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Evaluation of Time and Space Variations of Dynamic Traffic Information on a Traffic Control System

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Abstract

This paper studies the evaluation methods of the time and space variations of the dynamic traffic information on a traffic control system. The traffic control system is synthesized combining a signal control system and a dynamic route guidance system. The signal control system works to minimize the sum of error function of a traffic network by the feedback control of three signal control parameters. The dynamic route guidance system outputs recommendable routes and their travel time including the shortest mean travel time route and its travel time to drivers using the shortest mean travel time route algorithm. Applying the traffic control system to the traffic network, which is used most efficiently about reducing both the congestion length and the mean travel time. The information of the traffic control system are classified from viewpoints of static / dynamic and input / output. The static traffic information such as the link length, the lane number, the legal speed and the saturation flow are constant with respect to time. On the contrary, The dynamic traffic information such as the volume, the capacity, the queue length, the speed, the signal control parameters and the travel time are changeable with respect to time. In the signal control system, the dynamic traffic information such as the volumes, the queue lengths and the speeds are inputted to computers, and the optimal signal control parameters are outputted to signal controllers. In the dynamic route guidance system, the queue lengths, the speeds, the capacities and the optimal signal control parameters are inputted to computers, then the recommendable routes and their travel time are outputted to drivers. The dynamic traffic information are evaluated by following methods:The capacity of each signalized intersection is evaluated by summing up each lane capacity. Tne queue length is evaluated based on the volume balance at each signalized intersection. The optimal signal control parameters are evaluated by signal control algorithms using the feedback control. The mean travel time from a driver's origin to his destination is evaluated by the shortest mean travel time route algorithm.

Key Words: dynamic traffic information, signal control system, dynamic route guidance system, traffic control system

1. Introduction

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In recent years, the congestion has steadily increased in urban traffic networks along with the increase of the number of motor cars registered in Japan. Signal control methods and dynamic route guidance methods have been studied to control the congestion of traffic networks. The SCOOT is an adaptive system that adjusts the signal timings in frequent, small increment to match the latest traffic situation[1],[2]. A pattern selection method of the signal control parameters is presented on Tokyo's major road network[3]. A decentralized servomechanism is formulated for the traffic-light problem[4]. A decentralized dynamic routing strategy is proposed in single-destination congested networks with deterministic inputs[5]. The ideal case of known time-dependent origin-destination flows over the whole planning horizon is formulated as a dynamic system-optimal assignment problem[6].

This paper studies the evaluation methods of the time and space variations of the dynamic traffic information on a traffic control system. The traffic control system is synthesized combining a signal control system and a dynamic route guidance system. The signal control system works to minimize the sum of congestion lengths of a traffic network by the feedback control of three signal control parameters. The dynamic route guidance system outputs recommendable routes and their travel time including the shortest mean travel time route and its travel time to drivers using the shortest mean travel time route algorithm.

The information of the traffic control system are classified from viewpoints of static / dynamic and input / output. The static traffic information are constant with respect to time, and the dynamic traffic information are changeable with respect to time. In the signal control system, the dynamic traffic information such as the volumes, the queue lengths and the speeds are inputted to computers and the optimal signal control parameters are outputted to signal controllers. In the dynamic route guidance system, the queue lengths, the speeds, the capacities and the optimal signal control parameters are inputted to computers, then the recommendable routes and their travel time are outputted to drivers. These dynamic traffic information are evaluated by suitable methods as follows: The capacity of each signalized intersection is evaluated using green splits and correction factors[8]. The queue length is evaluated based on the volume balance at each signalized intersection. Three signal control parameters consisting of the cycle length, the green split and the offset are evaluated by signal control algorithms[9]. The mean travel time from a driver's origin to his destination is evaluated by the shortest mean travel time route algorithm[7].

The dynamic traffic information are evaluated in a traffic network of Fukuyama city, Japan. From the evauation results of the dynamic traffic information, main results are summarized as follows: The congestions occur at such signalized intersections that a little lane number roads used for many inhabitants cross an arterial. Three signal control parameters are controlled according to the variations of incoming volumes and queue lengths so as to smooth traffic flows. The mean travel time are affected by three signal control parameters. The evaluation of the time and space variations of the dynamic traffic information plays basic roles for the simulation, the detector arrangement and the design of the traffic control system.

2. Traffic Control System

A traffic control system is synthesized combining a signal control system and a dynamic route guidance system. The configuration of the traffic control system is shown in Fig.1.

2.1 Signal Control System

The signal control system of the congestion length is synthesized in a traffic network (see Fig. 2).

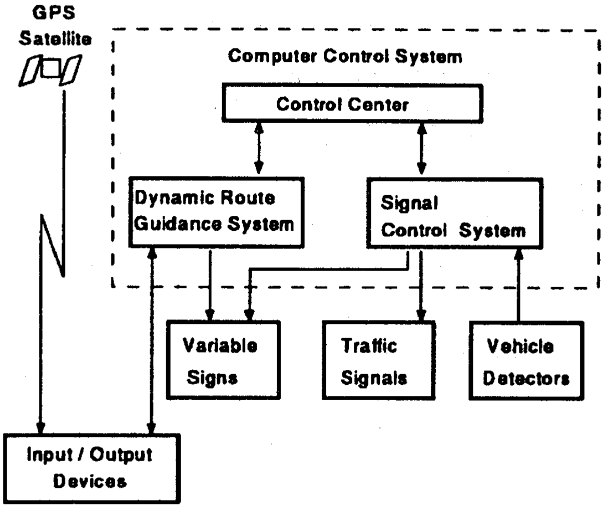

Fig.1. Traffic control system.

The volume balance at each signalized intersection of the traffic network is written as follows:

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

$$\begin{cases} x_o(i,j,m,l,k) < c_x(i,j,m,l,k) \\ x_e(i,j,m,l,k) \geq 0 \end{cases} \tag{2}$$

The variables used for the signal control system are listed in Table 1. In the volume balance at each signalized intersection of Equation(1), the incoming volume $x_i(i,j,m,l,k)$ is given, and the outgoing volume $x_o(i,j,m,l,k)$ is controlled by the three signal control parameters at the signalized intersection concerned

$$x_i(i,j,m,l,k) - x_o(i,j,m,l,k) = f[c_y(i,j,m,l,k), r_g(i,j,m,l,k), t_{off}(i,j,m,l,k)] \tag{3}$$

where $c_y(i,j,m,l,k)$, $r_g(i,j,m,l,k)$ and $t_{off}(i,j,m,l,k,)$ denote the cycle length, the green split and the offset respectively. The control input $u(i,j,m,l,k)$ is defined by

$$u(i,j,m,l,k) \triangleq f[c_y(i,j,m,l,k), r_g(i,j,m,l,k), t_{off}(i,j,m,l,k)] \tag{4}$$

The signal control system is then written as follows:

$$\begin{cases} x_e(i,j,m,l,k) = x_e(i,j,m,l,k-1) + u(i,j,m,l,k) \\ y_c(i,j,m,l,k) = l_m(i,j,m,l,k) x_e(i,j,m,l,k) \end{cases} \tag{5}$$

In the signal control system, the reference input, the control input and the output are given by the permitted congestion length $l_r(i,j,m,l,k)$, the three signal control parameters and the congestion length respectively. The congestion length $y_c(i,j,m,l,k)$ is defined by the queue length at the beginning of the red signal. In this way, we synthesize the feedback control system of the congestion length at each signalized intersection (see Fig.3). The purpose of the signal control system is to find such control inputs that they make the following performance criterion minimize

$$J_n(l,k) = \sum_i \sum_j \sum_m f[e(i,j,m,l,k)] \tag{6}$$

$$\begin{cases} f[e(i,j,m,l,k)] = 0 & e(i,j,m,l,k) \geq 0 \\ f[e(i,j,m,l,k)] = |e(i,j,m,l,k)| & e(i,j,m,l,k) < 0 \end{cases} \tag{7}$$

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

$$e(i,j,m,l,k) \triangleq l_r(i,j,m,l,k) - y_c(i,j,m,l,k) \tag{8}$$

Table 1 Notation

i,j	Location of signalized intersection
m	Moving direction of motor cars
l	A day of the week
k	Time
x_e	Excess incoming volume
c_x	Capacity
l_r	Permitted congestion length (Reference input)
e	Control error
u	Control input
l_m	Transformation factor

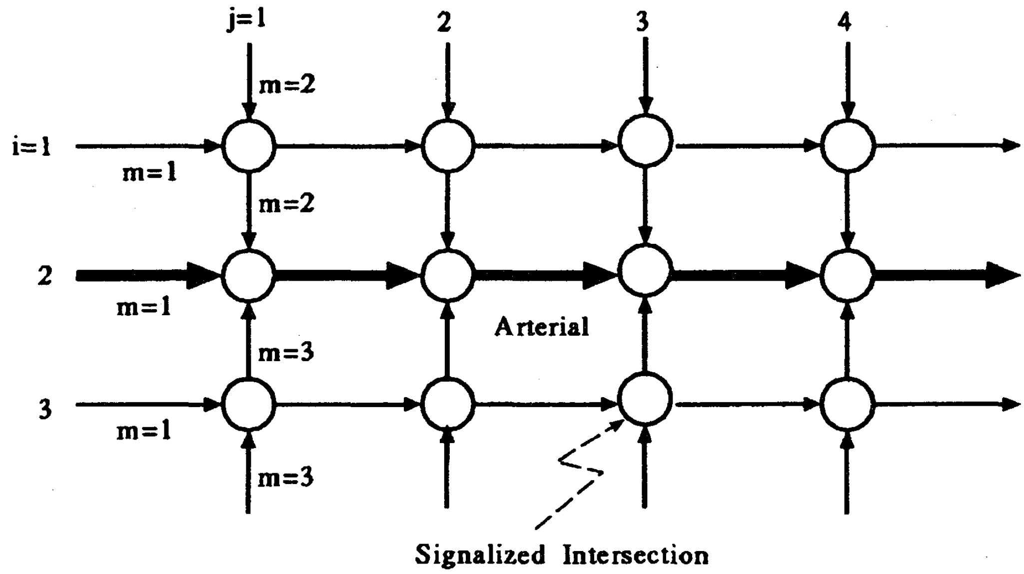

Fig.2. One-way traffic network consisting of a rectangular grid of intersecting streets.

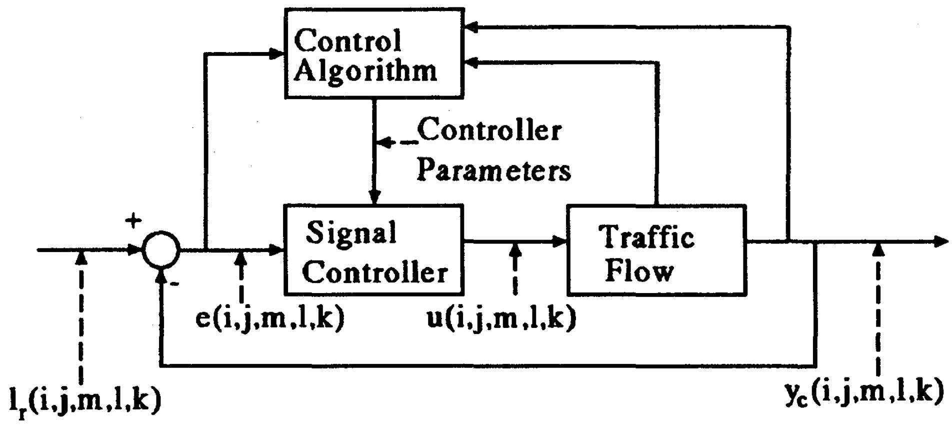

Fig.3. Signal control system.

2.2 Dynamic Route Guidance System

The dynamic route guidance system is presented in the traffic network using dynamic route guidance algorithms. Two dynamic route guidance algorithms which play an essential role in the dynamic route guidace system are presented; one is "the shortest distance route algorithm", the other is "the shortest mean travel time route algorithm". The shortest distance route algorithm gives recommendable routes using the Dijkstra's algorithm [10] weighted by the link distance. On the other hand, the shortest mean travel time route algorithm gives recommendable routes including an optimal route of the traffic network using the Dijkstra's algorithm weighted by the mean link travel time. In the dynamic route guidance system, the queue lengths, the speeds, the capacities and the optimal signal control parameters are inputted to computers and the travel time of recommendable routes are outputted to drivers.

Table 2 Inputs and outputs of traffic control system

Dynamic Traffic Information	Signal Control System	Dynamic Route Guidance System
Queue length	Input	Input
Speed	Input	Input
Signal control parameters	Output	Input
Capacity	Evaluation	Input
Volume	Input	–
Travel time	–	Output

2.3 Traffic Control System

The dynamic traffic information of the traffic control system are classified from viewpoints of the input and output. The input and output of the traffic control system are shown in Table 2. In the signal control system, the incoming volumes, the queue lengths and the link running speeds are inputted, and the capacities are evaluated for each signalized intersection. The optimal signal control parameters which minimize the sum of congestion lengths of the traffic network are outputted to signal controllers. In the dynamic route guidance system, the optimal signal control parameters, the queue lengths, the link running speeds and the capacities are inputted to computers. The travel time of recommendable routes including the shortest mean travel time route are outputted to drivers. The process scheme of the traffic control system is drawn in Fig.4. The signal control parameters are controlled so as to minimize the sum of congestion lengths of the traffic network. The mean travel time evaluated under the optimal signal control are outputted to drivers. As the results, the concentration of motor cars on a specified link is avoided and the traffic network is used most efficiently.

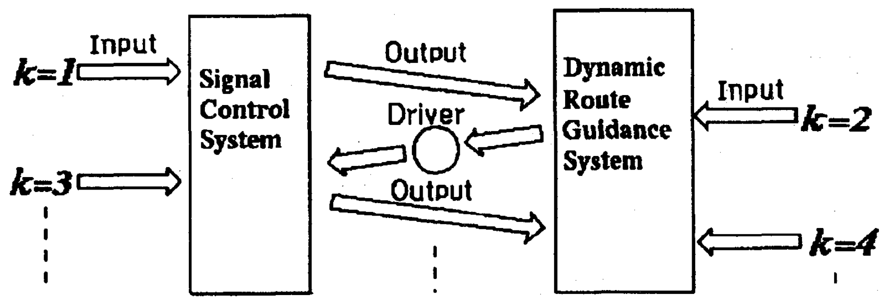

Fig.4. Process scheme of traffic control system.

3. Evaluation Methods of Dynamic Traffic Information

3.1 Capacity

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

$$c_x(i,j,m,l,k) = r_{gl}(i,j,m,l,k)c_{xl}(i,j,m,l,k)+r_{gs}(i,j,m,l,k)c_{xs}(i,j,m,l,k)+ r_{gr}(i,j,m,l,k)c_{xr}(i,j,m,l,k) \tag{9}$$

$$\begin{cases} c_{xl}(i,j,m,l,k)=s_l n_l r_l(i,j,m,l,k)r_t(i,j,m,l,k)r_b(i,j,m,l,k) \\ c_{xs}(i,j,m,l,k)=s_s n_s r_l(i,j,m,l,k)r_t(i,j,m,l,k)r_b(i,j,m,l,k) \\ c_{xr}(i,j,m,l,k)=s_r n_r r_t(i,j,m,l,k) \end{cases} \tag{10}$$

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

3.2 Queue Length

Based on the volume balance at each signalized intersection of the traffic network, the queue length $y_q(i,j,m,l,k)$ is described by

$$x_e(i,j,m,l,k) = x_e(i,j,m,l,k-1)+x_i(i,j,m,l,k)-x_o(i,j,m,l,k) \tag{11}$$

$$y_q(i,j,m,l,k) = l_m(i,j,m,l,k)x_e(i,j,m,l,k) \tag{12}$$

The maximum queue length appears at the beginning of the green signal, i.e.

$$y_{q,max}(i,j,m,l,k)=l_m(i,j,m,l,k)[x_e(i,j,m,l,k-1)+x_i(i,j,m,l,k)] \tag{13}$$

From the definitions, the maximum queue length is always longer than the congestion length. The maximum queue length is transformed into the congestion degree $y_{cd}(i,j,m,l,k)$ using a quantization function $f[\cdot]$

$$y_{cd}(i,j,m,l,k) = f[y_{q,max}(i,j,m,l,k)] \tag{14}$$

3.3 Signal Control Parameters

The three signal control parameters are controlled so as to minimize the sum of congestion lengths of traffic networks. Two signal control algorithms of the congestion lenth are presented on the arterial; one is a "priority control algorithm", the other is a "balance control algorithm". A network control algorithm is presented in the traffic network based on the balance control concept.

3.3.1 Priority control algorithm

The priority control of the congestion length means that congestion lengths of the arterial direction are controlled prior to other ones, and the three signal control parameters are sequentially controlled so as to minimize the following performance criterion of the arterial direction on the arterial(see Fig.5)

$$J_a(i,l,k)= \sum_j f[e(i,j,1,l,k)] \tag{15}$$

The priority control algorithm is proposed using the feedback control of the congestion length on the arterial [9].

3.3.2 Balance control algorithm

The balance control of the congestion length means that two 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 sequentially controlled so as to minimize the following performance criterion of the arterial (see Fig. 5).

$$J_a(i,l,k)=\sum_{j}\sum_{m} f[e(i,j,m,l,k)] \tag{16}$$

The balance control algorithm is proposed using the feedback control of the congestion length on the arterial [9].

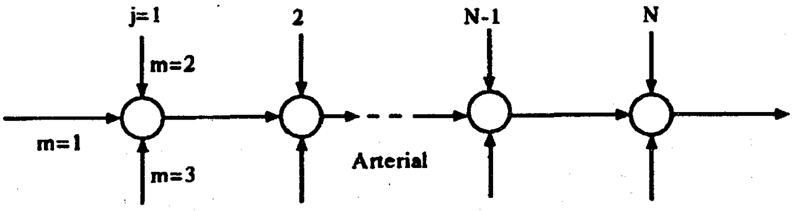

Fig.5. Traffic flows on arterial.

3.3.3 Network control algorithm

The network control of the congestion length means that the three signal control parameters are stepwise controlled so as to minimize the performance criterion of the traffic network described by Equation(6). The network control algorithm based on the balance control concenpt is proposed in the traffic network [9]. The control scheme of the network control algorithm is shown in Fig.6.

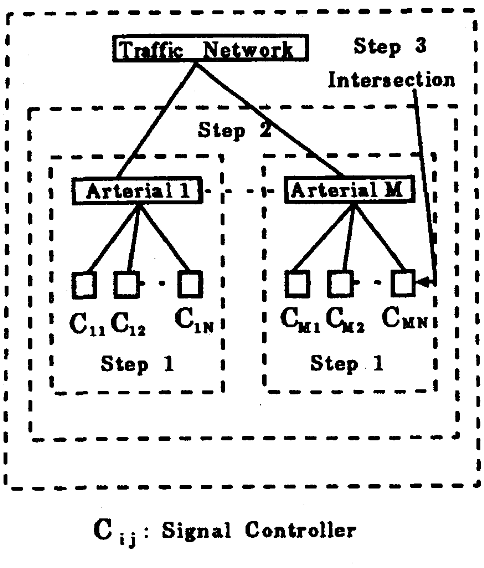

Fig.6. Network control scheme.

3.4 Travel Time

The mean travel time from a driver's origin to his destination is evaluated based on the classification for the evaluation of the mean travel time of each link as shown in Fig.7. An example of the evaluation of the mean travel time is described in the case of the congestion at the downstream signalized intersection.

It is assumed that drivers can not pass the downstream signalized intersection even if the signal is green. The variables used for the evaluation algorithm of the mean travel time are listed in Table 3.

In the case of straightaway

$$T_l(i,j,m,l,k) = P_g(t_{run}+\frac{1}{2}t_g+t_y+t_r+t_s+t_{cs})+P_y(t_{run}+\frac{1}{2}t_y+t_r+t_s+t_{cs})$$
$$+P_r(t_{run}+\frac{1}{2}t_r+t_s+t_{cs}) \tag{17}$$

with

$$t_{run} = \frac{d-y_q}{v} \tag{18}$$

$$t_{cs} = \frac{q}{\phi} \tag{19}$$

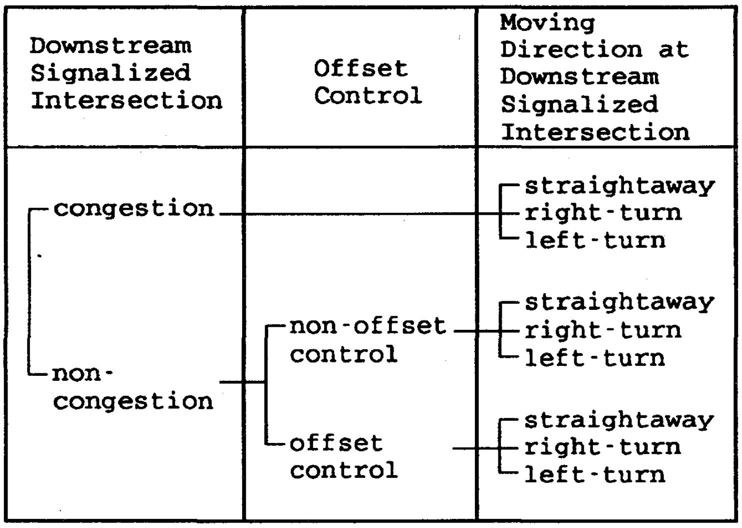

Fig.7. Classification for evaluation of mean travel time of each link.

where the subscripts i,j,m,l and k are omitted for each variable for simple descriptions.

In the case of right-turn

$$T_l(i,j,m,l,k) = P_g(t_{run}+\frac{1}{2}t_g+t_y+t_r+t_{dr}+t_s+t_{cr})+P_y(t_{run}+\frac{1}{2}t_y+t_r+t_{dr}+t_s+t_{cr})$$
$$+P_r(t_{run}+\frac{1}{2}t_r+t_{dr}+t_s+t_{cr}) \tag{20}$$

In the case of left-turn

$$T_l(i,j,m,l,k) = P_g(t_{run}+\frac{1}{2}t_g+t_y+t_r+t_{dl}+t_s+t_{cl})+P_y(t_{run}+\frac{1}{2}t_y+t_r+t_{dl}+t_s+t_{cl})$$
$$+P_r(t_{run}+\frac{1}{2}t_r+t_{dl}+t_s+t_{cl}) \tag{21}$$

The evaluation of the mean travel time in the other cases is described according to the classification of Fig.7. The mean travel time from a driver's origin to his destination $T_{OD}(l,k)$ is evaluated by summing up the mean travel time of each link $T_l(i,j,m,l,k)$.

$$T_{OD}(l,k) = \sum_i \sum_j \sum_m T_l(i,j,m,l,k) \tag{22}$$

4. Time and Space Variations of Dynamic Traffic Information

The dynamic traffic information are evaluated in the traffic network of Fukuyama city, Japan shown in Fig.8. The capacity of each signalized intersection is evaluated by summing up each lane capacity (see Fig.9). The capacity is controlled by the green split of each lane. The capacities of the Route 2 and the station street are large because of the multilane.

The queue length of each link is evaluated based on the volume balance at each signalized intersection. The maximum values of the queue length during a day are shown for each link in Table 4. The maximum values appear during the morning or evening rush hours.

Three signal control parameters consisting of the cycle length, the green split and the offset are controlled using the network control algorithm in the traffic network. The three signal control parameters are controlled according to the variations of incoming volumes and queue lengths so as to smooth traffic flows. From the simulation results, it is confirmed that the cycle lengths are controlled in a wide range according to the variation of incoming volumes in the same way in the traffic network (see Fig.10). Simulation values of the cycle length change drastically. The green time are controlled sensitively according to the variations of congestion lengths and incoming volumes. The green time are controlled preferentially as shwon in Fig.11 during a day. The offsets are controlled by the use of the optimal relative offset. The offset values during an evening rush hour are shown in Fig.12. The offset value corresponding to the square length of Fig.12 is equal to 100 second.

The mean travel time from a driver's origin to his destination is evaluated using both the shortest mean travel time route algorithm and the evaluation algorithm of the mean travel time[7].

5. Conclusions

The time and space variations of the dynamic traffic information are evaluated for a traffic control system in this paper. The capacity of each signalized intersection is evaluated by summing up each lane capacity. The queue length and the congestion length are evaluated based on the volume balance at each signalized intersection. The three signal control parameters consisting of the cycle length, the green split and the offset are controlled using the network control algorithm in the traffic network. The mean travel time from a driver's origin to his destination is evaluated using both the shortest mean travel time route algorithm and the evaluation algorithm of the mean travel time. The comparison between the evaluation values and the measurement values of the dynamic traffic information is a future problem.

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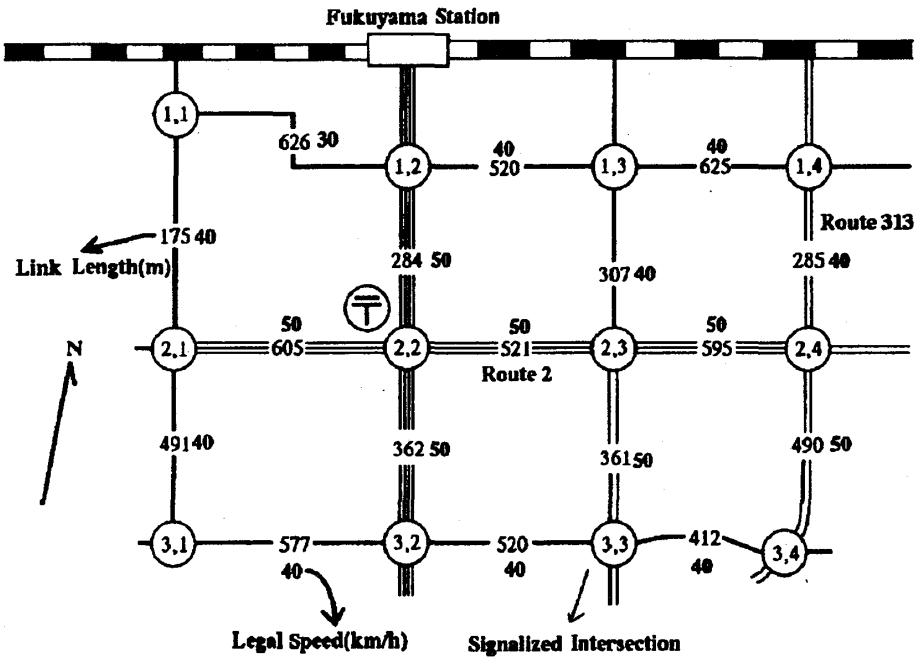
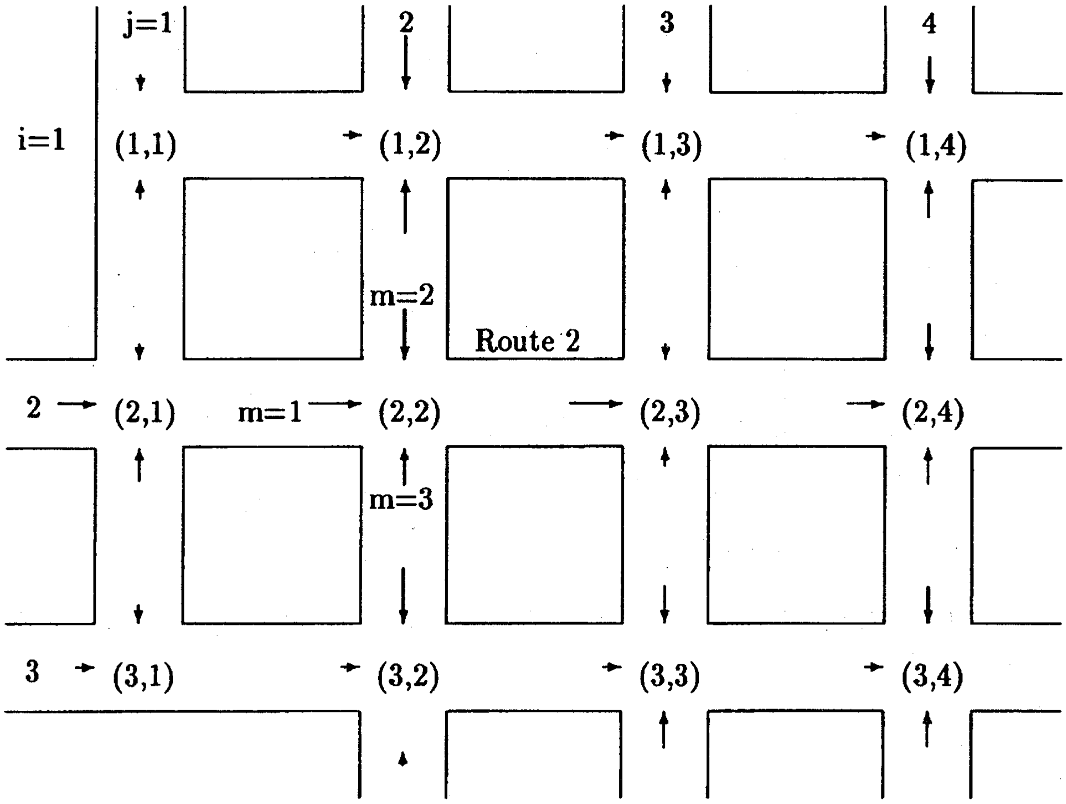


Fig.8. Traffic network.



Arrow length 1mm = 200veh./15min.

Fig. 9. Capacity at each signalized intersection (8:00-8:15).

Table 3 Notation

t_{run}	Running time
t_g	Green time
t_y	Yellow time
t_r	Red time
P_g	Probability of green time
P_y	Probability of yellow time
P_r	Probability of red time
t_{dr}	Time difference of the green initiation between straightaway and right-turn directions
t_{dl}	Time difference of the green initiation between straightaway and left-turn directions
t_{cs}	Outgoing time of straightaway lane queue
t_{cl}	Outgoing time of left-turn lane queue
t_{cr}	Outgoing time of right-turn lane queue
t_s	Starting delay
q	Queueing number of motor cars while the signal at the downstream intersection has been red
ψ	Saturation flow on the approach at the downstream intersection
d	Link length
v	Running speed
y_q	Queue length

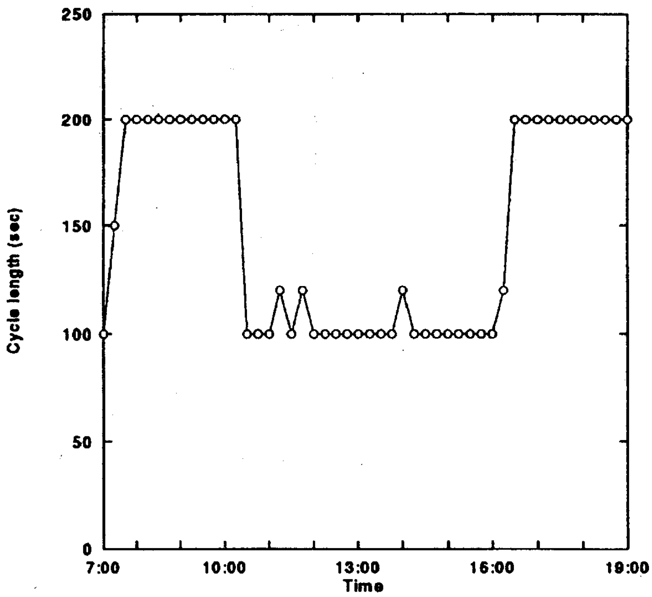


Fig.10. Cycle length.

Table 4 Maximum values of queue length (m/cycle)

i\j		1	2	3	4
1	m=1	-	98.1	79.9	73.6
2	m=1	288.9	83.3	87.6	79.8
	m=2	175.0	57.1	87.0	106.0
	m=3	67.8	65.4	62.6	103.3
3	m=1	106.3	84.5	54.5	71.9

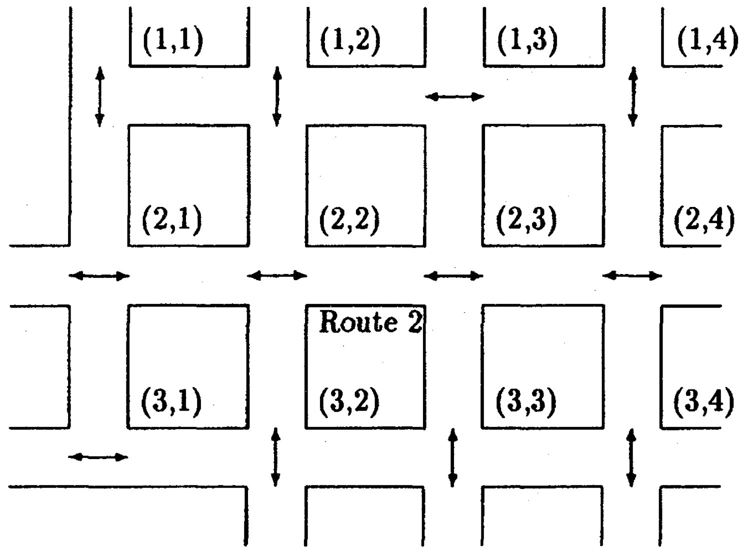


Fig. 11. Priority directions of green time at each signalized intersection.

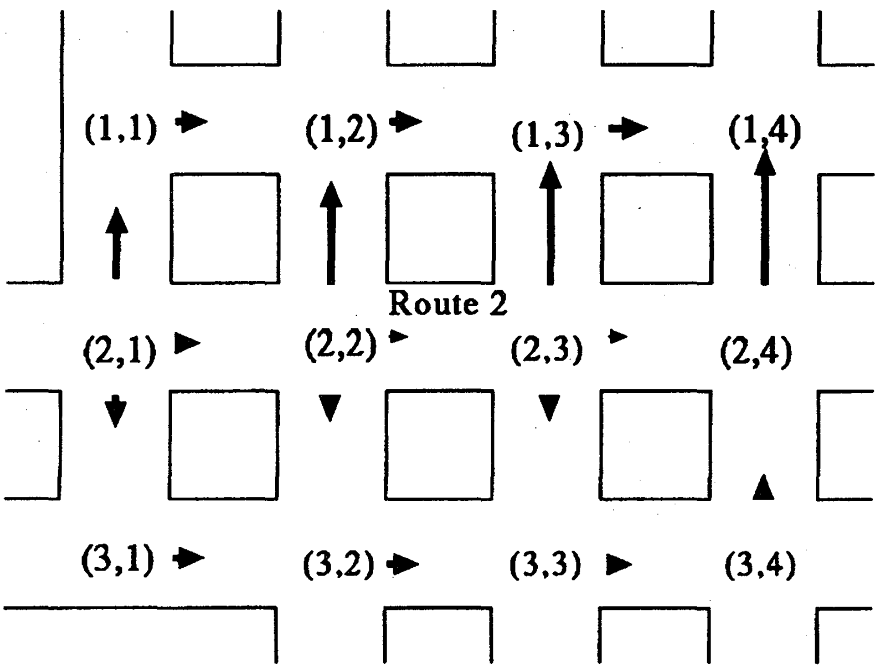


Fig. 12. Offset.