

EXPERIMENT OF RIGHT-TURNER ACTUATED SIGNAL CONTROL STRATEGY USING IMAGE SENSOR

Norio Kiryu*¹ Seiji Itakura*¹ Teruyuki Tajima

Universal Traffic Management Society of Japan.

2-6, Ichigaya, Shinjuku-ku, Tokyo 162-0843, Japan

Tel: (81) 3 3235 6520 - Fax: (81) 3 3235 6522 - e-mail: kiryu@signal.co.jp

*1 Traffic Systems Engineering Department, The Nippon Signal Co., Ltd.

SUMMARY

The right-turner actuated signal control strategy using the information of the presence of right-turning vehicles on the stretch of approach has been proposed as a method of solving the problems in the conventional strategy using a spot sensor (ultrasonic type vehicle detector). An image processing vehicle detector was actually installed and the field experiments of the proposed strategy were performed. The purpose was to examine quantitatively the improvement of the control efficiency yielded from the new method as well as to clarify to what extent it is possible to solve the problems in the conventional actuation method. And hence the experiments were in the form of a comparison between the existing method and the new method. As the results it was found that all the problems in the existing method could be solved by the new method and that the increase in right-turn traffic capacity could be expected. The experiments were conducted as a part of the activities of the Universal Traffic Management Society of Japan (UTMS).

INTRODUCTION

The right-turner actuated signal control in Japan has conventionally been one in which the right-turn green arrow indication is controlled by judging the presence of traffic demand based on the gap (in time) between successive right-turning vehicles measured by a spot sensor above a right-turn lane. However, the right-turning demand is not necessarily expressed fully using only the time interval between the vehicles directly below such a spot sensor, and sometimes there are cases when the green indication is not being made for the appropriate period due to the generation of misleading information. In order to solve this problem, the UTMS in Japan has been taking the initiative in developing image processing vehicle detectors for grasping the traffic demand spatially. UTMS has also been carrying out the development of a signal control strategy using image processing vehicle detectors with a view to advancing the Japanese UTCS named MODERATO (Management by Origin-DEstination Related Adaptation for Traffic Optimization).

In view of these conditions, since the technology of image processing vehicle detectors has already reached a practically usable level, it was applied to a right-turn vehicle actuated signal control strategy and the field evaluation was carried out.

PROBLEMS IN THE EXISTING CONTROL STRATEGY

In the existing method of right-turner actuated signal control a spot sensor is installed at a point about 30m behind the stop line on the approach to a signal and the gaps between the successive vehicles are

measured to determine whether to extend or terminate the right-turn green arrow indication. Its key control variables include minimum green, unit extension and maximum green. Because of the values of these variables are fixed once the control is in operation it is very difficult to highly respond to fluctuation in actual traffic flow. If the minimum green is set as a substantially long period, there will be frequent occurrences of wasted green periods under conditions of no right-turn demand. On the other hand, if this period is set very short, there will be too frequent occurrences of queue left over. Further, depending on the setting of the unit extension period, slow vehicles will find it hard to clear the stop line, but on the other hand, there is the likelihood of generation of wasted green periods when fast vehicles pass the spot sensor.

In addition, another problem in the existing method is that the detection area may by chance happen to lie between vehicles in a stationery queue, because of which there will be no detection of vehicles thereby causing the green to be terminated prematurely.

EXPERIMENTS

Test Site

The location of the experiments selected was the Kamegaya intersection, which is an intersection between a 4-lane street (National Highway No. 463) and a two-lane street in the suburbs of Tokorozawa City, Saitama Prefecture. At this intersection, 3-phase signal control is in operation including right-turn vehicle actuated control on the major street. An extremely large number of right-turning vehicles turn up on the south-bound approach, and the straight lane gets blocked due to spillback of right-turning vehicles at the entrance point of the 100m-long right-turn lane even from early morning hours. This right-turning traffic was the target of the experiments. The right-turning traffic volume on the opposite side is minuscule.

Tested Control Strategies and Test Programs

Comparison experiments were conducted between the existing right-turn vehicle actuated signal control strategies using ultrasonic spot sensor and the newly developed strategy using image processing vehicle detector.

The existing method of control uses an ultrasonic detector placed at a point 23m behind the stop line on the approach, and the set values of the control parameters were as shown in Table 1.

In the new strategy with image processing vehicle detector, the right-turn green arrow signal continues to be indicated as long as the presence of right-turning vehicles is being detected. Therefore, although there is no need for the minimum green concept, a minimum green period of three seconds was set considering the safety of the right-turning vehicles in the opposite side. Further, because of employing the existing signal controller, a unit extension was provided being equal to the minimum number of seconds (0.1 second) that can be set.

Installation of Image Processing Vehicle Detector

With the intention of spreading this method at a low cost, an image processing vehicle detector was installed on an arm on the existing signal pole (installation height: 6m). The green extension occurrence rate (the rate at which the vehicles trailing in the right-turn lane are given the green signal) at a specific degree of saturation is influenced by the set value of the unit extension in the case of control with spot sensor. On the other hand it is governed substantially by the length of the detection zone in the case of control with image processing vehicle detectors. In comparing the two methods the generation of a state of equilibration in the green extension occurrence rate for the saturated demand in both methods is an

important prerequisite. Hence the length of the image processing vehicle detection zone was determined according to the procedure described below.

Green Extension Occurrence Rate in the Existing Method

Since the saturated demand condition existed over almost the entire period during the experiments with the existing control strategy, we determined the rate of green extension occurrence due to queuing vehicles from the observed data according to the following equation. The results are shown in Table 2.

$$p = \frac{A}{A + B}$$

Where,

p :Green extension occurrence rate due to queuing vehicles

A :Number of times that queuing vehicles generated the green extensions

B :Number of times that green extensions could not be generated in spite of the existence of queuing vehicles

| Control strategy | Dates and time slots of experiments | | Control parameters | | |
|------------------|-------------------------------------|---|--------------------|----------------|----------------------------|
| | Date | Time slots | Minimum green | Unit extension | Maximum green |
| Existing | November 18th (Thursday) | 06:00Hrs ~ 08:00Hrs 08:30Hrs ~ 10:30Hrs 11:30Hrs ~ 13:30Hrs | 5 seconds | 3 seconds | Proportional to flow ratio |
| | November 19th (Friday) | 06:00Hrs ~ 08:00Hrs 08:30Hrs ~ 10:30Hrs 11:30Hrs ~ 13:30Hrs | 5 seconds | 4 seconds | The same as the above |
| Proposed | February 3rd (Thursday) | 06:20Hrs ~ 08:00Hrs 08:30Hrs ~ 10:30Hrs 11:30Hrs ~ 13:30Hrs | 3 seconds | 0.1 second | The same as the above |
| | February 4th (Friday) | 06:00Hrs ~ 08:00Hrs 08:30Hrs ~ 10:30Hrs 11:30Hrs ~ 13:30Hrs | 3 seconds | 0.1 second | The same as the above |

Table 1 Experimental program

| Date of experiment | Green extension occurrence rate (%) |
|---|-------------------------------------|
| November 18th (unit extension: 3 seconds) | 94.61 |
| November 19th (unit extension: 4 seconds) | 98.07 |

Table 2 Green extension occurrence rate during experiments with the existing control strategy.

Estimation of Probability of Green Extension Occurrence When Using Image Processing Vehicle Detector

As is shown in Fig.1, in the case of the control method with image processing vehicle detector, the detection of Vehicle A traveling at a speed of v (m/s) is taken to have started at the instant 0 and to have

ended at the instant d . If the detection zone length is taken as L (m) and the vehicle length is taken as l (m), the detection time duration d (s) can be expressed by the following equation.

$$d = \frac{L+l}{V} \quad \text{Eqn.1}$$

In this case, a green period equal to the detection time duration (d) is given for Vehicle A that is traveling through the detection zone. Further, when the time headway h between the preceding Vehicle A and the following Vehicle B is less than or equal to d ($h \leq d$), a green extension occurs for Vehicle B, but the green will be terminated otherwise. As a result, the green extension occurrence rate $P(e_a)$ for the vehicle following Vehicle A can be expressed by the following equation when the detection time duration of Vehicle A is d_a .

$$p(e_a) = p(h \leq d_a) \quad \text{Eqn.2}$$

Further, since the vehicle speed v is a probabilistic variable, if we take its probability density function as $p(v)$, in general, the green extension occurrence rate $P(e)$ can be expressed by the following equation from Eqn. 1 and Eqn. 2.

$$P(e) = \int P\left(h \leq \frac{L+l}{v}\right) \cdot p(v)dv \approx \sum_v \left[P\left(h \leq \frac{L+l}{v}\right) \cdot P(v, v + \Delta v) \right] \quad \text{Eqn.3}$$

Determination of the Detection Zone Length

For the detection zone length L of 10m, 15m, 20m, 25m, 30m and 35m and for the vehicle length l of 6m, 6.5m and 7m, the probability of green extension occurrence was calculated by the approximation equation of Eqn. 3 with the observed data for the existing control on November 19th. The results of these estimates are shown in Fig. 2.

According to Table 2, the green extension occurrence rate in the existing method for a unit extension of three seconds is lower than that for a unit extension of four seconds, and hence it is evidently preferable to set the unit extension as four seconds. In order to guarantee a green extension occurrence rate (98.07% according to Table 2) corresponding to this case, the length of the image processing detection zone was decided to be 30m in view of the feature shown in Fig. 2. Since the image processing vehicle detector was installed on the signal pole close to the stop line, the downstream end position of the detection zone was taken to be right above the stop line. (Fig. 3)

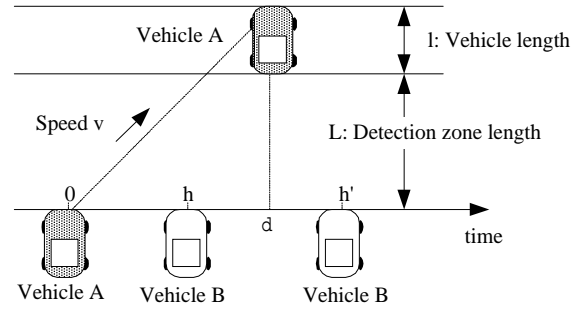


Fig.1 Detection duration when using the image sensor method.

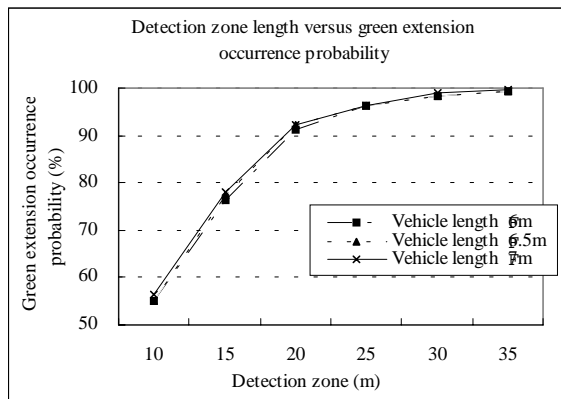


Fig.2 Computed values of the probability of green extension occurrence for different detection zone lengths.

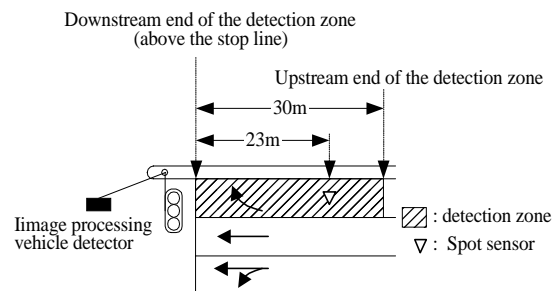


Fig. 3 Detection zone of the image sensor

EVALUATION

Evaluation of the Green Extension Operation

The period g during which the right-turn green arrow indication is being made is classified into the three cases of - $g =$ minimum green period, minimum green period $< g <$ maximum green period, and $g =$ maximum green period. And for each case the situations at the end of green were counted out with regard to the existence of right-turn queue left over. The results are shown in Table 3 where the figures mean the number of cycles. It is clear that the number of cycles in which right-turning queues were not released completely is far less in the image processing vehicle detector method compared to the existing method in the two cases of $g =$ minimum green period and minimum green period $< g <$ maximum green period.

| Date of experiments | | Condition of right-turn green arrow indication and existence of queue left over | | | | | |
|---------------------|--|---|----------------------|---|----------------------|-------------------------|----------------------|
| | | Minimum green period | | Minimum green period ~ maximum green period | | Maximum green period | |
| | | Without Queue left over | With Queue left over | Without Queue left over | With Queue left over | Without Queue left over | With Queue left over |
| Existing | November 18th (unit extension : 3 seconds) | 3 (2.0) | 15 (9.9) | 18 (11.9) | 40 (26.5) | 11 (7.3) | 64 (42.4) |
| | November 19th (unit extension : 4 seconds) | 2 (1.3) | 10 (6.5) | 12 (7.9) | 10 (6.5) | 15 (9.8) | 104 (68.0) |
| Proposed | February 3rd, 4th | 4 (1.4) | 0 (0) | 90 (32.3) | 5 (1.8) | 56 (20.1) | 124 (44.4) |

Unit: Number of cycles Constituent rate in parentheses (%)

Table 3 Condition of right-turn green arrow indication and existence of queue left over

The examination of the cause of faulty queue release in cases other than that of maximum green duration revealed that all were those cited above as the problems in the existing method. A big difference in the number of failure cycles between the result on November 18th and November 19th demonstrates that the set value of the unit extension exerts a great influence on the control performance. During the experiments with the image-processing vehicle detectors there were five failure cycles in the case of minimum green period $< g <$ maximum green period. In one of them it was not possible to detect an ordinary vehicle trailing behind a large-sized vehicle and in the other four cycles there were no queues remaining in the detection zone. The reason for the former case is that the image processing camera height was low being only 6m, and this type of problems will not occur if the camera height is made about 10m.

From the above discussions, it can be said that it is possible to clear all the problems in the existing control strategy if the proposed strategy with image processing vehicle detector is employed.

Definition of Demand Function Index and Service Function Index

The saturation flow rate can be one of the MOEs (Measures of Effectiveness) in evaluating the saturated flow. Also, it is possible to evaluate the undersaturated condition by investigating the relationship between the traffic volume and the delay. In this experiment, however, since the saturated condition and the undersaturated condition are randomly intermixed, it is difficult to evaluate the flow using normal MOE. This is because the demand function and the service function take on complex

forms, as shown in Fig. 4. In view of this, the indexes that can quantitatively express the demand function and the service function were defined here as described below.

Referring to Figs. 4(a) and (b), it is self-evident that the difference between the area of the part enclosed by the demand function curve OA and the lines OT and AT and the area of the part enclosed by the service function

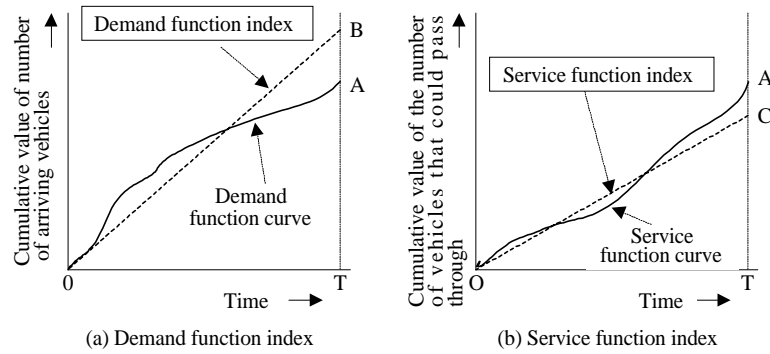


Fig.4 Conceptual diagram of the demand function index and the service function index.

curve OA and the lines OT and AT expresses the total delay. From this fact, it is possible to consider that the gradient of the side OB of the triangle OBT with an area equal to the area under the demand function curve indicates the magnitude of the demand. In the same way the gradient of the side OC of the triangle OCT with an area equal to the area under the service function curve can be considered to indicate the size of the handling capacity realized corresponding to the demand at that time. The former parameter can be called the demand function index and the latter can be called the service function index.

In actuality, the service function is obtained from the cumulative value of the number of vehicles that could pass through, and the demand function is obtained by adding to the service function the length of queue at each instant of time.

Analysis of Delay

It is noticed that there is no correlation between the value of the demand function index and the average delay per vehicle in queue obtained from the observed data at one minute intervals as is shown in Fig. 5.

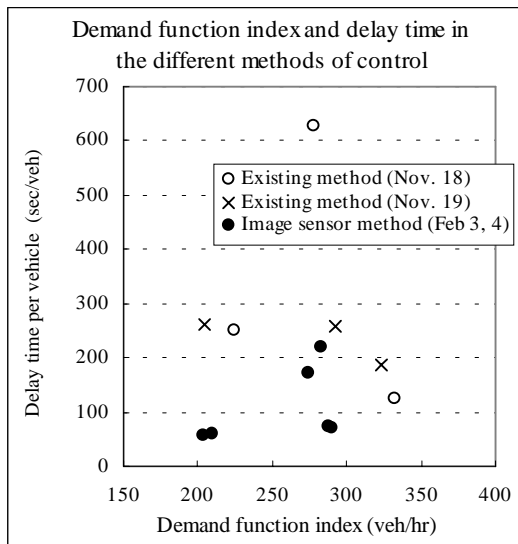


Fig. 5 Delay per vehicle in queue versus demand function index for the different control strategies

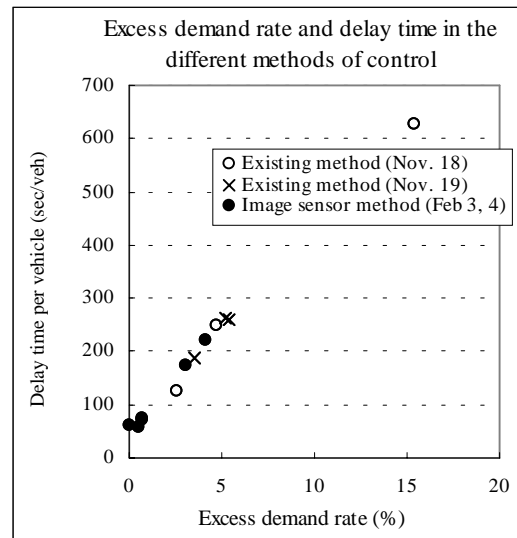


Fig. 6 Delay per vehicle in queue versus excess demand rate for the different control strategies

On the other hand, let's define $[100(\text{Demand function index value} - \text{Service function index value}) / \text{Service function index value}]$ as the excess demand rate and see its relationship with the average delay per vehicle in queue. A very marked correlation is seen between the two parameters as is shown in Fig. 6. This implies that the delay observed during these experiments is affected substantially not only by the demand function index but also by the service function index.

Comprehensive Evaluation Related to Right-turn Handling Capacity

The relationships between the demand function index value and the service function index value for the different control strategies are shown in Fig. 7. In this figure the regression line for the control strategy with image processing vehicle detector lies above those for the existing strategy. This implies that the right-turn handling capacity is higher in the former than in the latter.

In order to grasp quantitatively the difference in the handling capacity, the values of service function index for demand function index values of 200 and 300 veh/hr were determined respectively by the regression equations. (Table 4).

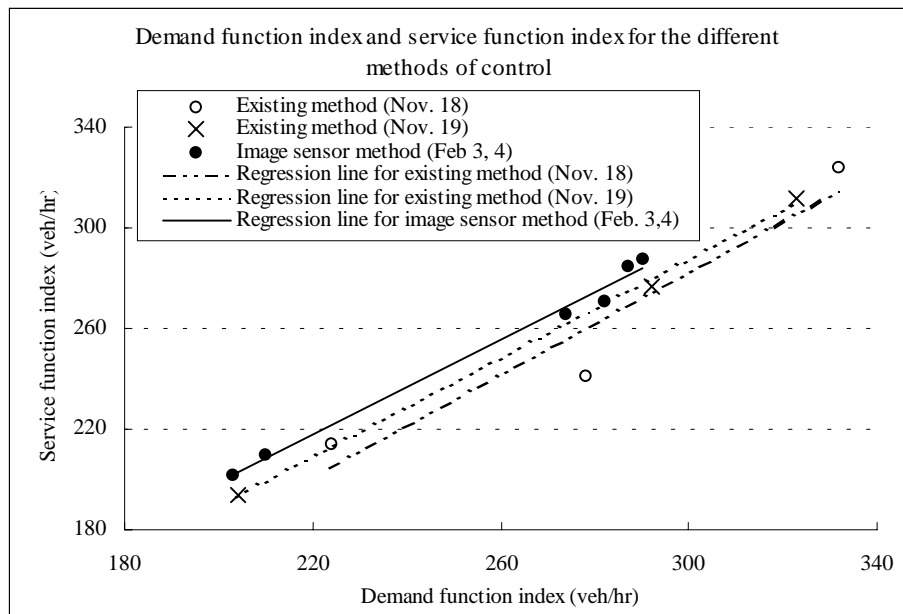


Fig. 7 Relationship between the demand function index and the service function index for the different control strategies

| Control strategy | Experiment date | Demand function index | |
|------------------|--|-----------------------------------|-----------------------------------|
| | | 200 veh/hr | 300 veh/hr |
| Existing | November 18th (A) (unit extension: 3 seconds) | 180.2 | 282.0 |
| | November 19th (B) (unit extension: 4 seconds) | 189.4 (B/A=1.05) | 287.5 (B/A=1.02) |
| Proposed | February 3rd, 4th (C) | 199.4 (C/B=1.05) (C/A=1.11) | 293.5 (C/B=1.02) (C/A=1.04) |

Unit: veh/hr

Table 4 Estimated values of the service function index for the different control strategies

From Table 4 it is seen that the handling capacity of the proposed control strategy with a image processing vehicle detector is higher by two to five percent compared to the existing scheme used on November 19th. And it is higher by four to eleven percent compared to the existing scheme employed on November 18th. For the existing strategy the capacity with a unit extension of four seconds is higher by two to five percent than that with a unit extension of three seconds.

CONCLUSIONS

The traffic demand is not always grasped completely in the conventional pulse mode actuation based only on the measurement of the vehicular arrival time at a spot. With the purpose of solving this problem, the right-turn vehicle actuated control strategy that employs the information of the presence of vehicles on the stretch of approach provided by an image processing vehicle detector was developed and the field experiments were carried out.

The results of the experiments demonstrated the following points:

- a) Using the new control strategy based on an image processing vehicle detector, it is possible to solve all the problems caused by the generation of misleading information in the conventional small area pulse-mode strategy. Consequently the rate of occurrence of premature termination of the green arrow for the right-turn queue was reduced greatly from 23 percent to only two percent.
- b) The handling capacity for the right-turn demand during the experiments increased by two to five percent with the proposed strategy. These values cannot be ignored considering a great adverse effect of the right-turning traffic on the critical intersection performance.
- c) Because of the relationship between the height of installation of the image processing camera and the vehicle height, there was a rare case of the vehicle presence information not being complete. The further study should be made to clear up this problem.

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