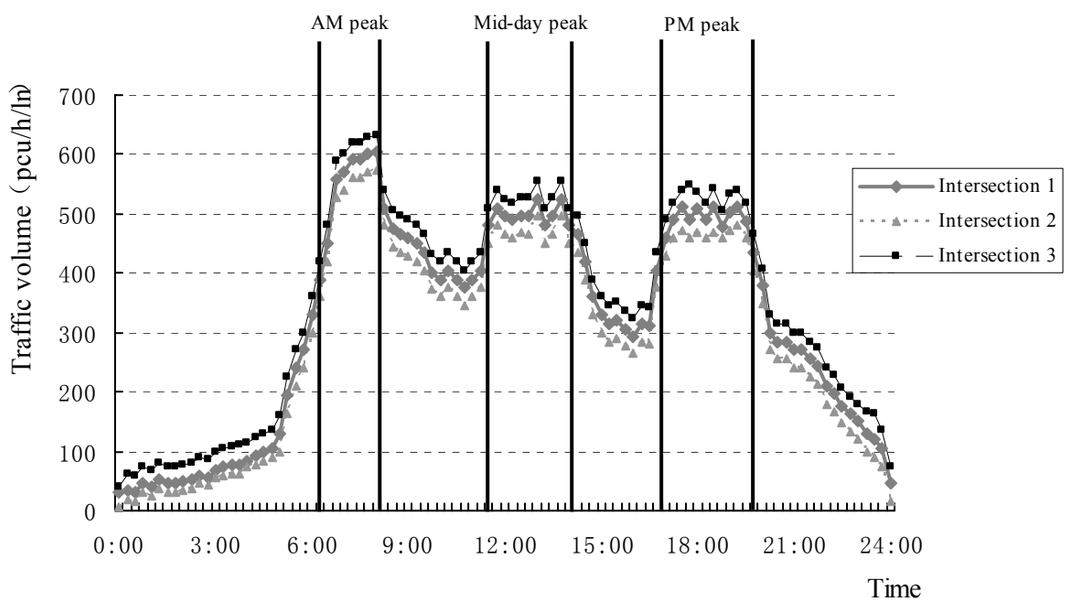

Figure 2. Variation of Traffic Volume over the Time

4. REVIEW OF EXITING METHODS OF TIMING TRANSITION

The current methods of handling the transition between TOD timing plans can be categorized as (1) Practical methods and (2) Theoretical methods (Selekwa M.F. et.al., 2003).

4.1 Practical Methods

(1) Dwell (longway) methods. A new offset shall be established by stopping the cycle timer in

the coordinated phase(s) green, until the synchronization is reached. The dwell can be infinite or interrupted by the permissive maximum dwell time. These methods favor the arterial streets traffic partly and increase the delay of vehicles on the minor streets.

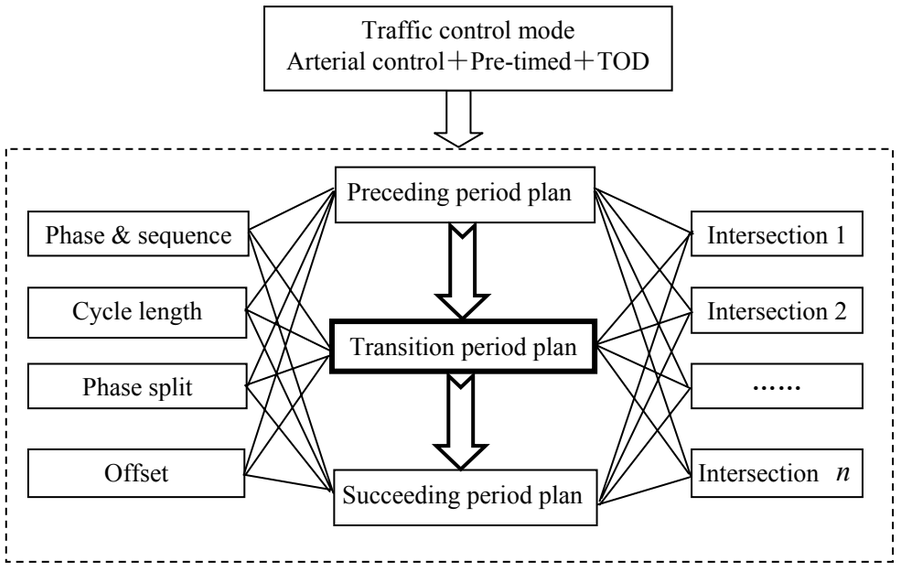

Figure 3. Timing Plan Design of TOD for Arterial Control

(2) Shortway (or shortroute) methods. The new timing plan is achieved along the quickest transition route by adjusting cycle length within a range defined by minimum and maximum values. The changes can be decreased or added only. Methods based on shortway usually disturb the progression of vehicles on the arterial streets because they adjust the offset of each intersection respectively.

For either type of transition method, variation direction and percentage of phase split are various. Coordinated phase (generally referred to the main street) usually is lengthened and non-coordinated phases (generally minor street) are shortened.

A number of studies have evaluated the efficacy of the above mentioned methods. Ross (1977) compared the shortway method and dwell method using NETSIM model and didn't find essentially difference in impacting the average vehicle speed and the number of stops per vehicle. In addition, the study found that the average performance measures of the transition algorithms are about 20%. Another study by Basu (1981) was about the shortway transition algorithm evaluated by NETSIM and TRANSYT models. He concluded that the increase in total network delay caused by transition increases with the increase of network saturation.

4.2 Theoretical Methods

Most of theoretical researches of timing plan transition were done before1980s according to the literature search. One important theoretical method for off-line signal timing technologies was Urban Traffic Control System (UTCS) transition procedure developed by the Federal Highway Administration (FHWA). Its optimal solution is obtained by minimizing the sum of the squares of the differences between the new and the old offsets. It aims to minimize the total disturbances caused by the signal transition interval changing from one signal timing plan to another. Selekwa M.F. et al. (2003) attempted to express this problem as a linear

quadratic optimization. But it neglected the relationship between cycle length and offset in the process of transition, and is difficult to be implemented because the transition values are decimal.

4.3 Method Evaluation

Practical methods are widely used by traffic controller software manufacturers because they are simple and practical. But the optimization objectives of them are not performance measures of traffic flow. So the values of transition parameters may not be optimal. While, theoretical methods are quite the contrary.

5. IMPROVEMENT OF PRACTICAL METHODS

Two principles of transition optimization are smooth transition and speedy transition which are mainly decided by offset and cycle length. In this paper, a method for determining transition plans is addressed. It improves the practical methods discussed above because the smooth of transition (mainly refer to offset) is taken into account. This method may partly decrease the disturbance.

1) Ascertainment of reasonable size of offset change at each step

The offset change value must be moderate to ensure the transition is smooth and speedy. These values can be obtained from the experience of traffic engineers (i.e. 5~7 seconds). These values can be saved in traffic controller and adjusted slightly according to the offset difference of two successive timing plans. So, how many transition steps each intersection needs to accomplish the transition process can be calculated. (In the last transition step, the offset transition value may be less than the offset change limit value because there is no sufficient remainder).

2) Ascertainment of cycle length of each intersection

Once the size of offset change is known, the speed of transition is decided by cycle lengths of intersections, especially the critical (or reference) intersection that has the highest degree of saturation. The small is the cycle length, the quick the transition is. So, if the next time interval is off-peak, the cycle length is small as soon as possible. Otherwise, the capacity needs to be considered.

(1) Off-peak. firstly, let the cycle lengths of the non-critical intersections equal to their minimal values. Then calculate the cycle lengths according to the relationship of the cycle length of non-critical intersection, the offsets of this step and last step individually (see Figure 4). The maximal value is the cycle length of critical intersection. The cycle length of non-critical intersections should be calculated again according to it.

(2) Peak hour. Suppose the cycle length of the critical intersection is the optimal value of the next time interval. Then find a cycle length value which is near the optimal value and make the cycle lengths of other intersections meet the limits (maximum and minimum values) at the same time.

3) Judgment

At this step, the current offset and the optimal values in the next interval should be judged. If the offsets of all intersections at current step equal to the optimal values in the next interval, the transition is over. The new timing plans in the next interval begin to be implemented. Otherwise, return 1).

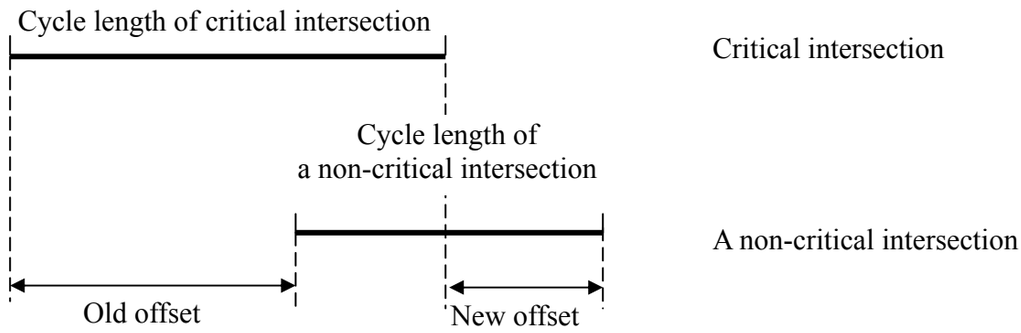

Figure 4. Demonstration of Relationship between Cycle Length and Offset at Transition Period

6. CONCLUSIONS AND FUTURE WORK

Timing plan transition is an important aspect of offline or online signal coordinated control systems. Based on the review of the exiting methods, a transition optimization procedure was presented in this paper for pre-timed TOD arterial traffic control. It can enhance the practical methods, and make traffic signal transition speedy and smooth to a certain extent. Further study is to calibrate and validate the algorithm proposed in this paper by micro-simulation software using field data collected from various traffic scenarios.

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