Traffic Signal Control based on Travel Time Information from Beacons

M. Massart[(1)], M. Koshi[(2)] and M. Kuwahara[(3)]
[(1)] ISIS Company, Lyon, France
[(2)] Dept. of Transportation Engineering, Nihon University, Funabashi-shi, Chiba 274, Japan
[(3)] Institute of Industrial Science, University of Tokyo, Minato-ku, Tokyo106, Japan

ABSTRACT

Roadside traffic beacons will possibly be installed at a large scale in the framework of ITS movement. This paper examines whether up-link travel time information provided by such beacons might be efficiently used for real-time traffic signal control purposes.

1. INTRODUCTION

Traffic beacons, which are designed to offer local communication between vehicles and traffic centers, have attracted a great deal of interest in the recent few years. In some projects (UTMS in Japan, Euroscout in Europe), the bi-directional communication allows beacons to receive on-line information from an equipped vehicle, in particular its travel time between two consecutive beacons.

Besides, travel time or delay is at the core of signal control optimization. Latest traffic-responsive algorithms aim to minimize global delay [4, 5, 7, 8], but so far, delay is not measured directly but estimated from the data of traffic detectors. Using travel time provided by beacons instead, it may become possible to measure global delay more accurately, and therefore to reach a better optimization of the signal.

This paper presents some methods for controlling traffic signals using *exclusively* travel time information collected from traffic beacons. In the first section, we present the modeling and define the objective function. The data processing method and the optimization algorithm are then presented in section 2. In section 3, we give some results of computer simulation for an isolated intersection.

2. MODELING

In this section, we first define the scope of the study. We then show how some relevant quantities can be derived from a curve called phase delay profile. The objective function is then defined.

2.1. Scope of the Study

The idea of using beacons in place of detectors for signal control purposes raises naturally many issues, notably in terms of cost. Here, we will merely confine ourselves to the question of technical feasibility. Furthermore, the study shall focus on aspects for which the beacon-based approach might provide innovative solutions.

We made following assumptions:

- There is one beacon directly downstream of every stop line, in every direction as shown in Figure 1 (where vehicles drive on the left side) so that travel time on a link can be measured by direction.

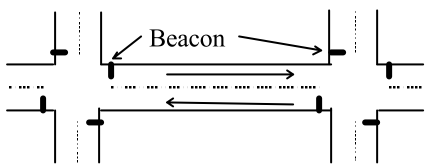

Figure 1 Spatial Configuration of Beacons

- Travel time between two <u>consecutive</u> beacons is just considered; that is, conventional detectors are simply <u>ignored</u>.

- Percentage of equipped vehicles is assumed to be given with a uniform distribution in space.

- We limit ourselves to <u>undersaturated</u> or <u>nearsaturated</u> traffic conditions. Oversaturation is out of scope.

2.2. Specification of Beacons

Using travel time instead of conventional traffic data such as flow, occupancy or speed induces some notable changes in the methodology. The major advantage of beacons compared to detectors is the direct measurement of individual delay. On the other hand, as data are collected only from equipped vehicles, it is no longer possible to directly measure traffic flows. Furthermore, a time interval while sufficient number of data are collected so as to update signal parameters will be strongly dependent upon the *equipment ratio*, *e*, i.e. the ratio of the number of equipped vehicles to the total number of passing vehicles.

2.3. Data Collection

Individual delay and departing time

From passing time t_1 at upstream beacon and t_2 at downstream beacon, we derive the individual delay d:

$$d = t_2 - t_1 - \frac{L}{v_f} \quad (1)$$

where L is the distance between two consecutive beacons and v_f denotes the free speed.

As beacons are assumed to be located directly downstream from stop lines, the departing time from stop line is directly given by t_2 .

Phase Delay Profiles

By tracing the individual delays of equipped vehicles against departure time from intersection stop line for each phase, we obtain a curve called phase delay profile. The relationship between a phase delay profile and the well-known cumulative vehicle pattern is illustrated in Figure 2.

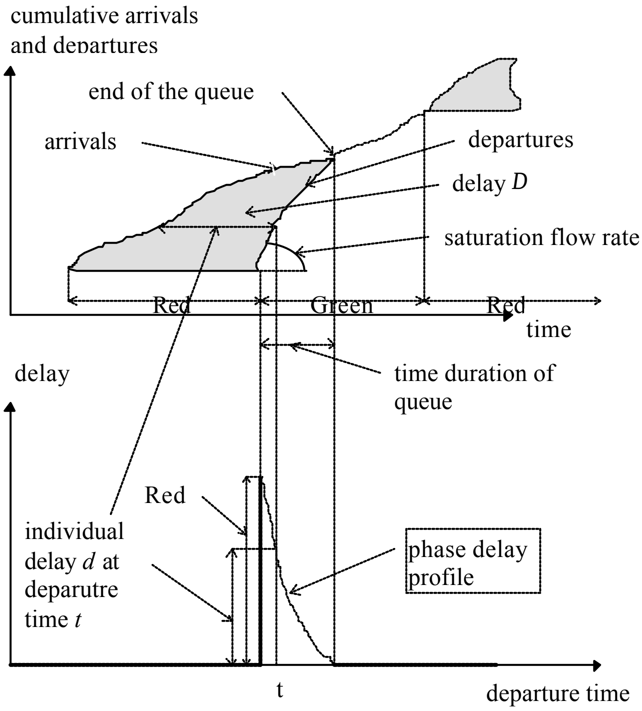

Figure 2 From Cumulative Arrivals/Departures to Delay Profile

A phase delay profile typically decreases from around red time (for the first delayed vehicle) to zero (for the first non-delayed vehicle). The delay profiles we collect in practice through beacons more likely present the shape shown in

Figure 3. A vertical line shows the individual delay of an equipped vehicle departing from the stop line at time on the horizontal axis. Generally, the quantity of data collected during one cycle does not suffice, if the equipment ratio is not large enough. Then, one have to aggregate the data over several cycles before starting data processing.

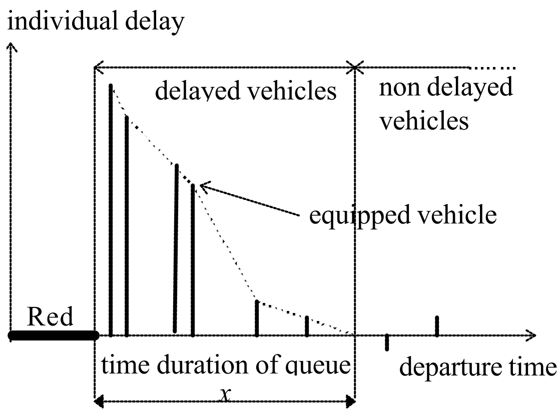

Figure 3 Delay Profile from Beacons

2.4. Data Processing

From a phase delay profile, it is possible to derive numerous information for the phase:

presence of saturation: by checking whether the maximal individual delay exceeds red time duration, it is easy to detect saturation. Note that this very basic examination can not be done with detectors.

time duration of queue, x. The time duration of queue is the time duration during which vehicles are delayed as shown in Fig. 3.

saturation flow rate, S, which is estimated by the number of delayed vehicles divided by the time duration of queue:

$$S = \frac{1}{\varepsilon} \cdot \frac{n_s^e}{N \cdot x} \quad ,$$

where N = the number of cycles over which the estimates is made,
n_s^e = the number of delayed equipped vehicles.

normalized flow, l, ratio of the arrival flow rate to the saturation flow rate. By counting the delayed equipped vehicles n_s^e over a numerous enough sample of n^e equipped vehicles, the normalized flow is estimated as

$$\lambda = \frac{(\frac{n^e}{\varepsilon}) / NC}{(\frac{n_s^e}{\varepsilon}) / Nx} = \frac{n^e}{n_s^e} \cdot \frac{x}{C}$$

From normalized flows, we derive the intersection *saturation degree*, and *Webster's minimal and optimal cycle length*:

$$C_{opt} = \frac{1.5L + 5}{1 - l} \qquad (2)$$

$$C_{\min} = \frac{L}{1 - l} \qquad (3)$$

where L stands for the loss time per cycle.

How to estimate *delay* for each phase is best explained by referring to Figure 4 .

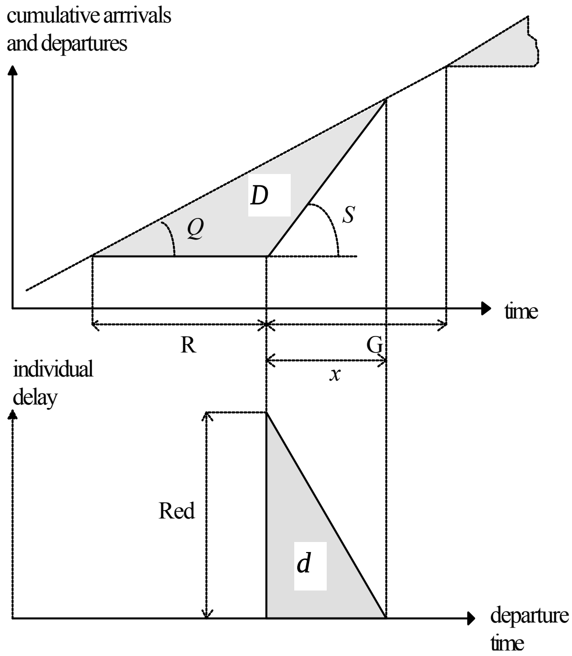

Figure 4 Estimation of Delay

The delay per cycle (gray area in the upper figure) is given by:

$$\Delta = \frac{1}{2} R(S \cdot x), \qquad (4)$$

whereas the area enclosed by the delay profile (gray area in the lower figure) is:

$$\delta = \frac{1}{2} R \cdot x = \frac{\Delta}{S} \quad . \qquad (5)$$

An estimator of the delay is hence given by:

$$D = \delta \cdot S \quad . \qquad (6)$$

We called this quantity as *delay index*. By dividing the delay index by the cycle length, we obtain the objective function: the *delay index per unit time*:

$$\Lambda = D / C \quad . \qquad (7)$$

3. ALGORITHM FOR AN ISOLATED INTERSECTION

The algorithm we present here controls simultaneously cycle and split for an isolated intersection. The framework of the algorithm is given in Figure 5.

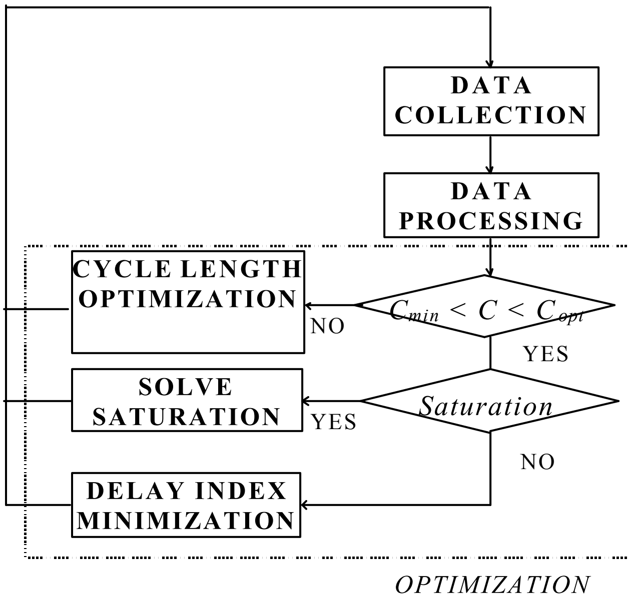

Figure 5 Framework of the Algorithm

When the current cycle length is not within C_{min} and C_{opt} as computed during the data processing stage, the *Cycle Length Optimization* sub-algorithm is applied. Else, we check whether some phase is saturated. If so, the sub-algorithm *Solve Saturation* is applied. Otherwise, the program chooses the *Delay Index Minimization* sub-algorithm, which is the core of the algorithm.

3.1. Cycle Length Optimization

If C exceeds C_{opt} (Webster's optimal cycle), we set a new cycle:

$$C' = ½ (C + C_{opt}) \qquad (8)$$

and if C is less than C_{min} (Webster's minimal cycle), we set

$$C' = ½ (C + C_{min}) . \qquad (9)$$

Then, green split of phase i, G_i, is simply set proportionally to the normalized flow l_i:

$$\frac{G'_i}{C' - L} = \frac{l_i}{\sum l_j} \qquad (10)$$

3.2. Solving Saturation

When a phase is detected to be saturated, some additional green time is allocated to it. If the same amount of green time can be taken out from other phases (constant cycle length) without risk of saturation, the program chooses this solution. Otherwise, it extends the cycle length until it finds some satisfactory solution, i.e. without any risk of saturation for any of the phases.

3.3. Delay Index Minimization

In this sub-algorithm, the cycle length and green split are optimized simultaneously in respect to the minimization of the objective function, the *delay index per unit time.* The principle of this sub-algorithm is rather simple. Considering a discrete green split shift of dG_i for a given phase i, we estimate the resulting *expected variation of delay index,* dD_i. Figure 6 shows a case where dG_i is negative; that is, the red time is elongated. Approximately, dD_i is given by $dD_i = - S \times dG_i$.

By examining some discrete green time variations ($dG_1 , .. ,dG_n$) and adding resulting expected delay index variations over all phases, we obtain dD:

$$dD = \sum_i dD_i \qquad (11)$$

It provides an iterative optimization process of the signal parameters in respect to the delay index per unit time.

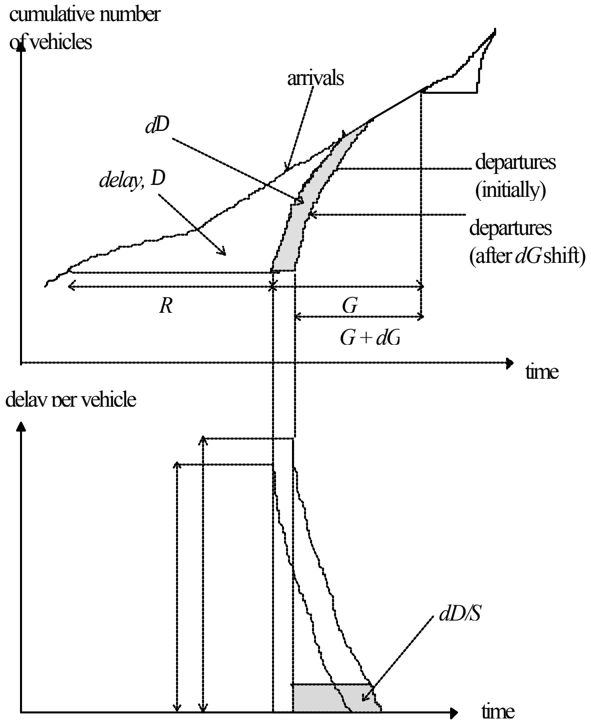

Figure 6 Phase Delay Index Variation

4. COMPUTER SIMULATION

We implement the optimization process into a traffic simulation model. The objectives of the simulation are:

- first, to assess the accuracy of the data processing stage (delay, time duration of queue, saturation degree, saturation flow rate estimation, etc.);
- second, to assess the efficiency of the optimization process itself.

We use a simple configuration of a four-leg intersection described in Figure 7 with two-phase control. Critical traffic demand rates are 1200 [veh/h] for phase 1 and 1000 [veh/h] for phase 2.

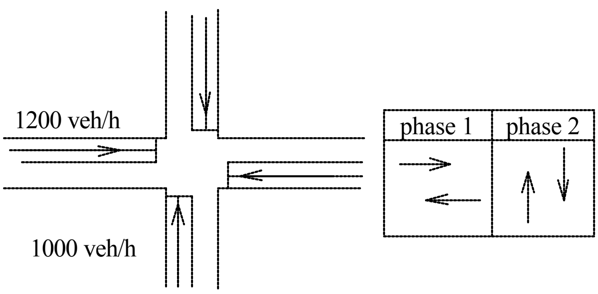

Figure 7 Configuration of the Intersection.

4.1. Data Processing

We first analyze the response time lag of the algorithm depending on the equipment ratio. Figure 8 gives the number of cycles which are required before updating signal parameters against equipment ratio.

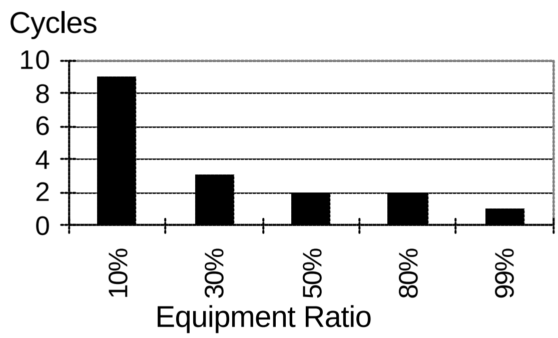

Figure 8 Number of Cycles between Two Consecutive Updates Against Equipment Ratio

This first result suggests that an effective *traffic-responsive* signal control is not feasible below a rate of 10% vehicles equipped, yet feasible from a equipment ratio as low as 30%. Note that, with this our method, the equipment ratio has no big influence on the accuracy of the data processing. It mainly determines the response time lag of the algorithm.

We assess the accuracy of the estimation of the parameters related to the delay profile (time duration of queue, saturation flow rate, normalized flows, delay). The accuracy was found to be:

- satisfying for the time duration of queue;
- rather unstable for the saturation flow rate;
- very good for the normalized flows and the delay.

This good agreement of the delay index with actual delay of passing vehicles is illustrated in Figure 9.

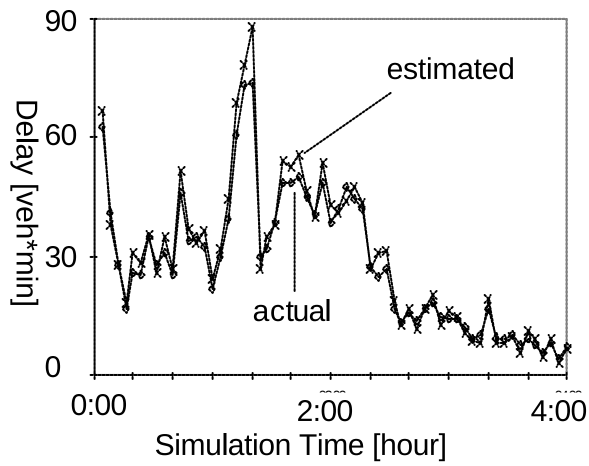

Figure 9 Actual Delay and Estimated Delay per Cycle against Time

4.2. Optimization Process

In order to assess the efficiency of the algorithm in realistic conditions (varying demand), we examine the proposed algorithm using the data shown in Table 1. The estimated total delay by implementing the optimization is found to be 28 hours, which is comparable to the result of the conventional programme selection control with four kinds of programs.

Time	arrival flows	(vehicles/ hour)
	phase 1	phase 2
0:00-0:30	984	1032
0:30-1:00	954	1270
1:00-1:30	922	1544
1:30-2:00	1032	1360
2:00-2:30	926	1106
2:30-3:00	914	904
3:00-3:30	812	742
3:30-4:00	730	534

Table 1 Traffic Demand

5. CONCLUSION

In this paper, some methods have been presented for controlling traffic signals by exclusive mean of intersection-crossing travel time information collected by roadside traffic beacons.

The results of computer simulation first indicate that it is possible to extract reliable information for signal control from the mere travel time information. The estimations of the normalized flows and delay proved in particular to be very satisfying. Then, using a quite simple algorithm, we were able to reach a better optimization (in terms of delay) than the well-established method of program selection control.

Those two results are very promising and suggest that, in addition to their current functions, beacons might be efficiently used for real-time traffic control purposes. But still, the research remains in its nascent age and much work and improvement are still to be done.

First, the algorithm has been tested in simulation only, and using a particular traffic configuration. Further simulation using different traffic configurations as well as a field test are now required to verify these preliminary results.

Second, the simulation should be extended to arterial control, so as to perform a simultaneous optimization of cycle, split and offset.

Third, we ought not to forget the initial scope of the study. Travel time could be used in many other ways. For instance, beacons could be efficiently combined with conventional detectors. Beacons could also be instrumental in network-wide signal control, for instance in helping balancing global travel time between competing routes throughout the network.

Anyway, in our opinion, future algorithms for signal control should allow for this new input that traffic beacons will probably provide in a near future.

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