EXPERIMENT OF RIGHT-TURN VEHICLE ACTUATION METHOD USING THE PRESENCE WITHIN A ZONE (II)

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INTRODUCTION

Japan employs left-hand traffic as in UK, while the USA and many other countries employ right-hand traffic. As a result, control of traffic lights on right-turn lanes is as important as signal control algorithm determining such parameters as cycle length, split, and offset. Mismanagement of right-turn vehicles will aggravate traffic congestion.

In Japan, a right-turn vehicle actuation method is successfully implemented as a part of MODERATO, Management by Origin-DEstination Related Adaptation for Traffic Optimization. In the conventional method, appropriate green time is calculated based on right-tern demand detected with a spot sensor.

However, traffic information under a spot sensor, whether or not a vehicle exists, may not be sufficient to derive appropriate green time depending on traffic demand. In consideration of this, a research group led by the UTMS, Universal Traffic Management Society of Japan, developed an image detector, which was able to detect vehicle presence in a designated area, and a right-turn vehicle actuation method that used the detector ("last year's method"). A field experiment confirmed that this method smoothed traffic and solved the problem of the current spot-sensor-based right-turn vehicle actuation method ("conventional method"), as presented at the World Congress last year.

Based on last year's method, we have further developed a control method that skips yellow light if no vehicles are likely to pass the stop line if it comes on after a green right-turn arrow signal, to enable even smoother traffic. To confirm the effects of this new control system, we performed a field experiment, collecting and analyzing data for evaluation of smooth traffic and right-turn traffic behavior.

OVERVIEW OF THE DEVELOPED METHOD

POSITIONING OF THE DEVELOPED CONTROL METHOD

Japan uses a traffic-signal control method called MODERATO to ensure smooth, safe traffic. The MODERATO consists of macro control, which determines control parameters (cycle length, split and offset) according to traffic demand, and responsive micro control, which finely adjusts the duration of each step (in seconds), determined based on the parameters, according to fluctuation in vehicle traffic. The right-turn vehicle actuation method is a typical responsive micro-control method. This method, conventionally using a spot sensor, is installed at most of the important intersections in Japan. The method we presented last year was developed by improving this conventional method. This year's method can be positioned as a more sophisticated version of the right-turn vehicle actuation method developed last year.

LAST YEAR'S METHOD

The right-turn vehicle actuation method developed last year keeps the green right-turn arrow signal on while vehicles make a right-hand turn, and turns it off when there are no more right-turn vehicles, based on the information of vehicle presence in the area ("detection area") monitored by an image detector. The image detector detects right-turn vehicles existing before the stop line, and enables the green right-turn arrow signal to come off as soon as the vehicle at the tail of the row passes the stop line, using the green right-turn arrow signal efficiently (Fig. 1). The method thus saves the useless time of the green right-turn arrow signal, smoothing right-turn traffic, while at the same time solving the problem of the conventional right-turn vehicle actuation method that uses a spot sensor. For more details on the effects of the method we presented last year, please refer to the Proceedings of last year's ITS.

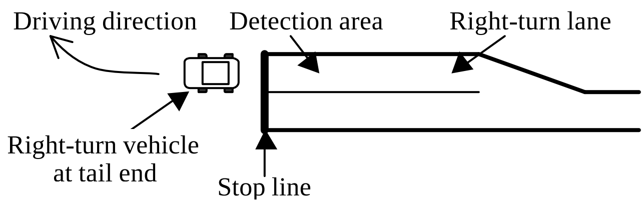


Fig. 1. Last Year's Method

DEVELOPED METHOD

The method presented last year was developed concerning the period during which the green right-turn arrow signal was indicated uselessly in the conventional right-turn vehicle actuation method. It succeeded in saving such period by means of an image detector. In the method we present this year, our focus is placed on the yellow light turned on after a green right-turn arrow signal comes off. We developed a control method that skips the yellow light when there are no right-turn vehicles. This development is expected to smooth traffic further, added to the method presented last year. This thesis calls this development "yellow light-skipping control."

Yellow Light-Skipping Control

In Japan, most of the intersection traffic signals that have a green right-turn arrow signal indicate yellow light after the arrow signal, and then switch to red light. Like the yellow light turned on after green light, the yellow light turned on after the arrow signal provides vehicles with time to pass the stop line when the signal changes as they are about to enter the intersection. However, if there are no such vehicles, the yellow light is of no use, and can be skipped. By diverting the time saved by this skipping (even if it is a few seconds) to the duration of green signal for other critical traffic flow, the throughput of the flow improves, alleviating congestion. This method is expected to provide even greater effects, because it reduces the duration of yellow-signal, which may be time loss in each cycle.

This yellow light-skipping control decides whether yellow light can be skipped or not based on the findings of an image detector. If the detector finds any right-turn vehicles in a designated area when the green right-turn arrow signal comes off, they are judged to be unable to stop at the stop line, turning on yellow light. If no right-turn vehicles are found in the designated area when the arrow signal comes off, the yellow light is skipped, allowing the traffic signal to turn on red light immediately after the arrow signal (Fig. 2 [i]). If any right-turn vehicle is found in the detection area, yellow light comes on after the arrow signal, and then red light comes on (Fig. 2 [ii]). When the signal changes from the green right-turn arrow signal to red light directly, those right-turn vehicles that have not entered the detection area can stop at the stop line safely, as indicated by the red light.

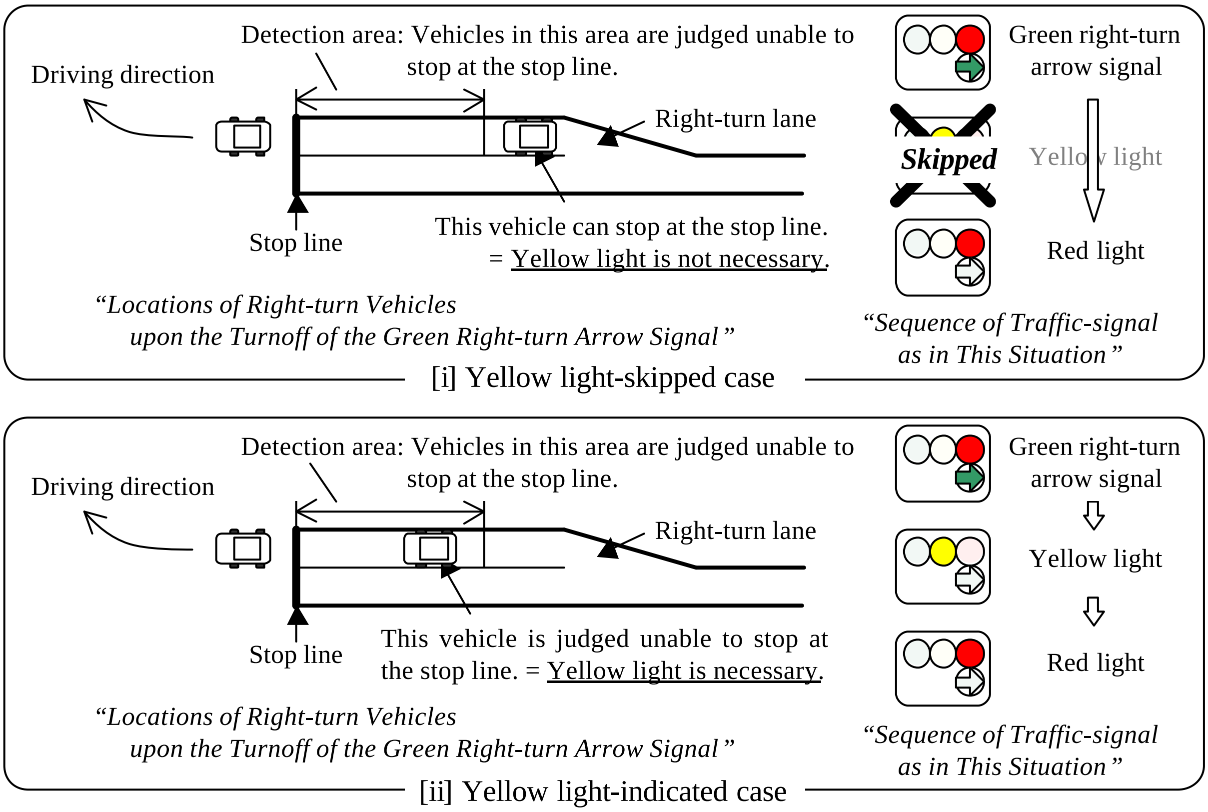


Fig. 2. Yellow light-skipping Control

Right-Turn Vehicle Detection Area

The area in which right-turn vehicles are detected (the area monitored by the image detector) is determined based on yellow-light skipping conditions. As mentioned above, right-turn vehicles in the area cannot stop at the stop line upon the turnoff of the green right-turn arrow signal. Whether a right-turn vehicle can stop at the stop line or not is determined depending on the distance it requires to stop (stopping distance), which varies depending on its approaching speed upon the turnoff of the arrow signal, as well as the distance between the vehicle and the stop line. If the stopping distance is shorter than the distance between the vehicle and stop line, the vehicle can stop at the line; otherwise it cannot stop. Generally, the relationship between the approaching speed upon the turnoff of the green right-turn arrow signal (switching of the signal) and stopping distance can be expressed by Eq. 1 below:

$$L = \tau V + \frac{V^2}{2d} \qquad \text{Eq.1}$$

where,

L : Stopping distance

τ : Driver's response time

(Delay time between switching of the signal and the start of braking-force application)

V : Vehicle's approaching speed upon the turnoff of the signal

d : Average deceleration after the start of braking-force application until vehicle stoppage

In this method, the detection area was established uniquely based on the stopping distance required for a right-turn vehicle approaching to the intersection at the highest speed in the right-turn lane, instead of adjusting the detection area according to the stopping distance obtained by Eq. 1 based on the approaching speed of individual right-turn vehicles. This is intended to ensure safety by making it possible to determine whether the right-turn vehicle approaching at the highest speed, which requires the longest stopping distance, can stop, even if right-turn vehicles enter the right-turn lane one after another at different approaching speeds, thus ensuring safety.

FIELD EXPERIMENT

EXPERIMENT LOCATION

We decided to perform a field experiment at the intersection that served as the entrance to Kanuma Kaido on Utsunomiya Orbital Road, in Utsunomiya City, Tochigi Prefecture. This was because the intersection had constantly fluctuating right-turn demand during peak hours and because it was a bottleneck intersection with excessive demand of vehicles driving straight ahead. This intersection is a critical one where major prefectural roads cross each other. During morning peak hours, traffic congestion of 300 to 500 meters is generated on the trunk road running from north to south. The yellow light-skipping control was provided for the right-turn lanes of the individual major roads (length of right-turn lane: approximately 30 m for north-headed vehicles and approximately 90 m for south-headed vehicles).

EXPERIMENT METHODS AND CONDITIONS

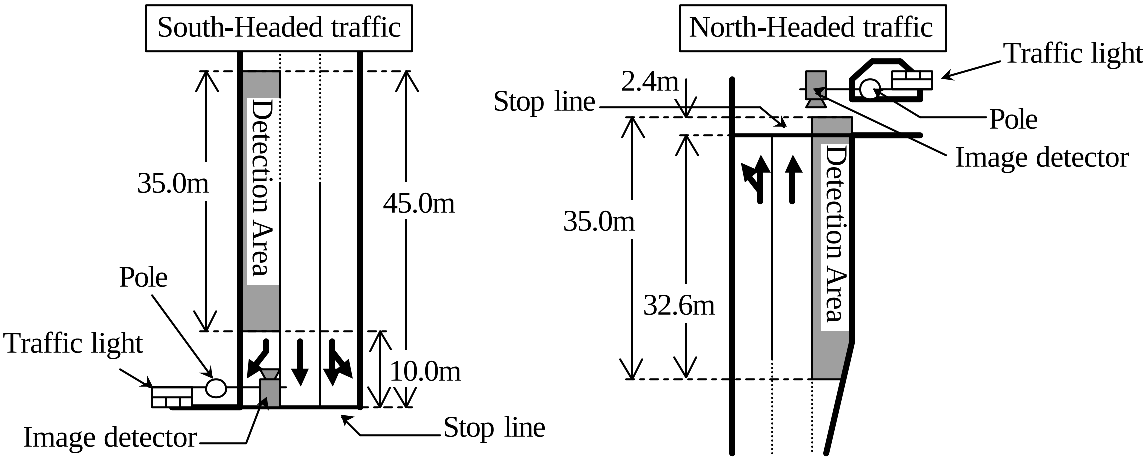
The purpose of this experiment was to confirm based on field data that the yellow light-skipping control smoothed traffic as expected without influencing right-turn traffic flow. We collected the data of traffic without the yellow light-skipping control ("before" research) and of traffic with the yellow light-skipping control ("after" research). Experiment conditions other than the yellow light-skipping control were the same (Table 1).

Table 1. Control Methods and Conditions Used in the Experiment

Research	Control Method	Date	Monitored hours	Parameters in green right-turn arrow signal
"Before" research	Right-turn vehicle actuation method using an image detector	11/15(Wed) 11/16(Thu)	07:00-09:00 09:30-11:30	• Minimum green time: 5 seconds • Extension of green time: 0.1 second • Yellow-time after: 3 seconds
"After" research	Right-turn vehicle actuation method using an image detector and <u>yellow light-skipping control</u>	11/22(Wed) 11/24(Fri)		

DETECTION AREA

The detection area was determined based on the data of the maximum approaching speed of vehicles in the right-turn lane, which was obtained before the experiment, as well as on the installation position of the image detector (Fig. 3). The image detector was installed on an existing pole for traffic lights to enable low-cost introduction of this system. It was installed six meters high.



Direction	Maximum approaching speed	Stopping distance[*1]
North-headed vehicle	40 km/h	28.4 m
South-headed vehicle	52 km/h	44.9 m

[*1] Conditions for estimation of stopping distance:
- Driver's reaction time: 0.7 second
- Average deceleration: 3 m/s^2
  = The critical deceleration for the driver to decide to enter the intersection or not upon the turnoff of the signal.

Fig. 3. Detection Area

EVALUATION

SKIPPING OF YELLOW LIGHT

We counted the signal cycles in which the yellow light was skipped during the experiment. As a result, it was skipped in 33% to 42% of the cycles during morning peak hours (7:00 to 9:00), and 62% to 73% during off-peak hours (9:30 to 11:30).

Table 2. Status of Yellow light-skipped Cycles

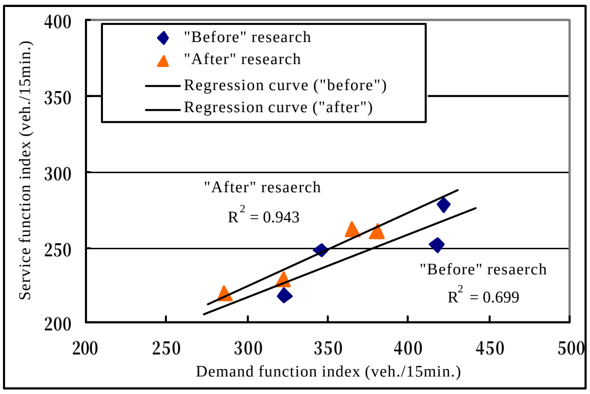
Hours	Checked item / Date	"Before" Wed., Nov. 15	"Before" Thu., Nov. 16	"After" Wed., Nov. 22	"After" Fri., Nov. 24
07:00-09:00	Cycle count	51	51	52	51
	Count of yellow light-skipped cycles	-	-	22 (42.3%)	17 (33.3%)
09:30-11:30	Cycle count	51	52	51	52
	Count of yellow light-skipped cycles	-	-	37 (72.5%)	32 (61.5%)

* The percentage of yellow light-skipped cycles is shown in parentheses.

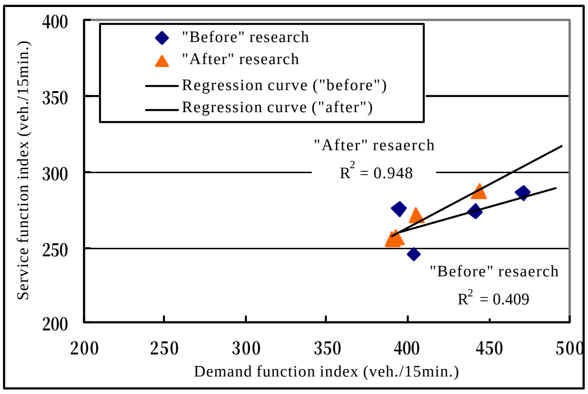
EVALUATION OF TRAFFIC-SMOOTHING EFFECTS

Comparative Evaluation of Throughput

The throughput varies depending on the demand, and should be evaluated in terms of a specific amount of demand instead of by direct comparison. Because demand and throughput have time-based variation, we represented both in indexes by aggregating the data obtained during periods of an equal length (15 minutes; we decided to use the data obtained during the congested-traffic hour of 7:30 to 8:30, during which the effects of the yellow light-skipping control were expected, and quartered the hour). Using the same method as last year's, we calculated the "service function indexes" that represent throughput and "demand function indexes" that represent traffic demand. We identified the relationship between the indexes for the individual control methods (Fig. 4).



[North-headed vehicle]



[South-headed vehicle]

Fig. 4. Relationship between Demand Function Indexes and Service Function Indexes

Fig. 4 shows that, for both north-headed vehicles and south-headed vehicles, the regression curve in the "after" research (with the yellow light-skipping control) is higher than that in the "before" research (without the control), indicating that throughput for an equal amount of demand is higher when the control is used. To present this finding quantitatively, we estimated the service function indexes in reference to the average value of demand function indexes for each driving direction based on the regression curves, and compared the obtained values as representing the throughput of the individual control methods. As a result, it was made clear that throughput was approximately 2% to 5% higher when the yellow light-skipping control was used (Table 3).

Table 3. Comparison in Throughput

Direction	Average of demand function index	Without yellow light-skipping control	With yellow light-skipping control	Improvement rate (%)
North-headed vehicle	357.77	240.89	251.93	4.6
South-headed vehicle	418.21	266.73	273.12	2.4

* Unit: veh. / 15 min.

Comparative Evaluation of Traffic Delay

For the individual control methods, we compared the average delay of the individual vehicles.

The average delay is subject to traffic demand in addition to the throughput discussed previously, we test-calculated the average delay for the individual control methods under an equal traffic demand (data obtained in the "after" research was used). Regarding the control with yellow-light skipping, we calculated the average delay based on the directly obtained data such as the number of vehicles that passed the stop line and the queue lengths. Regarding the control without yellow-light skipping, we calculated the average delay based on the difference between the number of vehicles that passed the stop line under the yellow light-skipping control and the number of vehicles that passed the stop line during the period diverted from the time saved by skipping yellow light, along with the queue lengths in consideration of its increase due to reduction in the number of vehicles that passed the stop line. The result showed that, the average delay time was cut 13% to 15%, depending on how often yellow light was skipped (Table 4).

Table 4. Comparison of the Average Delay

Direction	Without yellow light-skipping control	With yellow light-skipping control	Reduced delay (sec.)	Reduction rate (%)
North-headed veh.	354.3	302.7	51.6	14.6
South-headed veh.	416.1	362.8	53.3	12.8

* Unit: sec.

EVALUATION OF INFLUENCE ON RIGHT-TURN VEHICLES

To confirm that this yellow light-skipping control does not influence right-turn vehicles, we examined how vehicle behavior and driving conditions might differ regarding the below-listed specific behaviors and situation. The findings are summarized in Table 5:

a) Vehicles enter the intersection in spite of red light at a high speed from a position before the detection area.
b) To stop at the stop line, the driver is enforced to apply hard braking.
c) The driver cannot decide to stop at or pass the stop line easily due to the distance between the vehicle and stop line and to the approaching speed (a "dilemma condition").

As Table 5 shows, the yellow light-skipping control had no effect on the danger-increasing behavior or environmental change for all the research subjects. Furthermore, when the control is used, no vehicle had trouble for whether it should stop or pass (and no vehicle entered the intersection at high speed), indicating that the control improves the safety of right-turn traffic.

CONCLUSION

In this research we conducted a field experiment on the yellow light-skipping control that saves unnecessary yellow-light and diverts the time to critical traffic flow, and checked the smoothing effects and influence on right-turn traffic based on the collected data. The experiment confirmed that the throughput improves approximately 2% to 5% as a smoothing effect. Though depending on how often yellow light is skipped, the average delay time is reduced approximately 13% to 15%.

If yellow light is skipped, no vehicle entered the intersection when the signal was red. Under no conditions the drivers of right-turn vehicles needed to make a difficult decision whether to stop or pass the stop line. It indicates that the yellow light-skipping control does not influence right-turn traffic while improving safety.

The above findings confirm that the yellow light-skipping control developed this year is effective as a control method, smoothing traffic while improving safety of the right-turn traffic, if right-turn vehicles can be detected correctly.

Table 5. Findings of the Research on the Possible Influence on Right-turn Vehicles

Research subject	Change in the behavior of right-turn vehicles and driving conditions due to the yellow light-skipping control 1) When yellow light is not skipped (303 cycles) 2) When yellow light is skipped (108 cycles)
Vehicles' entrance to the intersection in spite of red light	In case 1), ten vehicles fell under this category, but in case 2), no vehicle did.
Vehicle driving at high speed*1	Because there was no vehicle driving at high speed in case 2), it is impossible to make comparison, but that there was no such vehicle means that it does not influence safety.
Vehicles that stopped by hard braking*2	The total of the deceleration data of cases 1) and 2) shows the maximum value was smaller in case 2). When compared with the previously mentioned critical deceleration (3 m/s^2), deceleration in case 2) was still smaller. Therefore, in case 2), driver stopped at a deceleration deciding to stop without becoming confused whether to stop or pass, so there was no vehicle that stopped by hard braking.
Vehicles in the "dilemma condition"*3	In either case 1) or 2), no vehicle was put into the dilemma condition. For those that are located before the detection area, the driver can make a decision to stop or pass easily because of the skipping of yellow light and facing red-signal.

*1 For the vehicles that entered the intersection after the turnoff of the green right-turn arrow signal, we evaluated their speed at the stop line.

*2 For the vehicles that were the first to stop near the stop line because of the turnoff of the arrow signal, we evaluated deceleration between the location of the vehicle before the detection area and their stop position.

*3 For the vehicles that passed the stop line last and those that stopped at the stop line first after the turnoff of the green right-turn arrow signal, we checked whether any of them were in a dilemma condition (where it is difficult for the driver to stop at or pass the stop line), based on the relationship between the distance between the vehicle and stop line at the time of the turnoff of the arrow signal as well as on the approaching speed.

REFERENCES

1. (1982) *Study on Traffic Signal Control Strategy (III).* (The Japan Traffic Management Technology Association, Tokyo)
2. (1994) *Manual on Traffic Signal Control.* (The Japan Society of Traffic Engineers, Tokyo)
3. Seiji I (2000) Experiment of right-turn vehicle actuation method using the presence within a zone. *Proc 7th World Congress on Intelligent Transport Systems,* Turin. (ITS Congress Association, Brussels)