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Feedback Adaptation of Traffic Congestion Length

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1. Introduction

Traffic control is exercised through a combination of road markings, traffic signs and signals. Some traffic signal control methods, such as SIGOP[1], TRANSYT[2], SCOOT[3] and a congestion control method[4], were developed within the traffic engineering framework. Since the three signal control parameters consisting of the cycle length, green split and offset are independently controlled in these traffic signal control methods, the methods are a lack of systematic control. A decentralized controller for the green time[5] was considered under some restricted assumptions in a general interconnected network consisting of intersecting one-way streets. This paper studies how to control systematically and adaptively the three signal control parameters so as to minimize the sum of the traffic congestion lengths in a traffic network from the control theoretic viewpoint.

A long term system model of traffic volume is derived by assuming the periodicity on month, a day of the week and hour, and formulated as a linear time-varying discrete system. A short term system model of traffic volume is also derived and formulated as a linear time-varying discrete dynamical system.

The traffic volume balance is held at each signalized intersection of a traffic network for a certain sampling period. Based on the traffic volume balance at each signalized intersection, the traffic congestion mechanism which plays a basic role for traffic congestion control can be described quantitatively.

The feedback adaptation system of the traffic congestion length at each signalized intersection is proposed in a traffic network using a decentralized control concept. The three signal control parameters are systematically and adaptively controlled so as to minimize the sum of the traffic congestion lengths in a traffic network. The controllability of the system is also considered.

We propose two feedback adaptation algorithms for traffic congestion length control in a traffic network consisting of a rectangular grid of intersecting streets; one is a "priority control algorithm", the other is a "balance control algorithm". In the priority control algorithm, the traffic congestion lengths of the arterial directions are controlled prior to the other ones, and the three signal control parameters are adaptively controlled according to

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the variation of incoming traffic volumes so as to minimize the sum of the traffic congestion lengths of the arterial directions. In the balance control algorithm, the two traffic congestion lengths which cross each other on a road are controlled so as to become equal. In order to accomplish this balance control, the three signal control parameters are adaptively controlled so as to minimize the sum of the traffic congestion lengths of a traffic network.

We simulate the priority and balance control algorithms of traffic congestion length using data obtained in Fukuyama city, Japan. The simulation confirms that the cycle lengths, green time and offsets are adaptively controlled according to the variation of incoming traffic volumes, and two feedback adaptation algorithms work well to control the traffic congestion lengths at two-adjacent signalized intersections.

2. Time-dependent characteristics of traffic volume

We derive a long term system of hourly traffic volume at any spot in a traffic network by assuming that hourly traffic volumes vary depending on year, month, a day of the week, and hour. A short term system of traffic volume at any spot is also derived by assuming that traffic volumes vary only depending on a day of the week and time.

2.1 Long term system representation

A long term system of hourly traffic volume $x(i, h, l, k)$ at any spot is described by the following linear time-varying discrete system[6].

$$x(\alpha, \beta, l, k) = a_t(s)c_a(\alpha)c_m(\beta)c_w(l)c_t(k) + w_1(\alpha, \beta, l, k) \tag{1}$$

$$y(\alpha, \beta, l, k) = c(\alpha, \beta, l, k)[x(\alpha, \beta, l, k) + v_1(\alpha, \beta, l, k)] \tag{2}$$

where α, β, l, and k denote year, month, a day of the week and hour respectively. The factors $a_t(s)$, $c_a(\alpha)$, $c_m(\beta)$, $c_w(l)$, and $c_t(k)$ denote annual average daily traffic volume of the standard year s, annual factor, monthly factor, weekly factor, and hourly factor respectively. The state noise $w_1(\alpha, \beta, l, k)$ is assumed to be additively added. The observation equation of hourly traffic volume is described in such a way that the state variable is additively affected by the observation noise $v_1(\alpha, \beta, l, k)$, and the right hand side of the equation is multiplied by an "adjusting factor" $c(\alpha, \beta, l, k)$ of the sensitivity of detector. The state noise and the observation noise are assumed as the white random sequences described by

$$E[w_1(\alpha, \beta, l, k)] = \bar{w}_1(\alpha, \beta, l, k) \tag{3}$$

$$E[v_1(\alpha, \beta, l, k)] = \bar{v}_1(\alpha, \beta, l, k) \tag{4}$$

$$E\{[w_1(\alpha, \beta, l, k) - \bar{w}_1(\alpha, \beta, l, k)][w_1(\alpha, \beta, l, \gamma) - \bar{w}_1(\alpha, \beta, l, \gamma)]\} = \delta_{k\gamma}\sigma^2_{w_1}(\alpha, \beta, l, \gamma) \tag{5}$$

$$E\{[v_1(\alpha, \beta, l, k) - \bar{v}_1(\alpha, \beta, l, k)][v_1(\alpha, \beta, l, \gamma) - \bar{v}_1(\alpha, \beta, l, \gamma)]\} = \delta_{k\gamma}\sigma^2_{v_1}(\alpha, \beta, l, \gamma) \tag{6}$$

$$\delta_{k\gamma} = \begin{cases} 1 & k = \gamma \\ 0 & k \neq \gamma \end{cases} \tag{7}$$

where $\delta_{k\gamma}$ denotes the Kronecker's delta function.

2.2 Short term system representation

A short term system of traffic volume $x(l, k)$ at any spot is described by the following linear time-varying discrete dynamical system[6].

$$x(l, k) = a(l, k-1)x(l, k-1) + w_2(l, k-1) \tag{8}$$

$$y(l, k) = c(l, k)[x(l, k) + v_2(l, k)] \tag{9}$$

where time $k = k\Delta T$, ΔT is sampling time. The state noise $w_2(l, k-1)$ and the observation noise $v_2(l, k)$ are assumed to be additively added and the white random sequences described by

$$E[w_2(l, k)] = \bar{w}_2(l, k) \tag{10}$$

$$E[v_2(l, k)] = \bar{v}_2(l, k) \tag{11}$$

$$E\{[w_2(l, k) - \bar{w}_2(l, k)][w_2(l, \gamma) - \bar{w}_2(l, \gamma)]\} = \delta_{k\gamma}\, \sigma^2_{w_2}(l, \gamma) \tag{12}$$

$$E\{[v_2(l, k) - \bar{v}_2(l, k)][v_2(l, \gamma) - \bar{v}_2(l, \gamma)]\} = \delta_{k\gamma}\, \sigma^2_{v_2}(l, \gamma) \tag{13}$$

3. Traffic congestion mechanism

The traffic volume balance is held at each signalized intersection of a traffic network for a certain sampling period(see Fig.1), and described by the following difference equation[6].

$$x_e(l, k) = x_e(l, k-1) + x_i(l, k) - x_o(l, k) \tag{14}$$

$$\begin{cases} x_o(l, k) < c_x(l, k) \\ x_e(l, k) \geq 0 \end{cases} \tag{15}$$

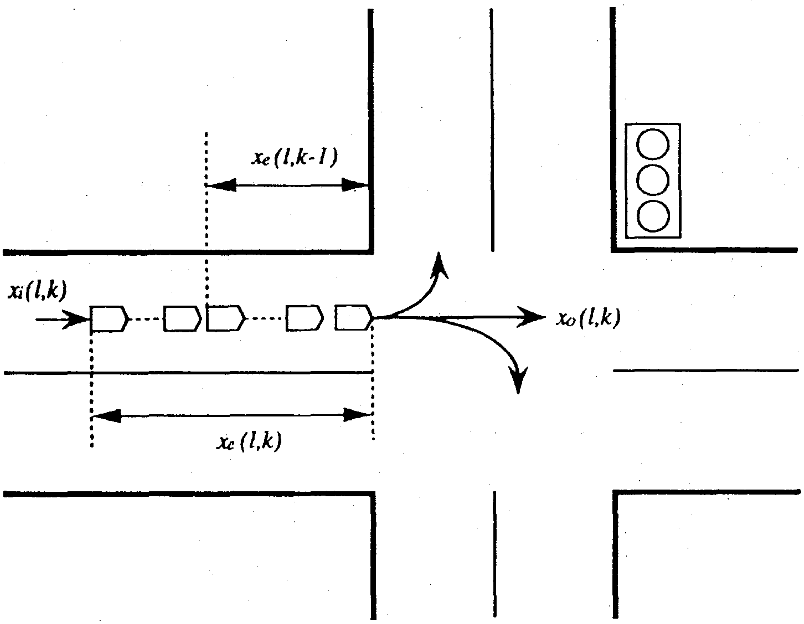

Fig.1 Traffic volume balance at each signalized intersection.

where $x_e(l,k)$, $x_i(l,k)$, $x_o(l,k)$, and $c_x(l,k)$ denote the excess incoming traffic volume, the incoming traffic volume, the outgoing traffic volume, and the capacity at each signalized intersection.

The capacity at each signalized intersection is evaluated summing up each lane capacity as follows.

$$c_x(l,k) = r_{gl}(l,k)c_{xl}(l,k) + r_{gs}(l,k)c_{xs}(l,k) + r_{gr}(l,k)c_{xr}(l,k) \tag{16}$$

$$\begin{cases} c_{xl}(l,k) = s_l n_l r_l(l,k) r_t(l,k) r_b(l,k) \\ c_{xs}(l,k) = s_s n_s r_l(l,k) r_t(l,k) r_b(l,k) \\ c_{xr}(l,k) = s_r n_r r_t(l,k) \end{cases} \tag{17}$$

where $r_{gl}(l,k)$, $r_{gs}(l,k)$, $r_{gr}(l,k)$ are the green splits and $c_{xl}(l,k)$, $c_{xs}(l,k)$, $c_{xr}(l,k)$ are the capacities, of left-turn-, straightforward- and right-turn-traffic lanes respectively. The correction factors $r_l(l,k)$, $r_t(l,k)$ and $r_b(l,k)$ denote for left turns, trucks and local buses stopping respectively. The constant factors s_l, s_s, s_r denote the saturation flows and n_l, n_s, n_r denote the lane numbers, of each traffic lane.

The traffic congestion mechanism can be described quantitatively based on the traffic volume balance at each signalized intersection of (14).

i) The traffic congestion at each signalized intersection occurs at the time when the excess incoming traffic volume becomes greater than zero, i.e.

$$x_e(l,k-1) = 0 \quad \text{and} \quad x_i(l,k) > x_o(l,k)$$

ii) It disappears at the time when the excess incoming traffic volume becomes equal to zero, i.e.

$$x_e(l,k-1) > 0 \quad \text{and} \quad x_e(l,k-1) + x_i(l,k) = x_o(l,k)$$

iii) It continues so long as the excess incoming traffic volume is positive, i.e.

$$x_e(l,k-1) > 0 \quad \text{and} \quad x_e(l,k-1) + x_i(l,k) > x_o(l,k)$$

4. Feedback adaptation system of traffic congestion length

The feedback adaptation system of traffic congestion length is constructed in a traffic network(see Fig.2). The traffic volume balance at each signalized intersection of the traffic network is rewritten as follows.

$$x_e(i,j,m,l,k) = x_e(i,j,m,l,k-1) + x_i(i,j,m,l,k) - x_o(i,j,m,l,k) \tag{18}$$

$$\begin{cases} x_o(i,j,m,l,k) < c_x(i,j,m,l,k) \\ x_e(i,j,m,l,k) \geq 0 \end{cases} \tag{19}$$

In the traffic volume balance at each signalized intersection of (18), the incoming traffic volume $x_i(i,j,m,l,k)$ is controlled by the three signal control parameters at the upstream

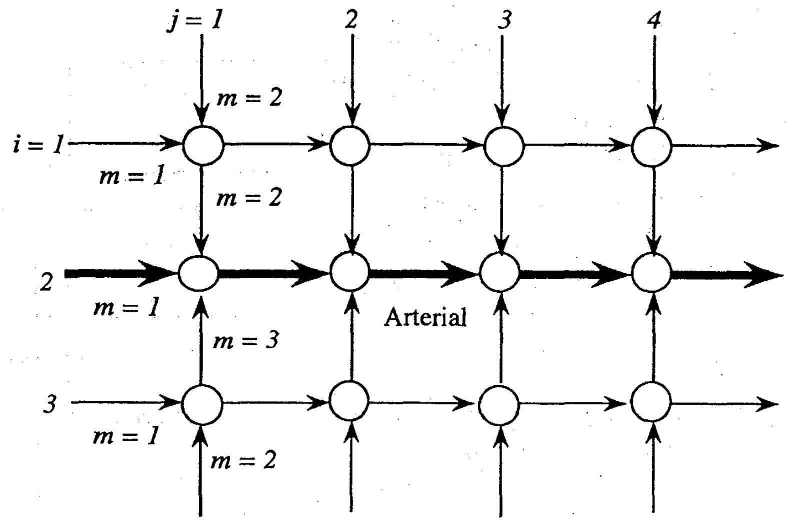

Fig.2 Traffic network consisting of a rectangular grid of intersecting streets.

signalized intersection, and the outgoing traffic volume $x_o(i,j,m,l,k)$ is controlled by those at the signalized intersection concerned.

$$x_i(i,j,m,l,k) - x_o(i,j,m,l,k) = f[c_y(i,j,m,l,k), r_g(i,j,m,l,k), t_{off}(i,j,m,l,k)] \quad (20)$$

The control input $u(i,j,m,l,k)$ is defined by

$$u(i,j,m,l,k) \triangleq f[c_y(i,j,m,l,k), r_g(i,j,m,l,k), t_{off}(i,j,m,l,k)] \quad (21)$$

the traffic congestion control system is then written as follows.

$$\begin{cases} x_e(i,j,m,l,k) = x_e(i,j,m,l,k-1) + u(i,j,m,l,k) \\ y_l(i,j,m,l,k) = l_m(i,j,m,l,k)x_e(i,j,m,l,k) \end{cases} \quad (22)$$

The observation equation of traffic congestion length $y_l(i,j,m,l,k)$ is described in such a way that the state variable is multiplied by a "transformation factor" $l_m(i,j,m,l,k)$.

If $x_e(i,j,m,l,k-1) = 0$ and we can find $u(i,j,m,l,k) \leq 0$, then we can transfer $x_e(i,j,m,l,k)$ to $x_e(i,j,m,l,k) = 0$. Therefore, provided that $x_e(i,j,m,l,k-1) = 0$ and $x_i(i,j,m,l,k) \leq x_o(i,j,m,l,k)$, the traffic congestion control system (22) is controllable.

The feedback adaptation system of traffic congestion length in a traffic network is then considered; in this control system, the reference input, control input and output are given by the permitted queueing length $l_r(i,j,m,l,k)$, three signal control parameters and traffic congestion length respectively. In this way, we construct the feedback adaptation system of traffic congestion length at each signalized intersection (see Fig.3). The purpose of the system in a traffic network is to find such the control inputs that they make the following performance criterion minimize.

$$J = \sum_{l} \sum_{k} \sum_{i} \sum_{j} \sum_{m} | e(i, j, m, l, k) | \quad (23)$$

where the control error $e(i,j,m,l,k)$ is defined by

$$e(i,j,m,l,k) \triangleq l_r(i,j,m,l,k) - y_l(i,j,m,l,k) \quad (24)$$

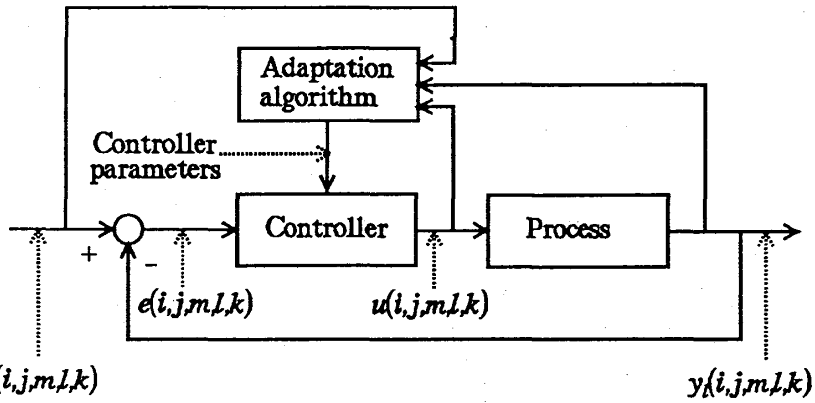

Fig.3 Feedback adaptation system of traffic congestion length at each signalized intersection.

5. Feedback adaptation algorithms of traffic congestion length

For the feedback adaptation system of traffic congestion length in a traffic network (see Fig.2), we propose two feedback adaptation algorithms; one is a "priority control algorithm", the other is a "balance control algorithm".

5.1 Priority control algorithm

The priority control of feedback adataption for traffic congestion length means that the traffic congestion lengths of the arterial directions are controlled prior to other ones, and the three signal control parameters are adaptively controlled so as to minimize the performance criterion of the arterial directions in a traffic network.

Step 1. The parameters, control indexes and initial conditions are set.

Step 2. The incoming traffic volume $x_i(i,j,m,l,k)$ is inputted, and the sampling time ΔT is equally set to the cycle length $c_y^{(n)}(i,j,m,l,k)$.

Step 3. The incoming traffic volume is recalculated.

$$x'^{(n)}_i(i,j,m,l,k) = x_i(i,j,m,l,k) + x_e^{(n)}(i,j,m,l,k-1) \tag{25}$$

Step 4. The capacity $c_x(i,j,m,l,k)$ is evaluated.

$$\begin{cases} c_{xl}^{(n)}(i,j,m,l,k) = r_{gl}^{(n-1)}(i,j,m,l,k)c_{xl}(i,j,m,l,k) \\ c_{xs}^{(n)}(i,j,m,l,k) = r_{gs}^{(n-1)}(i,j,m,l,k)c_{xs}(i,j,m,l,k) \\ c_{xr}^{(n)}(i,j,m,l,k) = r_{gr}^{(n-1)}(i,j,m,l,k)c_{xr}(i,j,m,l,k) \end{cases} \tag{26}$$

$$c_x^{(n)}(i,j,m,l,k) = c_{xl}^{(n)}(i,j,m,l,k) + c_{xs}^{(n)}(i,j,m,l,k) + c_{xr}^{(n)}(i,j,m,l,k) \tag{27}$$

where $^{(n)}$ denotes the repetition times of computation.

Step 5. The green time of straightforward traffic lane $g_s(i,j,m,l,k)$ to ensure outgoing traffic volume is evaluated.

$$g_s^{(n)}(i,j,m,l,k) = \frac{c_y^{(n-1)}(i,j,m,l,k) r_{gs}^{(n-1)}(i,j,m,l,k) x'^{(n)}_i(i,j,m,l,k)}{c_{xs}^{(n)}(i,j,m,l,k) + \dfrac{r_{gr}^{(n-1)}(i,j,m,l,k)}{r_{gs}^{(n-1)}(i,j,m,l,k)} c_{xr}^{(n)}(i,j,m,l,k)} + d_s \tag{28}$$

where d_s denotes the starting delay.

Step 6. The cycle length is evaluated by dividing the green time by the assumed green split.

$$c_y^{(n)}(i,j,m,l,k) = \frac{g_s^{(n)}(i,j,m,l,k)}{r_{gs}^{(n-1)}(i,j,m,l,k)} \tag{29}$$

Step 7. The excess incoming traffic volume $x_e(i,j,m,l,k)$ is evaluated based on the traffic volume balance.

$$x_e^{(n)}(i,j,m,l,k) = x'^{(n)}_i(i,j,m,l,k) - x_o^{(n)}(i,j,m,l,k) \tag{30}$$

$$\begin{cases} x_o^{(n)}(i,j,m,l,k) = \xi^{(n)}(i,j,m,l,k) c_x^{(n)}(i,j,m,l,k) \\ x_e^{(n)}(i,j,m,l,k) \geq 0 \end{cases} \tag{31}$$

$$\xi^{(n)}(i,j,m,l,k) = \frac{g_s^{(n)}(i,j,m,l,k) - d_s}{g_s^{(n)}(i,j,m,l,k)} \tag{32}$$

Step 8. The traffic congestion length $y_l(i,j,m,l,k)$ is evaluated.

$$y_l^{(n)}(i,j,m,l,k) = l_m(i,j,m,l,k) x_e^{(n)}(i,j,m,l,k) \tag{33}$$

Proceed to Step 9 for $m = 1$, or return to Step 2 for $m = 2, 3$.

Step 9. If the following control index $e^{(n)}(i,j,m,l,k) \geq 0$ is satisfied, we apply the green splits and the cycle length at optimum time values and proceed to Step 11.

$$e^{(n)}(i,j,m,l,k) = l_r(i,j,m,l,k) - y_l^{(n)}(i,j,m,l,k) \tag{34}$$

Step 10. If $e^{(n)}(i,j,m,l,k) < 0$, the green splits are corrected.

$$\begin{cases} r_{gs}^{(n)}(i,j,m,l,k) = r_{gs}^{(n-1)}(i,j,m,l,k) + \Delta r_{gs}(i,j,m) \\ r_{gl}^{(n)}(i,j,m,l,k) = r_{gl}^{(n-1)}(i,j,m,l,k) + \Delta r_{gl}(i,j,m) \\ r_{gr}^{(n)}(i,j,m,l,k) = r_{gr}^{(n-1)}(i,j,m,l,k) + \Delta r_{gr}(i,j,m) \end{cases} \tag{35}$$

Return to Step 2.

Step 11. The optimum relative offset $t_{off}(i,j,m,l,k)$ is evaluated.

$$t_{off}(i,j,m,l,k) = \frac{d(i,j,m)}{v(i,j,m,l,k)} - \frac{q^{(n)}(i,j,m,l,k)}{\psi^{(n)}(i,j,m,l,k)} \tag{36}$$

where $d(i,j,m)$, $v(i,j,m,l,k)$, $q^{(n)}(i,j,m,l,k)$ and $\psi^{(n)}(i,j,m,l,k)$ denote the road length, average speed, queueing number of motor-cars while the signal at the downstream intersection has been red, and the saturation flow on the approach at the downstream intersection.

Step 12. The green time, green splits and cycle length are evaluated for the cross direction to the arterial directions based on the relationships among the signal control parameters at each signalized intersection.

for $i=1,2,3$ $j=1,2,3,4$ $m=2$

$$g_r^{(n)}(i,j,1,l,k)=c_y^{(n)}(i,j,1,l,k)r_{gr}^{(n)}(i,j,1,l,k) \tag{37}$$

$$r_{gs}(i,j,2,l,k)=p(i,j,2,l,k)[1-r_{gs}^{(n)}(i,j,1,l,k)-r_{gr}^{(n)}(i,j,1,l,k)] \tag{38}$$

$$p(i,j,2,l,k)\triangleq\frac{r_{gs}(i,j,2,l,k)}{r_{gs}(i,j,2,l,k)+r_{gr}(i,j,2,l,k)} \tag{39}$$

$$r_{gr}(i,j,2,l,k)=\frac{[1-p(i,j,2,l,k)]r_{gs}(i,j,2,l,k)}{p(i,j,2,l,k)} \tag{40}$$

$$c_y(i,j,2,l,k)=c_y^{(n)}(i,j,1,l,k) \tag{41}$$

$$g_r(i,j,2,l,k)=c_y(i,j,2,l,k)r_{gr}(i,j,2,l,k) \tag{42}$$

$$g_s(i,j,2,l,k)=c_y(i,j,2,l,k)-g_r(i,j,2,l,k)-g_s^{(n)}(i,j,1,l,k)-g_r^{(n)}(i,j,1,l,k) \tag{43}$$

for $i=2$ $j=1,2,3,4$ $m=3$

The signal control parameters are equally set to the direction of $m=2$. Return to Step 2.

This control algorithm is executed from $k=1$ to $k=k_f$, $i=1,3,2$ $j=1,2,3,4$ $m=1,2,3$.

5.2 Balance control algorithm

The balance control of feedback adaptation for traffic congestion length means that two traffic congestion lengths which cross each other on a road are controlled so as to become equal. In order to accomplish this balance control, the three signal control parameters are adaptively controlled so as to minimize the sum of the traffic congestion lengths of a traffic network.

From Step 1. to Step 7. The same as the priority control algorithm.

Step 8. The traffic congestion length is evaluated from (33).

Step 9. The green time, green splits and cycle length are evaluated for the cross direction to the arterial directions based on the relationships among the signal control parameters at each signalized intersection.

Step 10. If the following control index

$$\max\{|e^{(\kappa)}(i,j,1,l,k)|,\ |e^{(\omega)}(i,j,2,l,k)|,\ |e^{(\lambda)}(i,j,3,l,k)|\}\leq\varepsilon$$

is satisfied, we apply the green splits and the cycle length at optimum time values and proceed to Step 12.

Step 11. If

$$\max\{\ |e^{(\kappa)}(i,j,1,l,k)|,\ |e^{(\omega)}(i,j,2,l,k)|,\ |e^{(\lambda)}(i,j,3,l,k)|\ \} > \varepsilon$$

then the green splits are corrected using (35). Return to Step 2.

Step 12. The optimum relative offset is evaluated from (36).

This control algorithm is executed from $k=1$ to $k=k_f$, $i=1,3,2$ $j=1,2,3,4$.

The main difference between priority control algorithm and balance control algorithm is as follows : The green splits and cycle length are corrected for the arterial direction or the corresponding cross direction depending on the control index value.

6. Simulation results at two-adjacent signalized intersections

We simulate the priority and balance control algorithms of traffic congestion length at two-adjacent signalized intersections (see Fig.4), using data from 7:00 a.m. to 7:00 p.m. obtained in Fukuyama city, Japan. The parameters are set as follows and the subscript ℓ which denotes a day of the week is omitted for simplicity.

$$\begin{cases} \Delta T = c_y(2,j,m,k) \\ l_m(2,j,m,k) = 6.46(m) \\ l_r(2,j,1,k) = 0(m) \quad \text{for the priority control} \\ l_r(2,j,m,k) = 0(m) \quad \text{for the balance control} \end{cases} \qquad \begin{cases} 0.50 \le r_{gs}(2,1,1,k) = r_{gs}(2,2,1,k) \le 0.65 \\ 0.075 \le r_{gl}(2,1,1,k) = r_{gr}(2,1,1,k) \le 0.090 \\ 0.11 \le r_{gl}(2,2,1,k) = r_{gr}(2,2,1,k) \le 0.14 \end{cases}$$

From the simulation results of the priority control algorithm, it is confirmed that the incoming traffic volumes at each signalized intersection vary widely at rush hour in the morning and evening(see Fig.5). The green time and the cycle lengths are adaptively controlled according to the variation of incoming traffic volumes(see Fig.6 and Fig.7). The optimum relative offset between the upstream and the downstream signalized intersection is also adaptively controlled according to the variation of queueing motor cars at the downstream signalized intersection(see Fig.8). The green splits are controlled in a small range at the upstream signalized intersection, and constantly at the downstream signalized intersection. As the results, the traffic congestion disappear in the arterial direction at the upstream signalized intersection, and no traffic congestion occurs at the downstream signalized intersection during the day(see Fig.9); we obtain such a result that the performance criterion $J=0$ for $m=1$.

From the simulation results of the balance control algorithm, it is confirmed that the incoming traffic volumes at each signalized intersection vary in a wide range at rush hour in the morning and evening (see Fig.10). The green time and the cycle lengths are adaptively controlled according to the variation of incoming traffic volumes (see Fig.11 and Fig.12). The optimum relative offset is also adaptively controlled according to the variation of queueing motor cars at the downstream signalized intersection (see Fig.13). The green splits are constantly controlled at both the signalized intersections.The traffic congestion lengths in the two orthogonal directions at both the signalized intersections are controlled so as to become equal and zero, and no traffic congestion occurs during the day; we obtain such a result that

$$\sum_{k} \sum_{j} \sum_{m} \mid e(2,j,m,k) \mid = 0$$

From the comparison of the simulation results for two feedback adaptation algorithms, it is confirmed that the balance control algorithm works more effectively to minimize the performance criterion, that is, the sum of the traffic congestion lengths in a traffic network.

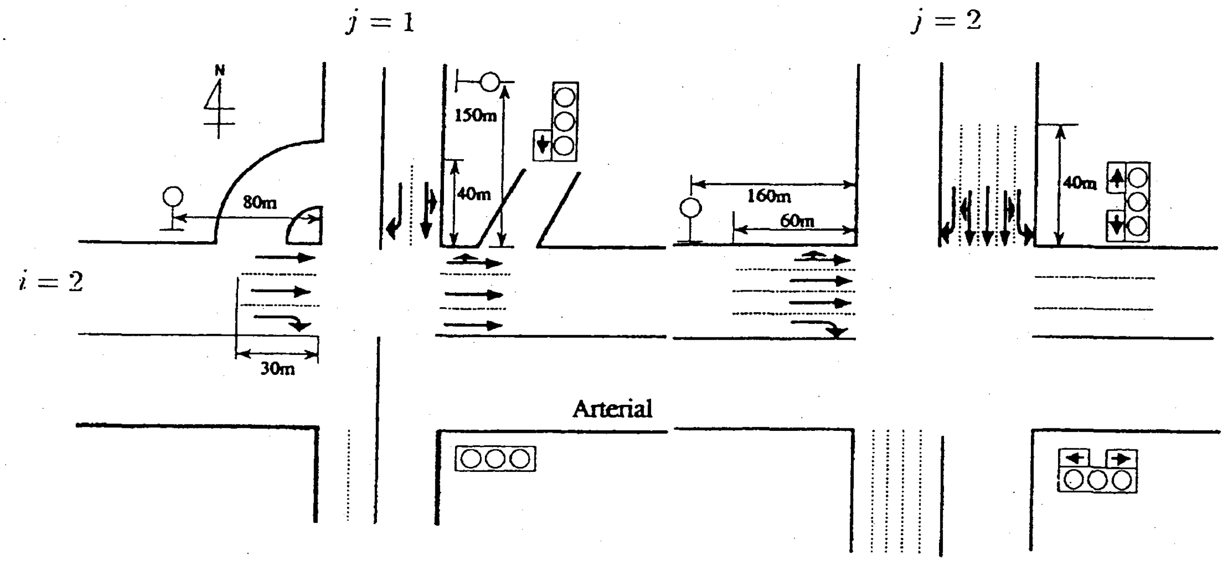

Fig.4 Traffic signals and lanes at two-adjacent signalized intersections.

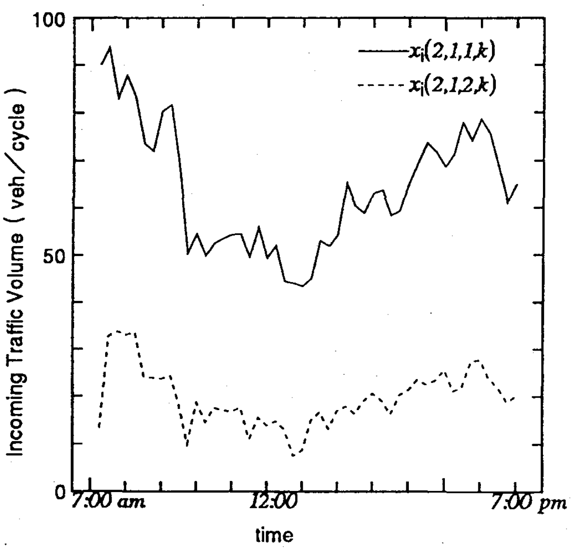

Fig. 5. Incoming traffic volumes at the upstream signalized intersection in a case of priority control.

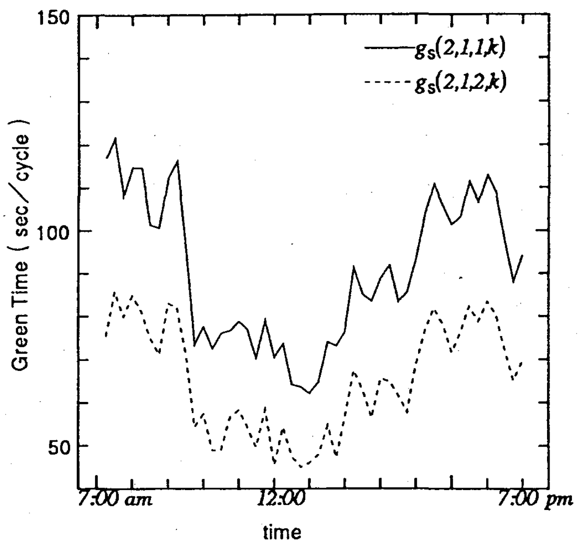

Fig. 6. Green time at the upstream signalized intersection in a case of priority control.

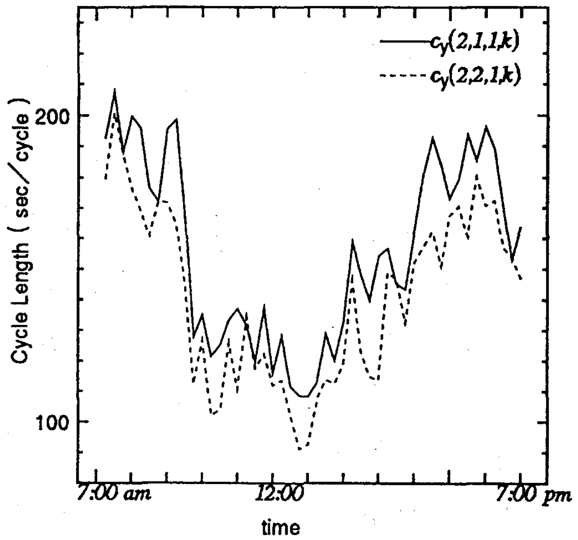

Fig. 7. Cycle lengths at both the signalized intersections in a case of priority control.

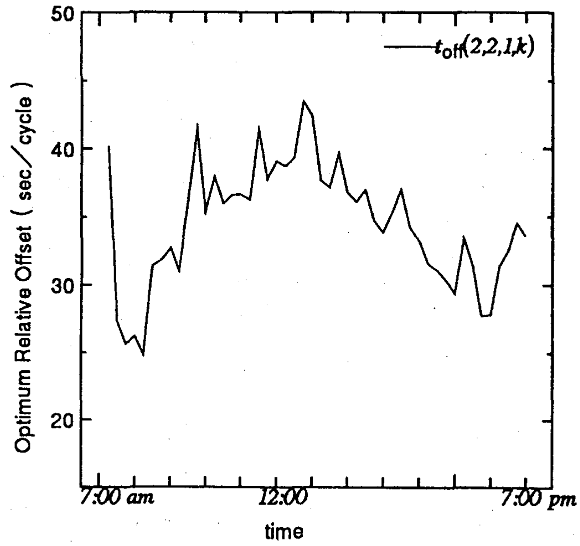

Fig. 8. Optimum relative offset between the upstream and the downstream signalized intersections in a case of priority control.

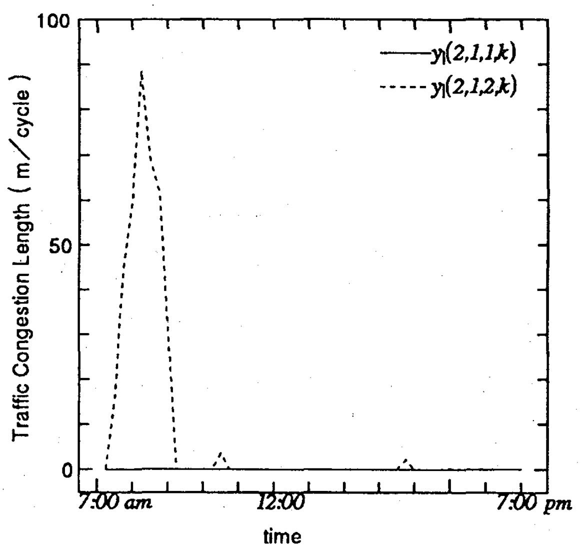

Fig. 9. Traffic congestion lengths at the upstream signalized intersection in a case of priority control.

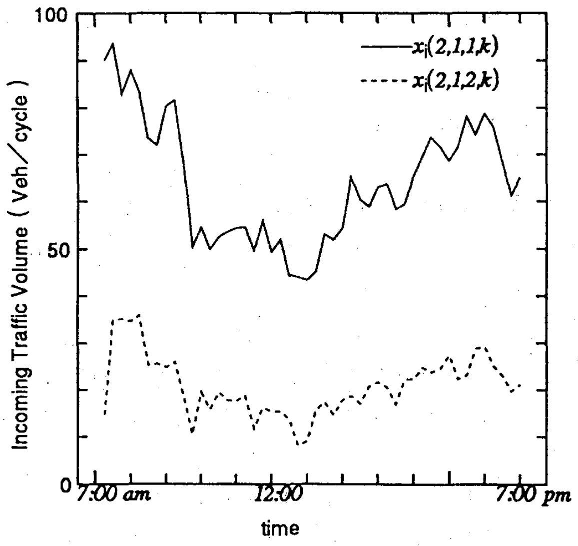

Fig.10. Incoming traffic volumes at the upstream signalized intersection in a case of balance control.

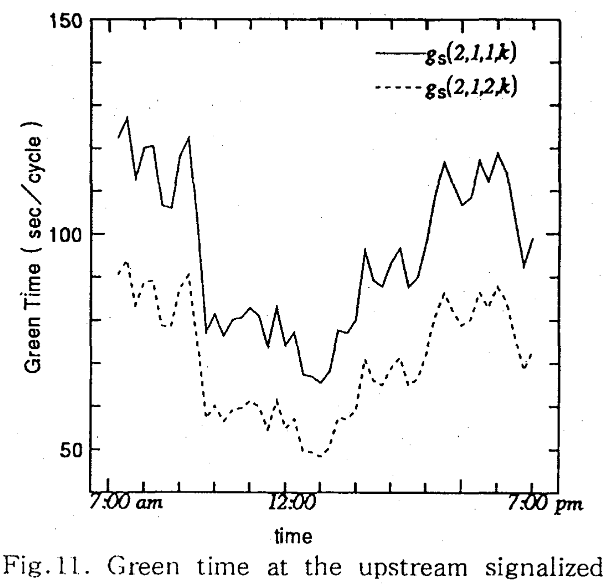

Fig.11. Green time at the upstream signalized intersection in a case of balance control.

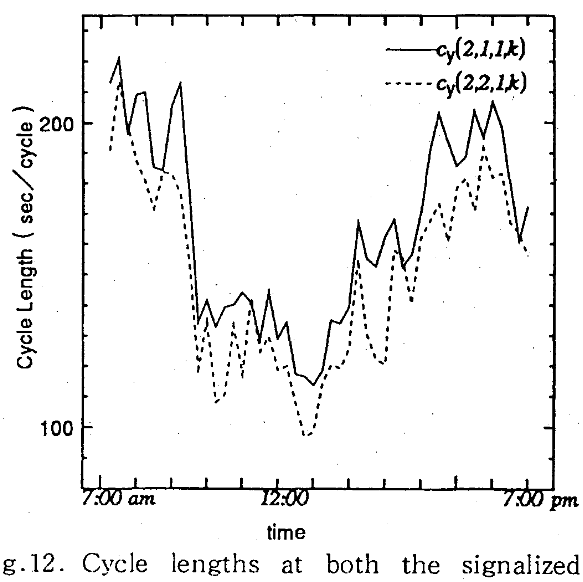

Fig.12. Cycle lengths at both the signalized intersections in a case of balance control.

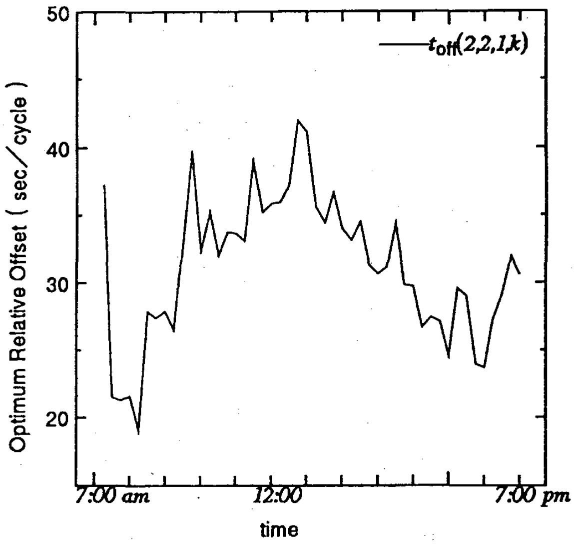

Fig.13. Optimum relative offset between the upstream and the downstream signalized intersections in a case of balance control.

7. Conclusions

We study the feedback adaptation of traffic congestion length in a traffic network from the control theoretic viewpoint. A summary of the main contents of this paper is given as follows.

i) The time-dependent characteristics of traffic volume are described by the linear time-varying discrete systems based on the data analysis of traffic volumes.

ii) The traffic congestion mechanism can be described quantitatively based on the traffic volume balance at each signalized intersection.

iii) The feedback adaptation system of traffic congestion length at each signalized intersection is proposed in a traffic network using a decentralized control concept.

iv) Two feedback adaptation algorithms for traffic congestion length control in a traffic network are proposed; one is a "priority control algorithm", the other is a "balance control algorithm".

v) The simulation results of two feedback adaptation algorithms confirm that the priority and balance control algorithms work well to control the traffic congestion lengths at two-adjacent signalized intersections.

The simulation of two feedback adaptation algorithms in the traffic network shown in Fig.2 is a future problem.

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