# REAL TIME TRAFFIC SIGNAL OPTIMIZATION CONTROL METHOD IN URBAN AREAS

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**Abstract.** In this paper a new method for determining a phase split for signal-controlled intersections is proposed. The method considers as its objective, the minimization of the total delay time at the intersection, and deals with both non-congested and congested traffic conditions. Simulation results show that this approach is more effective than the conventional methods, in particular for heavy traffic congestion. Moreover, it is expected to have the possibility to be implemented in practice.

**Key Words.** Traffic Control; optimization

## 1. INTRODUCTION

In Japan, more than twenty years have passed since traffic control systems were first put into operation. Until recently, these systems have contributed greatly towards making vehicular traffic flow smoother, safer and more convenient. Traffic control systems are now commonly used throughout urban areas in japan.

However, in recent years, the environment of most traffic control systems has changed remarkably, and in particular, the ceaseless growth and concentration of population resulting in more vehicles in urban areas has caused a constant increase of traffic congestion. Meanwhile it has become more difficult to build new roads to handle this serious problem. The primary aim of traffic control research in Japan is to maintain the smoothness and safety of the traffic flow, and improve methods of traffic signal control.

In existing traffic control systems, the signal control methods are based upon a set of traffic-patterns, determining the basic control parameters, namely cycle length, split and offset, for an area coordinated to a Green Wave. The chosen patterns may change depending upon the time of day and the day of week, but the basic setting is typically fixed and difficult to change on-line. Furthermore it is difficult to analyze any given traffic situation accurately to determine which control pattern must be selected at what moment. In the first few years after a system starts operating, if traffic is predictable and the control areas are not too large, the initially defined patterns may be adequate, but as time passes, particularly in large cities, the number of vehicles increases and the control areas must therefore expanded rapidly. A new approach for controlling larger areas of junctions has become necessary.

As computer technology has developed remarkably and rapidly, it suggests the possibility of the realization of an intelligent traffic control system, because it is now possible for a signal controller to calculate the signal control parameters in real-time.

One of the signal control parameters of a crossing, the phase split is the most important variable: particularly at critical intersections where traffic congestion often occurs.

In this paper a new method of determining the phase split in real-time is proposed. There have been previous methods for determining the *phase split points*, but very few of them consider the objective of *minimization* of the *total delay time* of all vehicles crossing an intersection. Moreover, very few approaches seem to be suitable for both, non-congested and congested traffic flow. The approach presented here satisfies both conditions.

This paper deals with a way of calculating this split at a critical intersection, and proposes a new approach which succeeds to optimize the split on-line.

In order to evaluate the validity of the approach, an experiment has been carried out, using a microscopic traffic flow simulator which simulates the behavior of each vehicle every second. In the simulation experiment the method could decrease queue lengths at the intersection, compared to the result using the conventional methods which did not do that efficiently.

## 2. THE CONVENTIONAL METHODS

### 2.1. The Pattern Selection Method

In today's traffic control systems in Japan, a pattern selection method has been developed by determining the signal control parameters for each control area or intersection in advance. The actual plan has to be determined by comparing pre-defined parameter plans with the actual traffic conditions. The split, which is the most important parameter of critical intersections, is classified into seven patterns according to the ratio of traffic indexes of the participating major and minor roads. The traffic index in the pattern selection method is defined by the following equation:

$$m_{ij} = \alpha \cdot q_{ij} + \beta \cdot o_{ij} \tag{1}$$

where

- $m_{ij}$ is the traffic index at approach $j$ in phase $i$,
- $q_{ij}$ is the traffic volume at approach $j$ in phase $i$,
- $o_{ij}$ is the time occupancy at approach $j$ in phase $i$,
- $\alpha$ and $\beta$ are weight coefficients.

The characteristics of the value $m_{ij}$ is that the more congested traffic becomes, the more its value increases, because the following principle applies:

As the traffic volume reaches its ceiling, the time occupancy becomes higher. By calculating these indexes for all approaches, the split pattern is determined according to Fig. 1:

In Fig. 1, the traffic index in phase $i$ is the maximum of the indexes of all approaches. However as a problem, this partly empirical index is not always suitable for heavy traffic conditions. Even if traffic congestion is continuing, light traffic patterns may be selected because the traffic volume crossing the intersection decreases.

Considering the above-mentioned, a method for calculating the split has been requested.

### 2.2. The Method Using the Degree of Saturation

For calculating phase splits of the intersections cyclic control, the most popular method for determining the optimum split ratio is Webster's method (Webster, 1958), in which the optimum green time for each phase is calculated in proportion to the critical degree of saturation in each phase.

For simplicity, consider a two-phased intersection where two roads cross. There are four approaches. Fig. 2 illustrates the intersection.

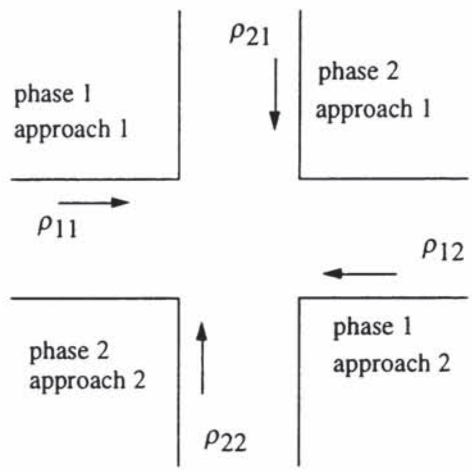


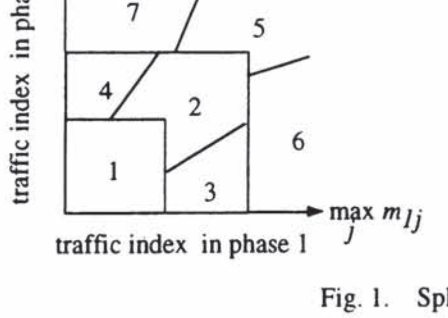

Fig. 2. Two-phase intersection

The degree of saturation in the phase of each approach road is expressed by the following equation:

$$\rho_{ij} = \frac{q_{ij}}{s_{ij}} \tag{2}$$

where

- $\rho_{ij}$ is the degree of saturation in approach $j$ and phase $i$,
- $q_{ij}$ is the traffic volume in approach $j$ and phase $i$,
- $s_{ij}$ is the traffic capacity in approach $j$ and phase $i$.




1 : light traffic pattern,
2 : equivallent pattern in middle traffic,
3 : phase 1 priority pattern in middle traffic,
4 : phase 2 priority pattern in middle traffic,
5 : equivallent pattern in heavy traffic,
6 : phase 1 priority pattern in heavy traffic,
7 : phase 2 priority pattern in heavy traffic.

Fig. 1. Split pattern selection diagram

Further, the degree of saturation in each phase is defined as the critical degree of saturation of two approaches, and it is expressed as follows:

$$\rho_i = \max_j \rho_{ij} \tag{3}$$

where $\rho_i$ is the degree of saturation in phase $i$.

In the conventional method, as shown by the following equation, the optimum split point is determined by the ratio of the degree of saturation in the phase:

$$\lambda_i = \frac{\rho_i}{\Sigma \rho_i} \tag{4}$$

where $\lambda_i$ is the optimum split in phase $i$.

Fig. 3 shows the relation between the degree of saturation and the split point of the two-phased intersection.

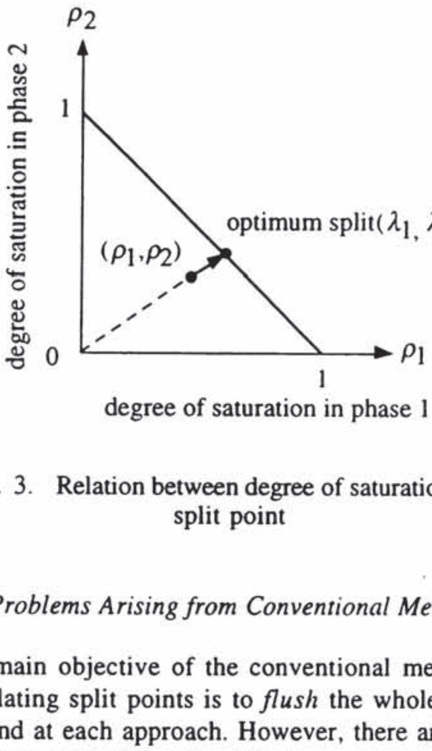



Fig. 3. Relation between degree of saturation and split point

*2.3. Problems Arising from Conventional Methods*

The main objective of the conventional method in calculating split points is to *flush* the whole traffic demand at each approach. However, there are some problems concerning this method:

- The first problem is that the determined split point is irrelevant to the traffic condition in the approach, when the degree of saturation is *not critical* according to the definition of the degree of saturation in the phase.
- Second; this method does not necessarily optimize the *traffic index*, for example: total delay time at all approaches to the intersection, because only the degree of saturation is considered.

Therefore, even if an optimum cycle length is used, the determined phase split point does not guarantee an optimum.

In order to overcome these problems, it is necessary to introduce the *traffic index* and to *optimize* it. In the following the new method for determining the optimum split point will be studied.

## 3. THE NEW APPROACH IN DETERMINING THE OPTIMUM SPLIT

*3.1. Introducing Delay Time*

In this paper, the total delay time for all approach roads to the intersection is introduced as being the *traffic index*, and the optimum split point is determined by *minimizing* the *total delay time*.

One of the models, which properly represents the delay time of vehicles arriving at an intersection, is contained in Webster's formula (Webster, 1958), and it has emerged as the most quoted and most used. The following equation shows Webster's formula:

$$d_{ij}^{\mathrm{W}} = \frac{c(1-\lambda_i)^2}{2\left(1-\frac{q_{ij}}{s_{ij}}\right)} + \frac{\left(\frac{q_{ij}}{\lambda_i s_{ij}}\right)^2}{2q_{ij}\left(1-\frac{q_{ij}}{\lambda_i s_{ij}}\right)} - 0.65\left(\frac{c}{q_{ij}^2}\right)^{1/3}\left(\frac{q_{ij}}{\lambda_i s_{ij}}\right)^{(2+5\lambda_i)} \tag{5}$$

where

- $d_{ij}^{\mathrm{W}}$ is the delay time for approach $j$ in phase $i$,
- $\lambda_i$ is the split in phase $i$,
- $c$ is the cycle length.

The formula is a sum of three terms. The second term is added due to the random distribution of arrival times, and the third term is added as a correction term, based upon simulation results.

However, because the delay time $d_{ij}^{\mathrm{W}}$ for an approach road increases toward infinity when the traffic flow nears the saturation point, the formula is not suitable for saturated traffic conditions (see Fig. 4).

Since it is necessary to deal with the delay time occurring when the system changes from a non-saturated to a saturated traffic condition, the model quoted from TRANSYT-6 (Hurdle, 1984; Mc Shane *et al.*, 1990) is adopted in this paper. The equation for calculating the delay time for one approach in the model is as follows:

$$d_{ij} = \frac{1}{c}\left[\frac{1}{2}\left(1-\lambda_i\right) + \frac{15}{\lambda_i s_{ij}}\left\{\left(q_{ij} - \lambda_i s_{ij}\right) + \sqrt{\left(q_{ij} - \lambda_i s_{ij}\right)^2 + 240 q_{ij}}\right\}\right] \tag{6}$$

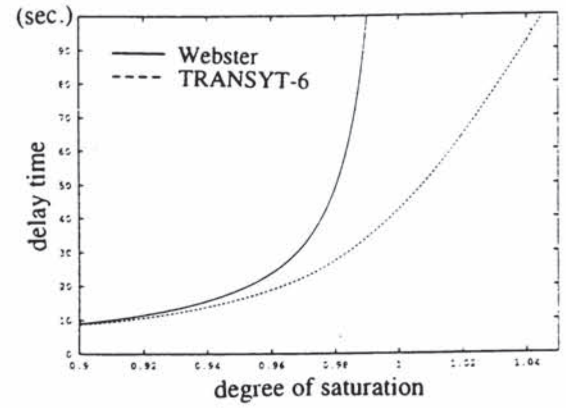



Fig. 4. Relation between delay time and degree of saturation

Fig. 4 illustrates the comparison of the delay time between Webster's formula and the TRANSYT-6 model, and Fig. 5 shows the general values for the delay time obtained by the TRANSYT-6 model. In Fig. 5 the delay time function of $d_{ij}$ is found to be *non-linear* and *convex*.

The total delay $D$ for an intersection can be expressed as follows:

$$D = \sum_i \sum_j d_{ij} \tag{7}$$

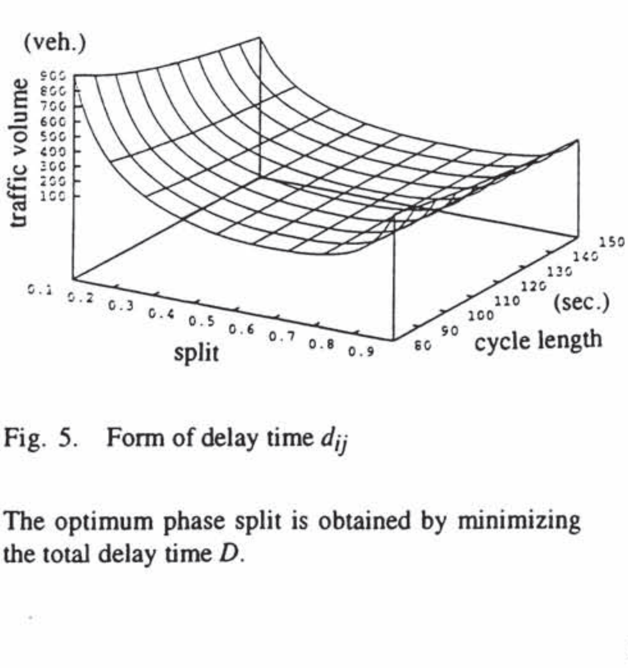



Fig. 5. Form of delay time $d_{ij}$

The optimum phase split is obtained by minimizing the total delay time $D$.

*3.2. Simulation Experiment*

*Contents of the experiment.* In order to evaluate the validity of the new approach, a simulation experiment was carried out, using a microscopic traffic flow simulator which can simulate the behavior of each vehicle every second. In this experiment, the new model and two other methods currently in use were studied, and split calculations from all three methods were carried out, using the simulation data. Then, the results were compared.

A critical intersection in the city of Yokohama, Japan, was used as the target intersection for the simulation. The traffic flow in the simulation was generated based upon field data during the morning (5:00 to 10:00 a.m.), around noon (11:00 to 14:00), and during the evening rush hour (16:00 to 19:00). The vehicle sensors used for the simulation process were placed at the points of 150m, 300m and 500m before the stop lines of the intersection, according to the actual standards of vehicle sensor allocation in Japan. Fig. 6 shows the layout of the simulated intersection.

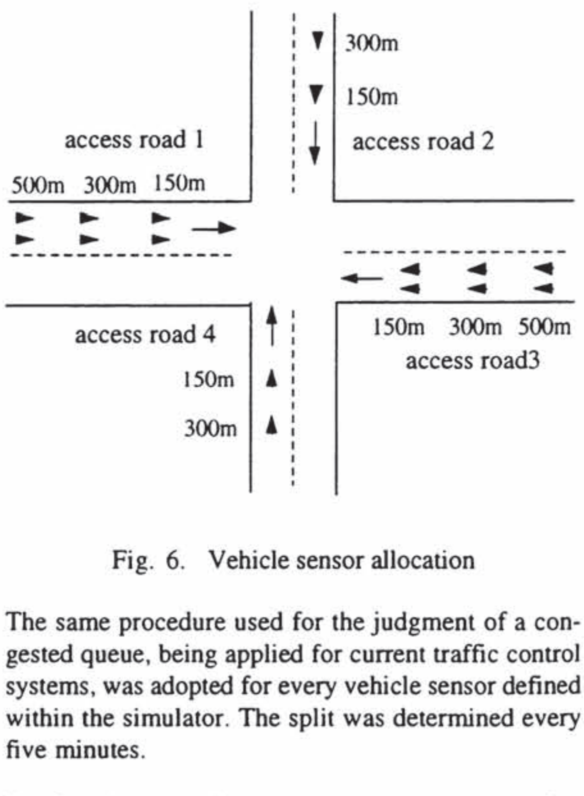



Fig. 6. Vehicle sensor allocation

The same procedure used for the judgment of a congested queue, being applied for current traffic control systems, was adopted for every vehicle sensor defined within the simulator. The split was determined every five minutes.

*Results of the simulation experiments.* As a performance index, the queue length measured at each approach was evaluated by the experiment. The results of the simulation experiments for the three ways of controlling the split point are shown in Fig. 7 and table 1. The three methods are the following:

- In the first method, the optimum split is calculated by minimizing the total delay time at an intersection. This method is described in this paper.

*Table 1 Queue lengths calculated by the simulation experiment*

| Time Period | Control Method | access road 1 | access road 2 | access road 3 | access road 4 | Total Queue Length |
|---|---|---|---|---|---|---|
| 5:00-10:00 | total delay time | 215m | 29m | 69m | 112m | 425m (100) |
| | degree of saturation | 273 | 27 | 104 | 181 | 582 (137) |
| | pattern selection | 265 | 25 | 100 | 137 | 527 (124) |
| 11:00-14:00 | total delay time | 96m | 29m | 55m | 44m | 224m (100) |
| | degree of saturation | 92 | 36 | 47 | 57 | 232 (104) |
| | pattern selection | 98 | 32 | 49 | 47 | 226 (101) |
| 16:00-19:00 | total delay time | 137m | 50m | 84m | 71m | 342m (100) |
| | degree of saturation | 207 | 70 | 101 | 79 | 457 (134) |
| | pattern selection | 172 | 70 | 95 | 73 | 410 (120) |

- Using the second method, the split point is obtained in proportion to the degree of saturation of the corresponding phase.
- The third method uses pattern selection, in which the split is not calculated directly but is selected from a previously calculated split plan, corresponding to the traffic situation.

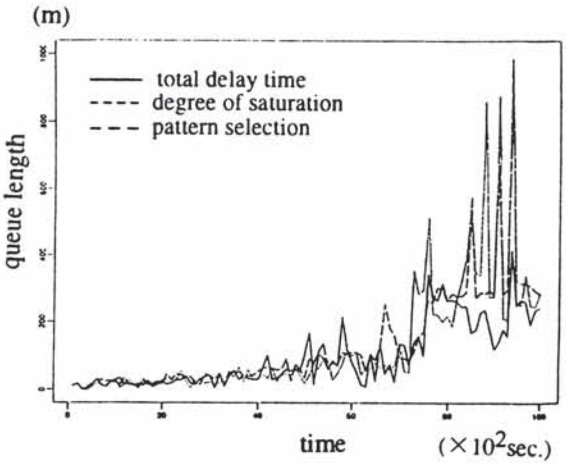



Fig. 7. Fluctuation of the queue length

From the simulation results, the following points became clear:

- The method of using total delay time as an objective in calculating the split points, can be claimed to be superior to other methods in heavy traffic conditions or conditions close to saturation. This can be seen best in approach roads 1, 3 and 4 during the morning, and in approach road 1 during evening rush-hour.
- At noon the differences are not so significant among the three methods, due to the lighter traffic which is encountered at noon.

On the whole, the new approach can be considered to be more effective than the two other methods. Therefore it can be expected to be advantageous when applied to the actual traffic situation in Japan.

## 4. CONCLUSIONS

In this paper, the problems of the current methods of determining a good phase split point were studied, and the proposed approach proved to be more effective than conventional methods. This has been shown by simulation experiments.

Based on these results, there are plans to continue various types of field experiments and to apply the proposed method in practice, to optimize the phase split at intersections with signals.

## 5. REFERENCES

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